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TWO-PHASE (GAS-LIQUID) SYSTEM: HEAT TRANSFER AND HYDRAULICS

An Annotated Bibliography

by

Robert R. Kepple and Thomas V. Tung

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This report was prepared in connection with a heat transfer program sponsored jointly by the Associated Midwest Universities and the Reactor Engineering Division of the Argonne National Laboratory.

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PREFACE

A systematic search for the references appearing in this bibliography was made in the following for the period 1950 to 1962:

Nuclear Science Abstracts
Chemical Abstracts
Science Abstracts, Section A
Engineering Index
Applied Mechanics Reviews

In addition, Chemical and Engineering Progress and Dissertation Abstracts were consulted for theses, and the references in the many bibliographies already prepared on this subject were also checked. Many references appearing prior to this period have been included because of their importance to the subject.

Although it is hoped that this bibliography is reasonably inclusive for the period mentioned above, undoubtedly some references have been omitted. The intent is to keep the survey updated by issuing an annual supplement. Information concerning omitted references, basic arrangement and the use of the bibliography will be appreciated and should be forwarded to the Argonne National Laboratory, Argonne, Illinois, attention: J. C. Andrews.

The arrangement is by broad subject, and an author index is provided. The categorizing of the abstracts according to subject was a difficult task since the majority of the references could appear under two or more headings, and it was decided not to duplicate entries. As an example, in many of the investigations cited burnout, pressure drop, and fluid density were studied simultaneously. The user is reminded to try several possibilities when seeking a particular reference, especially in the event that the first choice fails.

The authors gratefully acknowledge the assistance of M. Petrick and H. Fauske, who made the final subject arrangement.

BOOKS AND REVIEW ARTICLES

1. Adam, N. K.

PHYSICS AND CHEMISTRY OF SURFACES, 3rd Ed., New York, Oxford University Press, 1941.

2. Bakhmeteff, B. A.

HYDRAULICS OF OPEN CHANNELS, New York, McGraw-Hill, 1932.

3. Bakhmeteff, B. A.

THE MECHANICS OF TURBULENT FLOW, Princeton, N. J., Princeton University Press, 1941.

4. Baulk, R. H.

HEAT TRANSFER FROM SUBMERGED SURFACES TO BOILING LIQUIDS, Monthly Bull. Brit. Coal Utilization Research Assoc. 11, 185-92 (1947).

5. Bennett, J. A. R.

TWO PHASE FLOW IN GAS LIQUID SYSTEMS, A Literature Survey, AERE-CE/R-2497 (March 1958), 58 p.

A review is presented of the published literature to December 1957, concerning the hydrodynamics of two-phase gas-liquid flow with regard to the methods and accuracy of predicting pressure drop, liquid hold-up, etc. Particular emphasis has been placed on the annular flow pattern.

6. Bikerman, J.

SURFACE CHEMISTRY, New York, Academic Press, 1960.

7. Binder, R. C.

ADVANCED FLUID MECHANICS, 2 vols. Englewood Cliffs, N. J., Prentice-Hall, 1958.

8. Birkhoff, G. and Zarantonello, E. H.

JETS, WAKES AND CAVITIES, New York, Academic Press, 1957.

9. Bock, E.

SPRAY-KYLNING, EN SELEKTIV BIBLIOGRAFI, (Spray Cooling), A Bibliography of Selected Literature, VDIT-17 (1960), 24 p.

A bibliography containing 96 references is presented on various aspects of spray cooling.

10. Bock, E.

FLOW MEASUREMENT IN REACTOR TECHNOLOGY. A GUIDE TO SPECIAL LITERATURE ON THIS MATTER, VDIT-61 (1962).

A bibliography on flow-measurement problems and patterns in reactor engineering is presented. Twenty-two abstracts of publications dealing with measurement of gaseous and liquid flow are given.

11. Bosworth, R. C.

HEAT TRANSFER PHENOMENA, New York, Wiley, 1952.

12. Clauser, F. H.

ADVANCES IN APPLIED MECHANICS, New York, Academic Press, 1956.

13. Collier, J. G.

A REVIEW OF TWO-PHASE HEAT TRANSFER (1935-1957), AERE CE/R 2496 (1958), 122 p.

A review is presented of the published literature dealing with heat transfer to two phase gas-liquid mixtures flowing in vertical and horizontal tubes under natural or forced circulation. Both single component and two component two phase heat transfer is dealt with. From this analysis of the literature a general appraisal of the mechanisms of heat transfer is made. Special sections include those on the effects of agitation and surface on nucleate boiling. Recommendations for further work on the subject are put forward.

14. Collins, R. E.

FLOW OF FLUIDS THROUGH POROUS MATERIALS, New York, Reinhold, 1961.

15. Dallavalle, J. M.

MICROMERITIES: THE TECHNOLOGY OF FINE PARTICLES, 2nd Ed., New York, Pitman, 1948.

16. Dimopoulos, N.

HEAT TRANSFER TO FLOWING WATER IN CASE OF HIGH HEAT FLOW DENSITY AND IN CASE OF LOCAL BOILING (EVAPORATION COOLING), HEAT TRANSFER IN A TWO-STROKE DIESEL ENGINE: INFLUENCE ON THE SURFACE BOILING, Zurich, Leeman, 1955. (In German)

17. Dodge, B. F.

CHEMICAL ENGINEERING THERMODYNAMICS, New York and London, McGraw-Hill, 1944.

18. Eckert, E. R. G., Hartnett, J. P. and Irvine, T. F.

A REVIEW OF HEAT TRANSFER LITERATURE, 1957, Mech. Eng. 80, 64-75 (June 1958).

19. Eckert, E. R. G.

HEAT TRANSFER, Ind. Eng. Chem., 50, 543-54 (1958).

20. Eckert, E. R. G.

HEAT TRANSFER: A REVIEW OF CURRENT LITERATURE, Intern. J. Heat and Mass Transfer 3, 222 (1961).

A review is given of the literature published mostly in 1960. The review covers the following fields: conduction, channel flow, boundary-layer flow, flow with separated regions, transfer mechanism, natural convection, convection from rotating surfaces, combined heat and mass transfer, change of phase, radiation, liquid metals, low density heat transfer, measurement techniques, thermodynamic and transport properties, and heat transfer applications. The review on heat transfer contains over 400 references.

21. Eckert, E. R. G.

RESEARCH DURING THE LAST DECADE ON FORCED CONVECTION HEAT TRANSFER, Lecture presented at the 1961 Int'l Heat Transfer Conf., Boulder, Colorado, 1961.

22. Frank-Kamenetski, D. A.

DIFFUSION AND HEAT EXCHANGE IN CHEMICAL KINETICS, Princeton, N. J., Princeton University Press, 1955.

23. Frenkel, J.

KINETIC THEORY OF LIQUIDS, New York, Dover, 1955.

24. Geiringer, P. L.

HANDBOOK OF HEAT TRANSFER MEDIA, New York, Reinhold, 1962.

25. Gibbs, J. W.

COLLECTED WORKS, Vol. I, p. 229, Yale Univ. Press, New Haven, 1948.

26. Giedt, W. H.

PRINCIPLES OF ENGINEERING HEAT TRANSFER, Princeton, N. J., Van Nostrand, 1957.

27. Goldman, A. J.

A SURVEY OF COOLANT VAPORIZATION EFFECTS IMPORTANT TO FAST REACTOR SAFETY, UNC-5021 (June 30, 1962).

The role of coolant vaporization phenomena of importance in fast reactor safety analysis is evaluated for the various abnormal operating conditions which may lead to vaporization. The hydrodynamic, thermal, and nuclear phenomena of particular importance are discussed, their methods of prediction are reviewed and evaluated, and recommendations pertaining to future analyses and experiments are made. In general, experimental and analytical techniques are available to give insight to the gross behavior of vaporizing coolant. However, the technology is insufficient at present to make accurate predictions.

28. Harrison, W. B.

HEAT TRANSFER IN MANHATTAN DISTRICT AND ATOMIC ENERGY COMMISSION LABORATORIES: A CRITICAL SURVEY, ORNL-156 (1948), 274 p.

A survey of project literature on heat transfer was made. Data not sufficiently complete or accurate to justify correlation were discarded, and the remaining data were assembled into related groups based on the heat-transfer mechanism involved. An effort was then made to evaluate on a common basis all heat-transfer data of comparable nature. When possible, the data were compared with correlations recommended in the literature. For a few cases which were unique, it was possible to suggest some correlation based on present knowledge. The mechanisms which make up the body of the report are combined conduction and natural convection, and combined conduction and forced convection. These mechanisms are discussed for the cases with phase change (specifically, with boiling) and without phase change. Little data were located for the cases of radiation and condensation, but a few notes on these subjects are included. Although the data included in the body of the report are experimental, a bibliography of analytical solutions to conduction and other problems is included. A table of equivalents, physical properties data, and graphical calculation aids have also been included in the report to facilitate the making of heat-transfer predictions.

29. Hawkins, G. A.

A BRIEF REVIEW OF THE LITERATURE ON BOILING HEAT TRANSFER, COO-23 (1950), 50 p.

The discussion covers nucleate and film boiling, local boiling, variables, nucleate boiling heat transfer in nonflow systems, and nucleate boiling heat transfer in flow systems wherein the fluids flow through tubes and annular spaces.

30. Hunsaker, J. C. and Rightmire, B. G.

ENGINEERING APPLICATIONS OF FLUID MECHANICS, New York, McGraw-Hill, 1947.

31. Jacobs, J.

HEAT TRANSFER AND FLUID FLOW, A BIBLIOGRAPHY OF SELECTED REPORT LITERATURE, TID-3305 (Suppl. I) (June 1958), 435 p.

A total of 2519 annotated references to the unclassified report literature is presented. Subjects covered under heat transfer and fluid flow include radioinduced heating, boiling, boilers, evaporators, pumps, heat exchangers, hydrodynamics, coolants and their properties, thermal and flow instrumentation, high-temperature materials, thermal properties of materials, and thermal insulation. Subjects covered less completely include thermodynamics, aerodynamics, high-temperature corrosion, corrosion specific to heat transfer systems, erosion, mass transfer, corrosion film formation and effects, coolant processing and radioactivity, radiation effects of heat transfer materials, and pertinent data of thermonuclear processes. Subject, report number, and author indexes are given.

32. Jakob, M.

HEAT TRANSFER, 2 vols., New York, Wiley, 1949, 1957.

33. Jens, W. H.

BOILING HEAT TRANSFER: WHAT IS KNOWN ABOUT IT, Mech. Eng. 76, 981-6 (1954)

Boiling phenomena are reviewed for different conditions and temp. ranges and are related to max. heat transfer. The max. possible heat flux (with boiling water) appears to occur around $\frac{1}{3}$ of the crit. pressure, or about 1000 lb./sq.in., with a heat flux of $1\frac{1}{4} \times 10^6$ Btu/sq.ft./hr. This is about 3 times the max. heat flux at atm. pressure. In expts. on max. heat transfer, provision must be made for pos. liquid flow. Exptl. data are reviewed for heat flux prior to

burnout. Knowledge of these high rates of heat transfer is necessary for the design of rockets, jet engines, and nuclear reactors. CA-49-1384C.

34. Jens, W. H. and Leppert, G.

RECENT DEVELOPMENTS IN BOILING RESEARCH, J. Am. Soc. Naval Engrs. 67, 137-55 (1955).

A review covering heat-transfer and pressure drop. 70 references. CA-49-12887i.

35. Kay, J. M.

INTRODUCTION TO FLUID MECHANICS AND HEAT TRANSFER, New York, Cambridge U.P., 1957.

36. Keenan, J. H. and F. G. Keyes

THERMODYNAMIC PROPERTIES OF STEAM, New York, Wiley, 1936.

37. Knudsen, J. G. and Katz, D.

FLUID DYNAMICS AND HEAT TRANSFER, New York, McGraw, 1958.

38. Kramer, A. W.

BOILING WATER REACTORS, Reading, Mass., Addison-Wesley, 1958.

The history, development, and technology of the boiling water reactor are discussed. The physics underlying boiling reactor design is reviewed. Detailed descriptions are given of the various BORAX experiments, Experimental Boiling Water Reactor, Vallecitos Boiling Reactor, and the Dresden Power Reactor.

39. Krol, L. B.

CHARACTERISTICS OF HIGH PRESSURE BOILERS, Gozenergoizdat, Moscow, 1957.

40. Kutateladze, S. S.

PROBLEMS OF HEAT TRANSFER DURING A CHANGE OF STATE: A COLLECTION OF ARTICLES, AEC TR 3405 (1953), 193 p.

The first group of papers in the symposium deals with problems of heat transfer in the condensers of steam prime movers and refrigeration machinery. The second group of papers reports experimental data on the output of heat during boiling, especially in high-intensity processes. The last two papers are devoted to the rates of accumulation and melting of ice as functions of the conditions of heat transfer between the solid and liquid phases.

Heat Transfer in Surface Condensers of Steam Prime Movers, L. D. Berman, 6-49; Investigation of Heat Exchange in Condensation of Vapors of Some Refrigerants, I. V. Mazyukevich, 50-74; Heating of Jet of Water in Vapor-Filled Space, N. M. Zinger, 75-85; Influence of Pressure on Production of First Crisis in Boiling of Water on Horizontal Plate, E. A. Kazakova, 86-94; Experimental Study of Influence of Temperature of Liquid on Change in Rate of Boiling, S. S. Kutateladze and L. L. Shneiderman, 95-100; Influence of Pressure and Properties of Liquid on Cessation of Film Boiling with Free Convection in Large Space, V. M. Borishansky, 101-8; Heat Transfer to Liquid Freely Flowing Over Surface Heated to Temperature Above Boiling Point, V. M. Borishansky, 109-44; Heat Exchange in Quenching of Metal Parts in Liquid Media, V. M. Borishansky, M. M. Zamyatnin, S. S. Kutateladze and A. L. Nemchinsky, 145-54; Some Data on Number of Centers of Vaporization in Boiling on Industrial Heating Surfaces, L. M. Zysina-Molozhen, 155-9; Influence of Heating-Surface Material on Heat Exchange in Nuclear Boiling in Large Space with Forced Movement of Liquid, N. G. Styushin, 160-8; Experimental Investigation of Heat Exchange in Melting, A. G. Tkachev, 169-78; Heat Exchange in Freezing of Ice, A. G. Tkachev and G. N. Danilova, 179-93. (Translation from Russian).

41. Kutateladze, S. S., et al.

LIQUID METAL HEAT TRANSFER MEDIA, Translation of Atomnaya Energ. Suppl. No. 2 (1958), 152 p.

The thirteen chapters in this volume cover the following subjects: basic properties of liquid metals, application of liquid metal heat transfer media, hydraulic resistance in the flow of liquid metals, turbulent heat transfer in liquid metals, heat transfer during flow in tubes, heat transfer during the longitudinal flow around a plate, heat transfer during transverse flow around cylinders, heat exchange during free convection, heat transfer during vapor condensation, heat exchange during boiling, heat-exchanging equipment, stability of heat-resistant materials in liquid metals, and instrumentation.

42. Lamb, H.

HYDRODYNAMICS, 6th Ed., London, Cambridge Univ. Press (1932).

43. Lapple, C. E.

FLUID AND PARTICLE MECHANICS, New York, University of Delaware, 1954.

This book presents a critical review of recent developments in the field of fluid and particle mechanics as they pertain to applications in the chemical industry. Of special interest are chapters dealing with mass, energy, and momentum balances and two-phase flow in pipes.

44. Levitch, V. G.

PHYSICOCHEMICAL HYDRODYNAMICS, 2nd Ed., Gos. Izd. Fiz. Mat. Lit., Moscow, 1959.

45. Luikov, A. V.

HEAT TRANSFER BIBLIOGRAPHY-RUSSIAN WORKS, Intern. J. Heat Mass Transfer 5, 571-82 (1962).

46. McAdams, W. H., et al.

HIGH DENSITIES OF HEAT FLUX FROM METAL TO WATER, p 17-40 of HEAT TRANSFER LECTURES, Volume I, AECU-116 (NEPA-804), Dec. 1948, 278 p.

Three main topics are considered in this review of known experimental work: (1) boiling of saturated or

slightly superheated water, (2) boiling of sub-cooled water, and (3) heating of sub-cooled water without boiling. A few miscellaneous cases of high density of heat flux are mentioned. 21 references.

47. McAdams, W. H.

HEAT TRANSMISSION, 3rd ed., New York, McGraw-Hill, 1954.

48. McClain, Clifford

FLUID FLOW IN PIPES, New York, Industrial Press.

49. McLain, Stuart

REACTOR ENGINEERING LECTURES, ANL-5424 (March 1955), 336 p.

Lectures are presented on applications of fluid flow, heat transfer, ore refining, metallurgy, mechanical design, remote handling, and process engineering to the preparation of materials, design, construction, operation, and utilization of the products of nuclear reactors.

50. Maughan, G. I.

A BIBLIOGRAPHY ON BOILING WATER REACTORS, IGIS 54 (RD/R) (1959), 36 p.

A wide selection of book, report, and periodical references on heterogeneous boiling water reactors compiled from Nuclear Science Abstracts, 1948 to February, 1959, and Engineering Index, 1950 to 1957 is given.

51. Maurer, G. W.

BIBLIOGRAPHY ON TWO PHASE HEAT TRANSFER, WAPD-TM-249 (1960) 19 p.

A bibliography was prepared to provide a relatively comprehensive listing of the literature on two phase heat transfer and related topics. The bibliography should be especially useful to those beginning research on problems related to boiling heat transfer. Refs. on bubble dynamics are included which have proved useful in the analysis of boiling phenomena. In general, the bibliography does not include references on two phase flow pertaining to type of flow pressure drop, and vapor fractions although it was recognized that these phenomena may influence the process of boiling heat transfer to a flowing fluid.

52. Mikheev, M. A.

PRINCIPLES OF HEAT TRANSMISSION, (Osnovy teploperedachi. Izd. 3-e, perer, Moska, Gos. energ. izd-vo, 1956, 392 p.)

53. Morphew, A. T.

HEAT TRANSFER: A BIBLIOGRAPHY OF UNCLASSIFIED REPORT LITERATURE, TID 3022 (1952), 56 p.

This bibliography contains 320 annotated references to unclassified research on heat transfer. Reports held by the Technical Information Service as of March 7, 1952, are covered.

54. Moss, J.

HEAT TRANSFER-CONDUCTION; HEAT TRANSFER BETWEEN FLUIDS AND SURFACES; FLUIDIZED BEDS; HEAT EXCHANGERS; BOILING AND CONDENSATION; RADIATION; GAS TURBINES; ROCKETS; INDUCTION HEATING; ANALOG METHODS, Chem. & Process Eng. 33, 603-6 (1952).

A review with 142 references.

55. Muskat, Morris

FLOW OF HOMOGENEOUS FLUIDS THROUGH POROUS MEDIA, Ann Arbor, Mich., Edwards Bros.

56. Norris, R. H.

A LITERATURE SURVEY ON THE APPLICABILITY OF STEADY-STATE HEAT-TRANSFER COEFFICIENTS TO TRANSIENTS IN POWER OR IN FLOW WITH SINGLE-PHASE FLOW AND WITH TWO-PHASE FLOW, AECU-3611 (1957), 19 p.

A survey of all the known literature on the subject is presented. This survey consists of four parts and two appendices, namely: response of single-phase fluid forced-convection heat transfer to a rapid change of velocity, response of single-phase-fluid forced-convection heat transfer to a rapid change of temperature of the surface or of the incoming fluid, response of single-phase-fluid free-convection heat transfer to a rapid change of the surface temperature or of the heat flux through the surface, response time for boiling heat transfer to sudden increase in heat flux, or in temperature of the wall, summary of range and nature of published test results on the response to a sudden rapid rise in heat input which brings a surface immersed in water to a temperature above the boiling point, and symbols-nomenclature.

57. Oppenheim, A. K., et al.

FLUID DYNAMICS, Industr. Engng. Chem. 51, 437 (March, 1959).

Review of recent literature (books, periodical articles, conference proceedings and reports) on the following: Equations of motion and stability; Turbulence; Vortex flow and rotation; Jets and wakes; Flow near solid surfaces; Multiphase and free-boundary flow; Gas dynamics; Wave dynamics; Dynamics of reactive fluids; Dynamics of conducting fluids. The bibliography (arranged under the foregoing headings) contains 329 references.

58. Poppendick, H. F.

LIQUID-METAL HEAT TRANSFER, p. 77-100 in Heat Transfer Symposium, University of Michigan, Univ. of Mich. Press, 1952.

59. Prandtl, L.

ESSENTIALS OF FLUID DYNAMICS, New York, Hafner, 1952.

With application to hydraulics, aeronautics, meteorology and other subjects.

60. Roberts, H. A.

A REVIEW OF NET BOILING HEAT TRANSFER AND PRESSURE DROP FROM THE LITERATURE, AERE-ED/M-22 (1955), 44 p.

A literature survey of the present state of knowledge with regard to heat transfer, critical heat flux and temperature, pressure drop, relative velocities of steam and water, and the onset of unstable flow, for the net boiling of water, at high pressures, was made. Working formulas and curves are suggested for use in the absence of experimental evidence. 51 references, 9 curves.

61. Rohsenow, W. M.

HEAT TRANSFER, A SYMPOSIUM, Engrg. Res. Inst., University of Michigan (1952).

62. Rouse, Hunter

ADVANCED MECHANICS OF FLUIDS, New York, Wiley, 1959.

63. Sakiadis, B. C., and Coates, J.

A LITERATURE SURVEY OF THE THERMAL CONDUCTIVITY OF LIQUIDS, Bull. No. 34, Eng. Exp. Station, Louisiana State Univ., Baton Rouge, La., 1952.

Methods of measurement were described for both steady state and unsteady state heat conduction. Thermal conductivity values are tabulated for pure organic and inorganic liquids and solutions and miscellaneous liquids. There are three sections of bibliography and author indexes.

64. Sakiadis, B. C., and Coates, J.

STUDIES OF THERMAL CONDUCTIVITY OF LIQUIDS, Part II, Bull. No. 35, Eng. Expt. Station, Louisiana State Univ., Baton Rouge, La., 1953.

An investigation of factors affecting the design of a liquid thermoconductimetric apparatus. The possibility of having conduction heat transfer alone in thick liquid films heated downward by both steady and unsteady methods are explored and studied. Experimental apparatus were built and tested.

65. Sakiadis, B. C., and Coates, J.

A LITERATURE SURVEY OF THE THERMAL CONDUCTIVITY OF LIQUIDS, Bull. No. 48, Eng. Exp. Station, Louisiana State Univ., Baton Rouge, La., 1954.

A supplement to Bulletin No. 34 by the same authors.

66. Sakiadis, B. C., and Coates, J.

STUDIES OF THERMAL CONDUCTIVITY OF LIQUIDS, Part III- A Thermoconductimetric Apparatus for Liquids, Bull. No. 45, Eng. Expt. Station, Louisiana State Univ., Baton Rouge, La., 1954.

A description is given of an apparatus developed for highly dependable measurements of thermal conductivities of liquids. The various factors affecting the reliability of measurements are analyzed and discussed with quantitative data. Both steady and unsteady methods are included. The temperature range covered is 92 to 171°F.

67. Sakiadis, B. C., and Coates, J.

STUDIES OF THERMAL CONDUCTIVITY OF LIQUIDS, Part IV - A Literature Survey of Ultrasonic Velocities in Liquids and Solutions, Bull. No. 46, Eng. Expt. Station, Louisiana State Univ., Baton Rouge, La., 1954.

This survey covers past work done on the "Ultrasonic Velocities in Organic and Inorganic Liquids and Solutions and Their Temperatures and Pressure Dependence." The data collected are presented in tabular form. Data on molten metals and liquid gases have not been included.

Accurate prediction of the velocity of sound in different liquids from theoretical equations are also discussed.

68. Scheidegger, A. E.

THE PHYSICS OF FLOW THROUGH POROUS MEDIA, New York, Macmillan, 1957.

Author gives an almost complete survey of the present state of knowledge of fluid flow in porous media, obtained by studying a vast amount of literature to which the "Bibliography" refers chapter by chapter. Two introductory parts define the terms "porous media" and "fluids," and treat the measurement of pores and the consequences of the physical properties of fluids, such as viscosity, adsorption and miscibility. The third chapter on hydrostatics in porous media, taking into account the dimensions of the pores is divided into four sections: the case of one fluid, two phases of one fluid, two immiscible fluids, and, in the fourth section, attention is given to wettability.

On this physical basis author treats the different methods of approach of flow in porous media. At first Darcy's law is treated, and generalized for compressible and for anisotropic media, after which a chapter deals with solutions of the differential equation resulting from it, in the cases of steady-state flow, and gravity flow with a free surface. In the chapter "Physical Aspects of Permeability" phenomenological point of view in which the correlation between permeability and the other properties of porous media is studied. The capillaric models and the hydraulic radius theory are treated.

Under the heading "General Flow Equations" the limitations of Darcy's law are exposed and equations accounting for high flow velocities and for molecular effects are given. The last chapter deals with multiple phase flow, in which most attention is given to flow of immiscible fluids, extending Darcy's law by the analogy with single-phase flow, whereas in the case of miscible flow, only very slow displacement with very little mixing is considered, since for the phenomena of miscible displacement no satisfactory theory is yet available.

The work will be very useful for the research worker as it gives a summarization of information scattered over a vast number of publications.

69. Shapiro, A. H.

THE MECHANICS AND THERMODYNAMICS OF STEADY ONE-DIMENSIONAL GAS FLOW, Vol. 1, New York, Ronald, 1953.

70. Stoker, J. J.

WATER WAVES, New York, Interscience, 1957.

71. Styrikovich, M. A., ed.

HYDRODYNAMICS AND HEAT TRANSFER DURING BOILING IN HIGH PRESSURE BOILERS, AEC TR 4490 (1955), 272 p.

Thirteen papers dealing with a series of problems relating to the reliability of boiler water tubes are presented. The basic problems discussed are those of the hydrodynamics of a mixture of water and steam and the transfer of heat during boiling in the tubes. The first section of papers deals with the investigation of the flow of gas-liquid mixtures through tubes. The second section contains a discussion of problems in the circulation of steam-water mixtures in boilers. The third section is devoted to heat transfer problems during boiling in tubes.

72. Styrikovich, M. A., Kholodovskii, G. E. and Fomichev, M. S. eds.

HEAT ENGINEERING AND HYDRODYNAMICS, Volume IV, Translated from Trudy Vsesoyuz, Nauch, Tekh. Konf. Primenen. Radioaktiv. i Stabil. Izotopov i Izluchenii v Narod. Khoz. i Nauke, 1957, 4, AEC-tr-4206 (Publ. 1958), 99 p.

Abstracts were prepared for the 17 papers contained. The papers pertain to studies on steam engineering and tracer techniques.

73. Troy, M. T.

LITERATURE SEARCH ON BOILING OF WATER, Bettis Library, March 10, 1959.

74. Vukalovich, M. P.

Termodinamicheskie svoistva vody i vodianogo para. (Thermodynamic Properties of Water and Steam) In four languages: Russian, English, German and French. 6th ed. Nationally Owned Publishing House "Veb Verlag Technik," Berlin, 1958.

The book offers data concerning the thermodynamic properties of water as well as saturated and superheated steam. They have been obtained by means of a new equation of state, using modern and reliable experimental material.

The covered range is extended up to a temperature of 1000°C and a pressure of 1000 ata. The book gives a short account of the association theory on which the new equation of state has been based. There follow some remarks on the enclosed tables.

It is meant as a book for students of technical schools and colleges. Apart from that it may be used by members of institutes for scientific research and of offices for planning and design work, as well as by the technical staff of central power stations and energy plants.

75. Wilkinson, J. K.

HEAT TRANSFER TO BOILING WATER, Brit. Coal Util. Res. Assoc., Monthly Bull., 26, 109-28 (1962).

A review with bibliography.

76. Stanford University

PROCEEDINGS OF HEAT TRANSFER AND FLUID MECHANICS INSTITUTE, Stanford University Press, Stanford, Calif. (1949 to date).

77. Institution of Mechanical Engineers, London.

PROCEEDINGS OF THE GENERAL DISCUSSION ON HEAT TRANSFER, 11th-13th Sept. 1951, London, 1951, 496 p.

78. U. S. Atomic Energy Commission

POWER REACTOR TECHNOLOGY, Technical Progress Review, 1, 63 p (June 1958).

Buckling measurements are presented for D_2O moderated graphite lattices. The effects of changes in temperature on the reactivity of graphite lattices are presented. The conversion ratio of the PWR blanket is discussed. The results of capture-to-fission ratio measurements in the EBR-I are reported. Burnout measurements and heat transfer under supercritical conditions are presented. Transient boiling experiments and dynamics of boiling water reactors are reported. Reactor fuel elements consisting of U and U alloys of high U content, plutonium - aluminum, non-metallic elements of high fuel content, and elements of low fuel content are discussed. Control, moderator, shielding, and structural materials for applications in various reactors are presented. Progress is reported on liquid metal fuel reactors and fast reactors.

79. U. S. Atomic Energy Commission

POWER REACTOR TECHNOLOGY, Technical Progress Reviews, Vol. 2,90 p. (Sept. 1959).

General research and development are surveyed and progress on specific reactor types is reviewed. Economic analyses and comparisons of pressurized-water, boiling, organic-cooled, and heavy-water plants are made. The subject of fission neutron age in H_2O is treated. Heat transfer studies discussed include: Heat transfer and burnout in water at low pressure, critical heat flux and burnout in water at high pressure, heat transfer with organic coolants, and hot-channel factors. Brief notes are given on containment, radiation attenuation in concretes, and radioisotope MPC in air and water. Refueling methods are considered with reports on refueling programs, reactor performance with various programs, considerations in design of refueling machinery, typical refueling methods (tabulation of 23 reactors), and current designs (NRU, NPD-2, EBR-II, Fermi Fast Breeder, Calder Hall, G2or G3, Berkeley, and Hunterston). Beryllium is discussed as to properties, radiation damage, and health hazards, along

with a radiation damage study of boron-stainless steel. The progress reviews are presented on: Shippingport PWR, distillation of water in D_2O reactors, GCRE-I and -II, Turret experiment, and moderator controlled PWR.

80. Russian Conference

THESES REPORTS AND PAPERS AT THE CONFERENCE ON HEAT AND MASS TRANSFER, Translation of "Tezisy Dokladov i Soobshchenii na Soveshchanii po Teplo - i Massoobmenu, Minsk, NP-tr-827, June 5-9, 1961, 140 p.

Eighty-six papers are included which were presented at the Russian conference on heat and mass transfer; most of the papers appear to be merely summaries of what was actually given at the conference. The papers are divided into sections dealing with solution of problems, phase changes, chemical conversions, drying processes and construction designs, and thermal properties of materials. Separate abstracts were prepared for 20 of the papers.

BOILING

81. Addoms, J. H.

HEAT TRANSFER AT HIGH RATES TO WATER BOILING OUTSIDE OF CYLINDERS, Ph.D. Thesis, Chem. Engrg, MIT (1948).

82. Aladev, I. T., Dodonov, L. D., and Udalov, V. S.

HEAT TRANSFER IN TUBES WHEN UNDERHEATED WATER IS BOILING, Akad. Nauk SSSR, Doklady, No. 3, 593-595 (Nov. 1956).

83. Averin, E. K.

THE EFFECT OF THE MATERIAL AND THE MECHANICAL TREATMENT OF THE SURFACE ON THE HEAT EXCHANGE IN THE BOILING OF WATER, Transl. from Izvest. Akad. Nauk S.S.S.R. Otdel, Tekh. Nauk No. 3, 116-22, AERE-Lib/Trans-562 (1954), 9 p.

The critical values of the specific thermal load, temperature, excess, and heat exchange coefficient in the boiling of water on steel, Ce, Ni-plated Cu, and Al surfaces are approximately the same. A noticeable effect of the material and roughness of the heat-exchanging surface on the heat exchange coefficient in boiling is observed only for loads up to ~10^5 kcal/m^2h.

84. Averin, E. K.

EFFECTS OF MATERIAL AND OF THE MECHANICAL WORKING OF A SURFACE UPON HEAT TRANSFER, Izvest. Akad. Nauk S.S.S.R. Otdel. Tekh. Nauk, No. 3, 116-22 (1954), English Translation in: AERE-Lib/Trans. 562 (1955), 9 p.

The values of the specific heat load, pressure, thermal head, and the heat-transfer coeff. for water, boiling on a steel, Ni-plated Cu, and Al surfaces, are all approx. equal. Appreciable effects of the material and of the surface roughness of the heat-transmitting surface are only observed with the heat transfer reaching 100 x 10^3 kcal/sq m hr. The heat-transmitting surface becomes destroyed, probably at the loci of bubble formation. When the surface is hydrophobic, the heat-transfer coeff. decreases with increasing load. In such case the limiting heat load equals 100 x 10^3 kcal/sq m hr.

85. Averin, E. K., and Kruzhilin, G. N.

THE INFLUENCE OF SURFACE TENSION AND VISCOSITY ON THE CONDITIONS OF HEAT EXCHANGE IN THE BOILING OF WATER, Transl. from Izvest. Akad. Nauk. S.S.S.R. Otdel. Tekh. Nauk No. 10, 131-7, AERE-Trans-682 (1955), 10 p.

According to experimental data on the boiling of liquid in large volume, the coefficient of heat transfer varies proportionally to the surface tension to the power -0.333, and to the viscosity of the liquid to the power -0.45, while the critical heat flux is proportional (very approximately) to the surface tension to the power 0.25 and to the viscosity of the liquid to the power -0.20. During the boiling of water in large volume under atmospheric conditions and with a horizontally or vertically placed tubular heating surface made of technological materials (steel, copper, nickelized copper), the critical flux lies within the limits 1.2 x 10^6-1.3 x 10^6 kcal/m^2 hour. 6 references.

86. Bagdanov, V. V.

INVESTIGATION OF THE EFFECT OF THE RATE OF MOTION OF THE WATER CURRENT ON THE HEAT EXCHANGE COEFFICIENT ON BOILING IN AN INCLINED TUBE, Trans. by J. B. Sykes from Izvest. Akad. Nauk S.S.S.R. Otdel Tekh. Nauk, 136-40, AERE-Lib/Trans-596 (1955), 8 p.

87. Bogdanov, F. F.

INVESTIGATION OF THE EFFECT OF PRESSURE ON THE COEFFICIENT OF HEAT EMISSION IN BOILER TUBES, AEC-tr-2175 (1954), 7 p.

Data on effects of 2 to 160 atm pressure over the range 50,000 to 400,000 kcal/m^2/hr with circulation velocities from 0.5 to 2.5 m/sec are presented and analyzed. The experimental apparatus is illustrated.

88. Borishanskii, V. M.

THE COEFFICIENTS OF THE TRANSFER OF HEAT TO BOILING WATER AT EXCESSIVE PRESSURES, Energomashinostroyeniye 4, No. 7 (1958).

89. Boscov, J. L.

HEAT TRANSFER TO BOILING WATER UNDER PRESSURE, Thesis MIT (1947).

90. Carleton, J. T.

SMALL DIAMETER MOCK-UP TESTS OF BOILING IN PROCESS TUBES, HW-17563 (1950).

91. Chernobyl'skii, I. I., and Tananaiko, Yu. M.

HEAT TRANSFER TO BOILING WATER IN AN ANNULAR SPACE, Soviet Physics, Technical Physics, 1, 2244-49 (1956).

Heat transfer to water boiling in an annular space at moderate heat fluxes (q = 20,000-100,000 kcal/sq m hr) was investigated. The spacing δ was varied from 1.25 to 14 mm; steel and Cu surfaces were used; and both internal and external heating were used. Steam at pressures from 1.28 to 2.46 atm was used as the heating medium. The over-all temp. difference varied from 3 to 16°. Preliminary visual observations showed that the decrease of δ leads to a change in the character of the boiling, which at the same time takes place in a more even manner, and to a redn. in the size of the steam bubbles, during which the stream becomes highly turbulent and its vapor content increases. This eliminates local overheating of the liquid and causes a decrease of the temp. of the wall and also a substantial increase of the coeff. of heat transfer α. Thus, in comparison with an ordinary pipe, at δ = 2.75 mm, α increases by 20%, and at δ = 1.25 mm, by 50%. It was found, however, that at low δ and high q the H_2O content of the emulsion in the aperture suddenly is sharply reduced and α decreases. For H_2O at δ = 1.25 mm this takes place at q = 45,000 kcal/sq m hr. It was found that the position of the aperture with respect to the heat source (internal or external heating), and also the

surface material do not affect the boiling process. For the calcn. of α for boiling of H_2O in an aperture with a $\delta < 3$ mm either the modified equation of Tolubinskiĭ (Trudy Kiev. Politekh. Inst., Yubileĭnyĭ Sbornik 1948) $Nu = 26.4 \times K^{0.6}Pr^{-0.3} \times b^{0.46}$ or the modified equation of Kichigin and Tobilevich (Sbornik Rabot Kiev. Filiala Tsentral. Nauch.-Issledovatel. Inst. Sakhar Prom., 1946-1949, 1951) $Nu = 1.63 \times 10^{-4} \times Pe^{0.6} \times Ga^{0.125} \times K_p^{0.7} \times b^{0.46}$ can be applied, where $b = (D+d)/(D-d)$ is a dimensionless ratio, representing the ratio of the wetted perimeter to the equiv. diam. of the annulus, D is the inner diam. of the tube in which boiling occurs, and d is the external diam. of the inner tube. From Referat. Zhur., Khim. 1956, Abstr. No. 80309.

92. Clark, J. A.

STATEMENT OF PROGRESS FOR THE MONTH OF SEPTEMBER, NP 1785 (1950), 4 p.

Heat transfer data for water at pressures of 500 and 1000 psia, taken to obtain information on the effect of pressure on the boiling process, are included.

93. Clark, J. A.

STATEMENT OF PROGRESS FOR THE MONTH OF NOVEMBER, NP 1828 (1950), 4 p.

Data from six boiling runs with water at 2000 psia and 20 fps are tabulated.

94. Clark, J. A.

STATEMENT OF PROGRESS FOR THE MONTH OF DECEMBER, NP 1919 (1950), 4 p.

The status of boiling and non-boiling heat transfer studies is given. No data are included.

95. Clark, J. A.

STATEMENT OF PROGRESS FOR THE PERIOD 1 JANUARY 1951 TO 12 FEBRUARY 1951, NP 1659 (1951), 11 p.

Low velocity, heat transfer data for water in the boiling and non-boiling regions at 2000 psia and for fluid bulk temperatures ranging from 300 to 600°F are included.

96. Clark, J. A.

STATEMENT OF PROGRESS FOR THE PERIOD 12 FEBRUARY 1951 TO MARCH 1951, NP 1981 (1951), 12 p.

Heat-transfer data in both boiling and non-boiling regions at 2000 psia for water in the velocity range 0.04 to 1.4 fps are plotted.

97. Clark, J. A.

STATEMENT OF PROGRESS FOR THE PERIOD 1 MARCH 1951 TO 1 APRIL 1951, NP 3056 (1951), 6 p.

Low-velocity boiling and non-boiling heat transfer data have been obtained at 1500 psia for water velocities of approximately 0.20 and 1.40 fps, and at 500 psia for velocities of 0.56 and 1.2 to 1.4 fps. Results are shown graphically.

98. Clark, J. A. et al.

LOW HEAT FLUX BOILING, TID 14556 (1962), 68 p.

This report covers progress made in the design of a system to study boiling of water from the outer surface of tubes at low values of heat flux (from 5,000 to 100,000 Btu/hr ft^2) and pressures up to 2,000 psia for both natural and forced convection.

The primary and secondary electrical power systems are discussed. The various water piping systems (primary flow, purification, and pressure control loops) are described.

The results of a literature survey are presented. The survey covers effects of heating surface, pressure, gravity, and vapor quality on nucleate-boiling heat transfer. It also discusses heat transfer in two-phase flow.

99. Corty, C.

SURFACE VARIABLES IN BOILING, Ph.D. Thesis, University of Michigan, Dissertation Abs. 12, 480 (1952), 246 p.

100. Costello, C. P., Redeker, E. R.

BOILING HEAT TRANSFER AND MAXIMUM HEAT FLUX FOR A SURFACE WITH COOLANT SUPPLIED BY CAPILLARY WICKING, A.I.Ch.E. Preprint 28, New York (1962), 35 p.

Experimental results are presented for boiling heat transfer to ethanol from a stainless steel heater surrounded by a capillary wicking material. The ability of the wicking to convey coolant to a heater when the liquid level is such as to expose part of the heater is demonstrated. The effect of small accelerations directed normally toward the heater surface is studied. It is concluded that the full capabilities of capillary wicking to supply coolant to a heater cannot be realized without proper venting of vapor produced by boiling. Some recently obtained data are presented for a surface supplied with water by capillary action. In obtaining these data, proper venting was employed and extremely high heat fluxes were obtained, substantiating the conclusions of this paper.

101. Cowley, C. W., Timson, W. J., and Sawdye, J. A.

A METHOD FOR IMPROVING HEAT TRANSFER TO A BOILING FLUID, Ind. Eng. Chem. Process Design Develop., 1, 81-4 (Apr., 1962).

Heat transfer rates from thermally conductive solids to boiling liquids can be improved by coating the solid with an insulator having sufficient insulation value to adjust the temperature difference between the coated solid and the liquid nitrogen to a value where more efficient heat transfer will result. The method is particularly applicable to conditions where the solid is at a much higher temperature than the boiling liquid. Under these conditions stable film boiling occurs. The solid is then blanketed by a stable, highly insulating layer of vapor resulting in a low heat transfer rate. By coating the solid with an insulator, it is possible to alter the regime of boiling from stable film boiling to unstable film or nucleate boiling where higher heat transfer rates are possible.

102. Davidson, W. F. et al.

STUDIES OF HEAT TRANSMISSION THROUGH BOILER TUBING AT PRESSURES FROM 500 TO 3300 POUNDS, Transactions of the American Society of Mechanical Engineers, 65, 553-91 (1943).

This paper is a report on studies of heat transfer and pressure drops in steam-generating tubes at pressures from 500 to 3300 lb/sq in. and under exposure to furnace heat in large steam-generating units. Most of the test surfaces were in the form of flat spirally coiled tubes, but for comparison one straight tube 50 feet long was tested. Specific problems investigated include the influence of variations of the steam-water ratio and of variations in tube dimensions (scale factor) on tube-metal temperatures and on pressure drops. Some data relate to tubes operating under conditions approaching those often associated with operating failures. The test conditions were extended in several instances to include water below the saturation temperature.

Some of the possible engineering analyses of the data have been made. Such an analysis of the relation of metal temperature to heat absorption and internal fluid conditions led to the proposal of a function ϕ which seems to offer some possibilities of development as a function correlating the factors influencing an abnormal rise in metal temperature. Similarly an analysis of the pressure drop has led to the proposal of a modification of the usual pressure-drop correlation to include the thermodynamic effect of transverse momentum changes during evaporation.

Supplementary investigations reported upon include pressure drop of water at saturation temperature for the pressure range 250 to 2500 lbs/sq in. through flow-distributing equipment designed for forced-circulation boilers and heat-transfer coefficients for the specific auxiliary equipment used.

103. Dunskus, T. B.

TRACE ADDITIVES IN BOILING LIQUIDS, Ph.D. Thesis, U. of Ill., 154 pp. (1961).

104. Dyer, J. C.

AN INVESTIGATION INTO THE GROWTH OF A BOILING BOUNDARY LAYER IN TURBULENT FLOW, Chem. Eng. Thesis, MIT (1956).

105. Ellion, M. E.

A STUDY OF THE MECHANISM OF BOILING HEAT TRANSFER, JPL-Memo-20-88 (1954), 88 p.

The conventional laboratory equipment for studying boiling heat transfer was modified so that it could be operated in a stable manner with subcooled liquids in the regions of nucleate, partial film, and complete film boiling. The apparatus employed a secondary stabilizing fluid which flowed through the inside of an electrically heated stainless steel tube while the test fluid was flowing through an annulus formed by the tube and a Pyrex jacket. The stabilizing fluid absorbed the excess heat which could not be transferred to the test fluid. This arrangement allowed the apparatus to operate safely in all three boiling regions since the total heat transferred to the stabilizing fluid and the test fluid was a monotonically increasing function of wall temperature up to the melting point of the wall. The equipment retained the simplicity of electrical heating and was used to study boiling in distilled water which was flowing at various velocities, pressures, and temperatures in an annulus. The results of this investigation and a description of the apparatus are presented together with an approximate method for calculating the heat transfer in the complete film boiling region. High-speed motion pictures that were taken of the degassed water boiling on the electrically-heated tube showed the types of vapor formation in the three boiling regions. The mechanism of transition from nucleate to partial film and finally to complete film boiling as the wall temperature was increased is discussed. The second phase of the investigation consisted of a study of pool boiling using distilled water and commercially pure carbon tetrachloride. The experimental program was aimed at obtaining fundamental information on the behavior of nucleate bubbles forming on a stainless-steel heating strip and the role they play in boiling heat transfer. High-speed motion pictures were taken of the nucleate bubbles at a liquid pressure of one atmosphere, liquid temperature range from 170°F below saturation to saturation temperature, and heat fluxes from incipient boiling to the transition from nucleate to partial film boiling. In addition, the effects of dissolved gas and surface tension on bubble dynamics were studied. As a result of this program it has been possible to propose a mechanism for the growth and collapse of nucleate bubbles. An empirical expression has been obtained that relates the measured bubble velocity and size to the heat flux at the transition from nucleate to partial film boiling. This relation is $Nu = 0.053\ Re^{0.8}Pr$. The velocity and effective diameter appearing in this equation still have to be determined experimentally; all other factors are liquid properties. The values of the peak heat transfer calculated from this relation agree within 15% with the experimental data.

106. Elperin, I. T.

HEAT TRANSFER OF A TWO PHASE FLOW WITH A CLUSTER OF PIPES, Inzhener.-Fiz. Zhur. Akad. Nauk Belorus. S.S.R. 4, 30-5 (1961).

A method of intensifying convective heat transfer from gas to the heating surface by introducing into the gaseous medium an intermediate liquid heat transfer agent is described. Results are given of preliminary investigations of aerodynamics and heat transfer of a two-phase gas-liquid heat transfer agent with a cluster of pipes. Investigations showed a slight increase in the resistance of the model and an essential increase in the rate of heat transfer when an intermediate liquid heat transfer agent was introduced.

107. El'perin, I. T.

INTENSIFICATION OF HEAT TRANSFER BETWEEN GAS AND SOLID SURFACE THROUGH USE OF INTERMEDIATE LIQUID HEAT CARRIER, Translated from: Theses Reports and Papers at the Conference on Heat and Mass Transfer, Minsk, June 5-9, 1961, NP-tr-827, p. 77-9.

Heat transfer between a gas and the surface of a solid body is inefficient, and the possibility of using a liquid intermediate heat carrier to improve heat transfer is discussed. The liquid can be used in two ways: (1) with separate heating and cooling processes (gas never contacts surface), or (2) with combined processes (two-phase medium).

108. Frank, S., Jicha, J. and Norin, M.

LOCAL BOILING HEAT TRANSFER TEST - SINGLE TUBE HEAT TRANSFER AND PRESSURE DROP TESTS, MND-M-1857 (1961), 104 p.

Exptl. heat-transfer tests on simulated PM-1 tubular fuel elements are described. Local-boiling heat-transfer and pressure-drop data were obtained by using H_2O. Methods of data redn. and analysis are discussed. Local-boiling pressure-drop data were successfully correlated. Analysis of wall-temp. data provided reasonable confirmation of the Jens (CA 49, 1384c) and Lottes (CA 49, 15515d) local-boiling heat-transfer correlation. However, formation of scale on the tube wall during the tests probably resulted in some bias in the wall superheat data.

109. Fraser, J. P.

FLOW REDISTRIBUTION IN A MATRIX DUE TO BOILING, KAPL-M-RES-37 (1957), 18 p.

A method is presented for estimating steady-state flow and temperature distributions in a nuclear reactor fuel matrix with nonuniform heat generation and boiling. The matrix considered is composed of cylindrical fuel elements offering negligible transverse flow resistance. The flow redistribution treated is caused by the pressure drop increase attending boiling. It is shown that the flow redistribution due to a transverse variation in axial flow resistance within a matrix may be greater than that due to a change in flow resistance between parallel matrix channels.

110. Fritz, W.

HEAT TRANSFER TO BOILING LIQUIDS, Z. Ver. deut. Ing., Beiheft Verfahrenstech, 1937, 149-55.

Relation of temperature to heat transfer coefficient k; results of experiments carried out on tubular spray cooler; application of results to other cooling apparatus.

111. Gamel, C. M., Jr.

EFFECT OF VELOCITY ON HEAT TRANSFER TO BOILING WATER, Cambridge, Mass. Institute of Technology, M.S. Thesis (1947).

112. Goldman, K.

BOILING SONGS, NDA-10-68 (1953), 23 p.

Longitudinal tube-wall-temperature profiles observed experimentally at Pratt and Whitney while heating H_2O at supercritical pressures and high heat fluxes looked remarkably similar to profiles obtained at subcritical pressures with boiling occurring toward the end of the heating tubes. It was hypothesized that a boiling-like phenomenon can occur at supercritical pressures. Whenever the boiling-like profiles were observed, a singing sound could also be heard and it appears that the sounds originate in the heated tubes themselves and are not generated by rubbing surfaces. Definite and tentative conclusions are presented from the studies and from information obtained in visits with boiling experts at other installations.

113. Grohse, E. W., Mueller, G. O., and Findlay, J. A.

FUNDAMENTAL INVESTIGATION OF BOILING HEAT TRANSFER AND TWO-PHASE FLOW, KAPL-M-EWG-1 (October 17, 1958), 128 pp.

Significantly improved theories of two-phase heat transfer and prediction of departure from nucleate boiling have recently been developed which for the first time are not based on empirical relationships. These theories should be critically analyzed in relation to naval reactor work and tested with all existing data from both classified and unclassified sources. Conflicting analyses of two-phase fluid flow regimes confuse this area, and essentially no data or theories are available for two-phase flow with superimposed boiling. Theories and understanding of two-phase flow with boiling should be developed, starting from proven theories without boiling, and tested against all existing data or new data as necessary. A substantial start has been made in analysis of the case of upward annular two-phase flow in vertical channels, based upon modern knowledge of boundary layer and vapor condensation principles.

114. Gusev, V. V., Pridantsev, A. I., Soloviyev, A. N.

DETERMINATION OF THE COEFFICIENT OF HEAT TRANSFER TO BOILING LIQUIDS WITH A CONTINUOUSLY CHANGING HEAT FLUX, Zhurnal prikladnoy mekhaniki i tekhnicheskoy fiziki, No. 4, 1962, 111-114.

The difficulties in obtaining heat transfer coefficients for boiling liquids, particularly the problem of measuring the temperature of the heating surface are explained. A method to overcome these difficulties is proposed. It is assumed that the heat transfer follows the law $\alpha = Cq^n$ and the effective temperature difference is given by $t_w - t_f = q/\alpha = 1/C\ q^{1-n}$. Since the thermocouple is situated a certain distance under the surface the relation $\Delta t_{w1} = K_1 q^m - K_2 q = \phi(q)$ is obtained, where Δt_{w1} is the temperature difference between the fluid and the thermocouple junction. The constants K_1, K_2, and m are determined experimentally. The heat transfer coefficient is obtained for the required range by a continuous change of the heat flux q. The method has been successfully applied

where speed was necessary because of high corrosivity of liquids. The relation for the heat transfer coefficient as a function of heat flux was obtained as $\alpha = 3.4\ q^{0.7}$. There are six figures.

115. Harden, H.

BHT-M: AN IBM DIGITAL COMPUTER PROGRAM TO CALCULATE BOILING HEAT TRANSFER OF STEAM GENERATORS, KAPL-M-NPA-15 (1960), 32 p.

An IBM computer program, BHT-M, for calculating the boiling heat transfer of steam generators is described. The program is written in Fortran II. Program output consists of heat transfer length, overall length of the horizontal U-tube steam generator, and hot and cold leg temperatures.

116. Harrison, W. B. et al.

WETTING EFFECTS ON BOILING HEAT TRANSFER, NP-5713 (Final Report for May 1, 1954 thru May 31, 1955), 66 p.

In order to study effects of wetting on heat transfer in the nucleate boiling regime, stearic acid was boiled in contact with different crystal planes of single crystals of copper, one of which was wetted by the acid and the other was not. Tentative data reported are to be checked and extended in a supplement to the present report. The present indications are that, in the region of low heat flux, where heat transfer is primarily non-boiling natural convection, the non-wetted, crystal required higher values of temperature difference than the wetted crystal for the same flux. This is consistent with the notion that, for heat transfer without phase changes, non-wetting conditions represent increased thermal resistance. At high values of heat flux, though not in the vicinity of the critical temperature difference, the situation was reversed. The non-wetted surface required lower temperature difference than the wetted surface. This is consistent with the notion that it is easier to form bubbles with non-wetting conditions than it is with wetting conditions. (NSA-9-6246)

117. Harrison, W. B.

WETTING EFFECTS ON HEAT TRANSFER, Final Report, September 1, 1957 through September 30, 1957, NP 6508, 131 p.

The first chapter deals with the general considerations involved in bubble formation and wetting effects. Specific problems related to the copper-stearic acid system also are discussed as background material pertaining to the boiling heat transfer studies described in the second and third chapters. Wetting effects on convective heat transfer are studied with a copper-stearic acid system, reported in the fourth chapter, and a copper-sodium system, reported in the fifth chapter. These convective studies were made in experimental apparatus which incorporated a thermal entry region so as to maximize the effect of additional thermal resistance created by nonwetting conditions at the heat transfer surface. In general, the work demonstrated a significant wetting effect on boiling stearic acid from different faces of copper single crystals, but wetting effects were not observed with stearic acid in forced convection past the same crystal surfaces without boiling. The convective studies with sodium were inconclusive, but they leave open the possibility that low and erratic data may be due to nonwetting conditions at the heat transfer surface. 74 references.

118. Hedgepeth, L. M.

ZERO GRAVITY BOILING AND CONDENSING, Paper No. 1322-60, presented at the ARS Space Power Systems Conference, Santa Monica, California, Sept. 27-30, 1960, New York, American Rocket Society (1960), 15 p.

A brief history is presented of the zero-gravity boiling and condensing test effort at WADD. This history is then brought up to date; and, in all cases, an account of the phenomenon occurring during the tests is given along with a possible explanation. Significant observations from the latest flights also are included along with preliminary plans for future tests.

119. Isakoff, S. E.

EFFECT OF AN ULTRASONIC FIELD ON BOILING HEAT TRANSFER - EXPLORATORY INVESTIGATION, Heat Transfer and Fluid Mech. Inst., Preprints of Papers (1956), Stanford Univ., Stanford, Calif. (June 1956), 278 p.

120. James, D. D., Bardoliwalla, C. J. and Martin, D. G.

PAPER 11, AN APPARATUS FOR THE STUDY OF BOILING HEAT TRANSFER TO A FLUID FLOWING IN A RECTANGULAR DUCT (Presented to the Thermodynamics & Fluid Mechanics Group of the Inst. Mech. Eng. on 7th Feb. 1962).

Most investigations of boiling heat transfer to liquids flowing in tubes have been conducted in apparatus in which the surface was heated by causing an electric current to flow through the material of the tube. This inevitably requires the use of expensive electric generators and has the disadvantage that the apparatus tends to destroy itself if the 'burnout' heat flux is exceeded. In this paper a method of studying boiling heat transfer from one side of a tube of rectangular section to an internally flowing fluid is described which is based on combustion heating. The apparatus itself is not destroyed if the burnout heat flux is reached and can be used for studying burnout heat flux for this reason. Some experimental results obtained with this apparatus are given to permit the performance of the apparatus to be assessed. Despite the fact that the instrumentation employed in these experiments was not very satisfactory, these tests show that the apparatus can provide a valuable tool for the study of boiling heat transfer.

121. Kane, D. E.

HEAT TRANSFER TO BOILING LIQUIDS FROM ELECTRICALLY HEATED HOLLOW RODS, S.M. Thesis in Chem Eng., Mass. Inst. Tech. (1951)

122. Katz, D. L. et al.

BOILING - OUTSIDE FINNED TUBES, Petroleum Refiner 34, 113-6 (1955).

Use of large external heat transfer area provided by finned tubes; effect of tube position; comparison of boiling coefficients for propane and dichlorodifluoromethane with plain and finned tubes; example calculation of design of plain and finned tube units.

123. Kaulakis, A. F. and Sherman, L. M.

EFFECT OF PRESSURE ON HEAT TRANSFER TO BOILING LIQUIDS, BS Thesis, MIT (1938).

124. Kichigin, M. A. and Tobilevich, N. Yu.

AN EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER DURING BOILING, Collection of Articles of the Kiev Branch, Central Scientific Research Institute of the Sugar Industry, 1946-9.

125. King, W. J.

HEAT TRANSFER TO BOILING LIQUIDS, Refrig. Eng. 25, 83 (1933).

126. Kirov, N. Y.

HEAT TRANSMISSION IN SHELL BOILER SMOKE TUBES, J. Inst. Fuel 23, 121 (1950).

Analysis of relative importance of factors affecting transmission of heat in tubes; how rates of heat transfer and performance of Lancashire and Economic boilers are influenced by internal scale of varying thickness; effect of deposits formed on heating surfaces in contact with combustion gases; heat transfer to boiling water; method for calculation of heat transfer coefficient; heat transfer by convection. Main factors influencing heat transfer; it is shown that general equations developed for single tubes can be applied to bank of smoke tubes; experiments described show beneficial effect of high gas velocity on rate of heat transfer in Economic boiler; use of higher gas velocities in tube design is suggested for increasing steaming capacity and efficiency of shell boilers.

127. Kornbichler, H. and Kretzinger, N.

HEAT TRANSFER IN BOILING, AEG-MITT, 48, 30-7 (Jan. 1958).

Heat transfer in boiling can only be calculated by means of empirically obtained formulas or diagrams. Although a large number of research results have been published, no comprehensive and interpretive work is found in the literature. It is shown that known numerical material will suffice for obtaining a number of regularities if the effect of a single parameter could be explained by more extensive experimental work.

128. Kovalenko, V. F.

INFLUENCE OF VIBRATION ON HEAT TRANSMISSION, Teploenergetika 5, No. 2, 76-7 (1958).

With the use of a specially designed calorimeter it was shown in general that the rate of heat transmission from boiling water through a Cu tube at heat fluxes from 4000 to 25,000 kcal/sq m hr was lowered rather than increased by subjecting the tube to vibration of a frequency of 700-3000/hr. An exception appeared in the heat flux range of 4000 to 6000 where vibration brought about a slight increase.

129. Kulakov, I. G. and Povarnin, P. I.

ELECTRON BOMBARDMENT HEATING FOR CRITICAL BOILING STUDIED, Inzhener. Fiz. Zhur. Akad. Nauk BSSR 1, 52-5 (March 1958).

Application of electron bombardment heating in studying critical boiling and the installation for experiments with critical boiling on large volume cylindrical surfaces are described. Future uses of the method in heat exchange studies are discussed.

130. Kurihara, H. M.

FUNDAMENTAL FACTORS AFFECTING BOILING COEFFICIENTS, Ph.D. Thesis, Purdue Univ. (1956).

131. Lienhard, J. H. and Schrock, V. E.

THE EFFECT OF PRESSURE, GEOMETRY, AND THE EQUATION OF STATE UPON THE PEAK AND MINIMUM BOILING HEAT FLUX, American Society of Mechanical Engineers, New York, Preprint Paper No. 62-HT-3 (1962), 8 p.

The peak and minimum boiling heat fluxes for a variety of fluids were correlated with pressure, with geometry as a parameter. These correlations were achieved with the use of nondimensionalizing functions of invariant fluid properties that are based upon Zuber's proposed mechanism for the extreme heat fluxes and upon the Law of Corresponding States. The method of correlation was applied with success to data from the literature as well as to new measurements provided by the authors. A clear contribution of geometry was identified.

132. Love, W. J.

COMPUTATIONAL AIDS FOR ESTIMATING PERFORMANCE OF LIQUID TO BOILING WATER HEAT EXCHANGERS, HW-61738 (September 1959), 17 p.

Heat transfer equations for liquid to boiling water heat exchangers are presented. Charts of terminal $q/A-\Delta T$ are included to permit rapid variation of the liquid and boiling side heat transfer coefficients in the general surface area equations for transfer at 10^4 to 10^6 Btu/sq ft/hr. These may be used to investigate the effects of errors in boiling and liquid film coefficients.

133. Lukomskii, S. M.

A METHOD FOR APPROXIMATING THE HEAT TRANSFER IN BOILING, Khim. Prom. 6, 9-14 (1944).

The many empirical formulas for heat transfer in boiling essentially can be reduced to $\alpha = C\Delta t^{2.5}$, where α is the coeff. of heat transfer from the wall of the vessel to the boiling liquid in cal. per sq m hr, C is a coeff. of proportionality different for different liquids and Δt is the temp. difference between the wall and the boiling liquid. This relation holds only up to a certain (crit.) Δt. By plotting the available

exptl. data on ratios of heat flow ($Q/Q_{max.}$) as ordinate vs. $\Delta t/\Delta t_{crit.}$ as abscissa the curve obtained rises sharply to a max. and then drops. $Q_{max.}$ is calcd. empirically from $Q_{max.}/r^{0.8}\gamma_l \simeq$ const., where r is the heat of vaporization in cal per kg and γ_l is the sp. gr. of the liquid at the satn. temp. in kg per cu m. A table gives $Q_{max.}$ in cal per sq m hr, r in cal per kg, γ_l in kg per cu m and the value of the calcd. const. for a number of liquids and various metals in contact with the liquids. $\Delta t_{crit.}$, read from the curve, makes it possible to approximate the most economical conditions for a given heat-transfer process.

134. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Sixth Monthly Report, March 18-April 18, 1947, 10 p. NEPA-488.

This report includes current status of design, construction, and installation of experimental equipment including final batch boiler, low pressure and high pressure flow apparatus, equipment for investigation of effect of velocity normal to a cylindrical boiling surface, and data from preliminary batch boiler operating up to 400 psig.

135. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Seventh Monthly Report, April 18-May 18, 1947, 14 p. NEPA-489.

This report includes boiling data from preliminary batch boiler for range from 400 psig to 1400 psig, recalibration of all standard resistances used and recalculation of all previous data, status of other projects and equipment including final batch boiler, low pressure and high pressure flow apparatus, and apparatus for study of velocity effects and wire diameter effects.

136. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Eighth Monthly Report, May 18-June 18, 1947, 48 p. NEPA-490.

Included are a discussion and analysis of data for boiling water at atmospheric pressure with horizontal platinum wires of different diameters and lengths, description of procedure and apparatus, discussion of similar work of Nukiyama, calibration data for standard resistors, and tabulated experimental data and corresponding charts.

137. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Tenth Monthly Report, July 18-August 18, 1947, 18 p. NEPA-492.

Boiling characteristics of water with velocity 10 ft per sec normal to the heating wire, at atmos pressure in the nucleate range, test run data with the low pressure flow apparatus, and current status of other related projects and equipment are presented.

138. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Eleventh Monthly Report, August 18-September 18, 1947, 36 p. NEPA-493.

Included are data for boiling water in the nucleate range at one atmos pressure for natural circulation and for flowing water at 15 ft per sec normal to a 0.032 inch platinum wire, results for test runs with low pressure flow apparatus at velocities of 2 to 32 ft per sec and pressures 30 to 120 psia, and current status of related equipment.

139. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Twelfth Monthly Report, September 18-October 18, 1947, 14 p. NEPA-494.

Included are calibrations of electrical standards and pressure gages for final batch boiler and 5 test runs at 400 psig completed but data invalid, and current status of low pressure and high pressure flow apparatus and of other related equipment.

140. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Fourteenth Monthly Report, Nov. 18-Dec. 18, 1947, 26 p. NEPA-496.

Included are operation difficulties and photographs of final batch boiler, changes in procedure for effects of velocity normal to the heating element, test runs with low pressure flow apparatus at 30 psia, subcooled 50°F, and 1 per sec, study of effect of degassing on water boiling, and initial pressure tests and trial run on high pressure flow apparatus.

141. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Fifteenth Monthly Report, Dec. 18-Jan. 18, 1948, 13 p. NEPA-497.

This report discusses effects of dissolved air on heat transfer coefficients and effect of bulk temp on local boiling, equipment changes in final batch boiler, repairs and changes in high pressure flow apparatus, and first runs with velocity normal to a stainless steel heating element with inclosed thermocouples.

142. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Third Monthly Report, December 18-January 18, 1947, 24 p. NEPA-485.

This report includes calibration procedure and data on a platinum heating element for preliminary batch boiler, experimental results for water boiling at atmospheric pressure, comparison of these results with similar ones from the literature, and discussion of preheater design for high-pressure flow apparatus.

143. McAdams, W. H.

INVESTIGATION OF HEAT TRANSFER AT HIGH FLUX DENSITY FROM METAL TO WATER, Twentieth Informal Monthly Report, May 18-June 30, 1948, 6 p. NEPA-679.

In calculating the results of superheating steam in the high-pressure flow apparatus, an improvement has been made which eliminates the assumption that the resistance of the twisted Cu cables in the expansion device is dependent only on temperature. All previous data are being recalculated by basing heat dissipation in the test section on the product of resistance and the square of the current, rather than on the product of current and voltage drop. The resistance of the stainless steel heating element has been measured at temperatures up to 1200°F. Additional runs have been made at 500, 2000, and 3000 psia.

144. Markels, M. and Durfee, R. L.

ANNUAL PROGRESS REPORT ON THE EFFECT OF APPLIED VOLTAGE ON BOILING HEAT TRANSFER, NYO-10-345 (1962).

145. Martin, A. V.

HEAT FLOW FROM A FIN TO A BOILING LIQUID, AECD-2968 (May 11, 1945), 10 p.

A mathematical analysis is made of the smallest length that a fin can have if it is to dissipate to a boiling liquid 9/10 as much heat as would a fin of infinite length. The conclusion is made that in order to operate a cooling fin in a boiling liquid, and to be certain that the fin will operate stably with a high degree of efficiency, despite any possible mishap which may raise the temperature momentarily, the length of the fin must exceed a certain minimum value. This minimum length depends very sharply on the maximum temperature to which the base of the fin may rise. In practice this maximum temperature should be decided upon arbitrarily, and the fin length should then be chosen to exceed the calculated minimum fin length.

146. Matzner, B.

BASIC EXPERIMENTAL STUDIES OF BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report, May, 1962, TID-15969 (May 31, 1962).

Emphasis on the test program was temporarily shifted to study the effect of helium gas dissolved in the coolant stream on the subcooled boiling burnout heat flux for a large internally heated annulus. A new test section capable of achieving heat fluxes in excess of 2.5×10^6 Btu/hr-ft^2 was installed in the loop. Systems for injecting helium gas and measuring the gas content of the water going to the test were also designed and fabricated. Experimental testing will begin early in June 1962. All the available two phase pressure drop data for high heat flux 19-rod test sections were analyzed, and it was shown that a simple plot of total pressure drop versus average steam quality at constant mass velocities might be more useful than the more complex Martinelli-Nelson type analysis.

147. Matzner, B.

BASIC EXPERIMENTAL STUDIES OF BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report, June 1962, TID-16217 (June 29, 1962).

Test data were obtained with the Dissolved Helium Annular Test Section which was designed to study the effect on subcooled boiling burnout of helium gas dissolved in the coolant stream. The Solid Tubular Test Section is ready for final assembly.

148. Mead, B. R., Romie, F. E., and Guibert, A. G.

LIQUID SUPERHEAT AND BOILING HEAT TRANSFER, Heat Transfer and Fluid Mechanics Institute, Preprints of Papers, Stanford University Press, p. 209 (1951).

149. Meyer, J. E. and Rose, R. P.

APPLICATION OF A MOMENTUM INTEGRAL MODEL TO THE STUDY OF PARALLEL CHANNEL BOILING FLOW OSCILLATIONS, Americal Society of Mechanical Engineers, Preprint Paper No. 62-HT-41, New York (1962), 9 p.

A method is discussed for treating oscillations in flow through a heated boiling channel which connects two plenum regions of constant pressure difference. The approach is based on a numerical solution of pointwise difference equations representing conservation laws in fluid and metal. It is appropriate for spatially varying heat flux, flow with or without slip, and large perturbations. Details of the method, comparison with experiment, and features which distinguish it from other analytical models are discussed.

150. Meyer, L.

A THERMAL ANALYTICAL STUDY OF THE EQUILIBRIUM BETWEEN A BOILING LIQUID AND ITS VAPOR, A. physik. Chem. A175, 275-83 (1936).

A knowledge of this equil. is necessary for the prosecution of the process of rectification. In a flask fitted with a Pt resistance thermometer the heating and cooling curves were detd. by the onset of condensation during the cooling of a gas mixt. and the onset of boiling during the heating of a supercooled condensate. Results obtained by both methods checked well.

151. Morgan, A. I., Bromley, L. A., and Wilke, C. R.

EFFECT OF SURFACE TENSION ON HEAT TRANSFER IN BOILING, Indus. & Eng. Chem. 41, 2767-9 (1949).

Heat transfer coefficients observed to increase qualitatively with decrease in surface tension of liquid for temperature differences below critical value; critical t temperature difference occurs at lower values of temperature difference as surface tension is lowered; other results.

152. Myers, J. E.

THE EFFECTS OF FLUID PROPERTIES ON BOILING COEFFICIENTS, Thesis, University of Michigan, Dissertation Abs. 12, 168-9 (1952).

153. Nesis, E. I. and Frenkel, Y. I.

BOILING OF A GAS-FILLED LIQUID, Zhur. Tekh. Fiz. 22, 1500-5 (1952).

Solution of gas in the metastable state, i.e., when the total vapor pressure of dissolved gas and solvent exceeds the external pressure, is analyzed. Velocity of boiling is found to depend only on total saturation, not on the ratio of partial saturation.(NSA-7-3071)

154. Nesis, E. I.

BOILING UNDER ACTUAL CONDITIONS, Zhur. Tekh. Fiz. 22, 1506-12 (1952).

The factors facilitating liquid boiling are analyzed. The shape of bubbles on the bottom of the vessel and the mechanism governing their separation and upward flow are discussed, as well as the effect of pores in the walls of the vessel. (NSA-7-3072)

155. Novikov, I. I.

APPLYING THE THEORY OF THERMODYNAMIC SIMILARITY TO THE PHENOMENON OF CRISIS IN A BOILING LIQUID, Kutateladze, S.S. ed. Voprosy teplootdachi i gidravliki dvukhfaznykh sred; sbornik statey, Moscow, Gosenergoizdat, 14-17 (1961).

The author points out that the critical properties and the molecular mass of a substance describe the qualitative effect of its intermolecular forces. Therefore, viscosity, thermal conductivity, diffusion etc. properties are functions of p_{cr}, T_{cr}, R, M/g, and can be obtained by dimensional analysis. In deriving the conditions of similarity only the dimensional factors of these properties or their values at corresponding points (e.g. critical points) need be used. For full similarity, substances under comparison must be thermodynamically similar, especially in the case of boiling. Considering a large volume of boiling liquid, thermodynamic similarity requires that the heat change Q divided by RT should be a general function of P/p_{cr}, C_{ro}/R and $V_{cr}^{1/3}/a$ (where a is the roughness of the heating surface). The latter variable is an additional criterion of similarity during a change of aggregation. To obtain a function for the critical heat load q_{cr} during boiling, the author combines these variables so as to obtain the dimension of the group $(Q/RT_{cr}S\tau) = 1/m^2$ sec (here S - area, τ - time). This gives Eq.

$$q_{kp} = \frac{g^{1/2}R^{1/2}p_{kp}T_{kp}^{1/2}}{M^{1/2}} \kappa \left(\frac{p}{p_{kp}} ; \frac{C_{vo}}{R} ; \frac{v_{kp}^{1/3}}{a} \right) .$$

Therefore at the same reduced pressure, thermodynamically similar substances should have the same value of the complex $q_{cr}M^{1/2}/g^{1/2}R^{1/2}T_{cr}^{1/2}p_{cr}$. The values of this complex for C_6H_6 and C_5H_{12} are compared and found to be practically equal. The relationship derived previously by Chichelli and Bonilla is a particular case of the above general formula.

156. Philipp, L. A. and Tiffany, B. E.

EBULLITION OF REFRIGERANTS, Refrigerating Eng. 25, 140-6 (1933).

It was found that when liquid SO_2 was mixed with a small quantity of lubricating oil, the liquid SO_2 could be superheated by as much as 50 F. without ebullition when the test was conducted in glass vessels and by as much as 30 F. when the test was conducted in Cu or brass vessels. The addn. of wood or any vegetable fibrous matter to the liquid reduced the superheating of the liquid SO_2 to only a few degrees. A general theory was given setting forth the mechanism of ebullition and the promotion of ebullition by initiators such as wood.

157. Poletavkin, P. G. et al.

A NEW METHOD FOR THE INVESTIGATION OF HEAT TRANSFER IN THE BOILING OF LIQUIDS, Translated from: Dokl. Adad. Nauk. SSSR 90 (5), 775-6, NP-tr-1 (1953).

158. Rachko, V. A.

INVESTIGATION OF HEAT TRANSFER WHILE BOILING WATER ON THE OUTER SURFACE OF A TUBE, SKTS (Reports of the Kirovgrad Alloys Plant), 9 (1940).

159. Rehm, T. R.

SUBCOOLED BOILING IN A NEGLIGIBLE GRAVITY FIELD, Denver Research Institute, Colo., Status Report No. 2, NASA Grant NsG-143-61 (1962), 5 p.

Upon completion of a drop tower with a free fall distance of about 119 feet, a dummy capsule was constructed to evaluate the effective drag on the capsule, test a new release mechanism, and evaluate the effectiveness of the deceleration device. Several drops were made with the dummy capsule and in each case the distance of the free fall was approximately 119 feet; whereas the penetration was about 6 feet for each drop. Calculations indicated than an average deceleration of approximately 20 g's was being experienced by the dummy capsule; motion pictures showed that the deceleration was essentially constant. A drag shield has been constructed, and an initial drop test with it indicates that the drag characteristics are within 5 percent of those of the dummy capsule. From information derived from a prototype test cell, the actual test cell for subcooled nucleate boiling studies was constructed. Fully-instrumented drops with the test cell will commence shortly with results obtained photographically of bubble growth rate and collapse for nucleate subcooled boiling. Simultaneously studies will be made on the same cell in a stationary situation. Depending on the interpretation of the results of the bubble studies subsequent drops with an altered test cell will be initiated to investigate heat flux characteristics in subcooled nucleate boiling.

160. Renaldo, P. M.

EFFECTS OF DIAMETER ON BOILING OUTSIDE TUBES, Thesis, MIT (1947).

161. Rhodes, F. H. and Bridges, C. H.

HEAT TRANSFER TO BOILING LIQUIDS, Ind. Eng. Chem. 30, 1401-6 (1938).

Results of experiments indicating that manner of boiling of liquid at surface of solid and observed unit rate of heat transfer are determined by ease with which liquid wets solid; small amounts of certain

substances in solution or in suspension in liquid may have great effect in altering manner of boiling and in changing unit rate of heat transfer. (CA-33-1181-1)

162. Rhodes, J. E.

HEAT TRANSFER TO A BOILING LIQUID, Am. J. Phys., 21, 67-68 (1953).

Boiling at the surface of a warm body in a much cooler liquid is described in terms of two types of heat transfer. When the gas film is thin (low temperature difference) "contact" transfer takes place. If the thickness of the film is greater than the mean free path (high temperature differences) the transfer is explained in terms of accommodation coefficients. Figures are discussed for a conical copper body, fitted with a heating coil, when placed in liquid air. (Sci. A. 56-3232)

163. Roberts, H. A.

BOILING HEAT TRANSFER, Progress in nuclear energy - Series 4: Technology and engineering. R. Hurst and S. McLain, editors, McGraw-Hill, New York (1956), Volume 1, p. 194-215.

Boiling heat transfer may be classified into three categories - (1) surface boiling, (2) nucleate boiling and (3) film boiling. Surface and nucleate boiling refer to vapour bubble production from a heated surface with, and without, vapour generation, respectively, and film boiling may arise from either of these, being caused by an overpopulation of bubbles at the surface. Each mode of heat transfer varies according to the many variables involved and some data are given whereby surface coefficients may be predicted for given circumstances.

With liquids, a limitation on the surface heat rating is the maximum flux attainable, where bubble boiling breaks down and film boiling is instigated. If an element is self-heated, as with a reactor element, this transition is accompanied by a rapid rise in surface temperature due to the poor rate of heat exchange obtainable with a surface vapour film. The prediction of the conditions under which vapour blankets the heated surface is important and data are given on recent correlations by which failure by this means may be estimated. However, some degree of uncertainty exists because of the many means by which vapour blanketing of the surface can be effected and present-day knowledge of these events is reviewed.

An important consideration in boiling nuclear reactors is the mean density of the moderator requiring an estimation of the relative velocity of steam in water. Here also there is a shortage of experimental data and rough estimations may be carried out with the aid of graphs and charts given.

164. Roberts, H. A. and Bowring, R. W.

BOILING NOMENCLATURE - a plea for consistency, Nuclear Power 4, 122 (Jan. 1959).

Many terms in common use in other connections need precise definition when applied to liquid-cooled reactors.

165. Rohsenow, W. M.

HEAT TRANSFER WITH BOILING, Paper in Modern Developments in Heat Transfer, MIT, Summer Session, June 1956.

166. Roll, J. B.

THE EFFECT OF SURFACE TENSION ON BOILING HEAT TRANSFER, Ph.D. Thesis, Purdue Univ., 159 pp. (1962).

167. Rose, A. and Sanders, W. W.

VERTICAL UMBRELLA-TYPE AGITATOR TO PROMOTE SMOOTH BOILING IN VACUUM DISTILLATION, Anal. Chem. 27, 331-2 (1955).

An umbrella-type agitator actuated by an external magnet is described. A new liquid surface is continuously formed by the movement of the agitator through the surface and by entrapment of vapor which escapes in the form of small bubbles. (CA-49-7896e)

168. Rose, W. J., Gilles, H. L. and Uhl, V. W.

SUBCOOLED BOILING HEAT TRANSFER TO AQUEOUS BINARY MIXTURES, A.I.Ch.E. Preprint 6, New York (1962), 27 p.

Binary aqueous mixtures of methyl alcohol, ethyl alcohol, isopropyl alcohol, n-butyl alcohol, and the pure components were subjected to subcooled nucleate boiling in an annulus on the surface of an electrically heated type 304 stainless steel heating element. Data were obtained at a pressure of 30 psia and a velocity of 4 ft/sec with subcooling between 60° and 110°F; the heating element was a $\frac{1}{4}$-inch O.D. by 6-inch long cylindrical tube with a measured wall thickness of 0.015 inch. The data are presented as plots of heat flux versus wall superheat and indicate that greater superheat is required to produce a given heat flux for the mixtures than for either of the pure components. This phenomenon is emphasized by plots of the wall superheat required to produce a given heat flux versus mixture composition and all show maxima at an intermediate concentration. These maxima occur when the constituent with the higher boiling temperature is dominant. The occurrence of these maxima is supported by recent theoretical and experimental studies which show that the rate of growth of vapor bubbles is a function of composition and also that the minimum rate of bubble growth occurs at an intermediate composition predominant in the high boiler.

169. Ruddick, M.

AN EXPERIMENTAL INVESTIGATION OF THE HEAT TRANSFER AT HIGH RATES BETWEEN A TUBE AND WATER WITH CONDITIONS AT OR NEAR BOILING, Ph.D. Thesis, QMC London (1952).

170. Rychkov, A. I. and Planovskii, A. N.

AN EQUATION FOR DETERMINING COEFFICIENTS OF HEAT TRANSFER FOR BOILING LIQUIDS, Translated from: Khim. Prom. 5, 31-3, NP-tr-40 (1955), 7 p.

Seven references are included.

171. Rychkov, A. I.

THE RELATIONSHIP BETWEEN HEAT EXCHANGE DURING BOILING AND INNER (MOLECULAR) PRESSURE OF A LIQUID, Inzhener. Fiz. Zhur., Akad. Nauk Belorus. S.S.R., No. 11, 63-71 (1959).

On the basis of experiments a simple relationship is indicated between the heat transfer of a boiling liquid and the inherent (cohesive molecular) pressure of the liquid. It is found that the effect of the inherent pressure of the liquid is higher, the greater the inherent pressure and the smaller the molecular weight of the liquid, and vice versa. The generalization of the experimental data makes it possible to derive a formula for calculating the coefficient of heat transfer to boiling liquids.

172. Sauer, E. T.

HEAT TRANSFER TO BOILING LIQUIDS, Thesis, MIT (1937).

173. Sauer, E. T. et al.

HEAT TRANSFER TO BOILING LIQUIDS, Mech. Eng. 60, 669-75 (1938).

Report on progress in program initiated over two years ago, showing that widely accepted generalities are by no means always true.

174. Schorr, M. M.

BOILING HEAT TRANSFER CORRELATIONS, KAPL-M-MMS-1 (1958), 27 p.

A study was made to obtain the best boiling heat transfer correlation applicable to DIG. It was determined that Rohsenow's correlation is the most applicable to the work at present.

175. Shcherbakov, V. K.

HEAT TRANSMISSION THROUGH A WALL WITH LONGITUDINAL RIBS AT HIGH THERMAL CURRENTS AND SURFACE BOILING, Energetika, No. 8, 1962, 78-86.

The temperature and thermal fields in the wall were determined on an electrical two-dimensional model. The following assumptions were made: (1) there is no longitudinal heat flow in the wall section; (2) the ribs are so placed that the regions of their influence on the heat transfer through the smooth wall do not touch; (3) the heat conductance coefficient λ is constant; (4) the contact heat exchange in the rib butt-end is negligible; (5) the heat perception on the inner side of the wall is constant at each point of the model cross-section and is equal to the thermal current through the smooth wall. The electrical model is a mesh of manganine 200 ohms resistors wound with 0.3% precision and fed by a dc current. It has the geometric form of half the rib section with the neighboring wall region that reaches out of the rib influence zone. Boundary conditions are based on the fact that there is a segment of a smooth wall where the influence of the adjacent ribs is not felt. The model was set up for thermal loads of $q = (0.5\text{-}6) \times 10^6 \frac{kcal}{m^2 \times hr}$ and heat transfer coefficients of 16000 to 80000 $\frac{kcal}{m^2 \times hr \times °C}$ on the smooth wall and 7000 to 27000 $\frac{kcal}{m^2 \times hr \times °C}$ on the rib. The thermal current, wall temperature and heat transfer coefficient reach their maximum at the rib base and fall off as one goes up the rib or along the wall for $q \geq 2 \times 10^6 \frac{kcal}{m^2 \times hr}$ and thermal resistance of $7.5 \times 10^{-5} \frac{m^2 \times hr \times °C}{kcal}$. The same values decrease with a decrease in thermal resistance. The experimental and theoretical results agree satisfactorily. Ribs may cause an increase in the thermal current density at their base. Formulas are given for the calculation of the excess thermal current and temperature head. There are 7 figures.

176. Siegel, R. and Usiskin, C. M.

A PHOTOGRAPHIC STUDY OF BOILING IN THE ABSENCE OF GRAVITY, J. Heat Transfer, Ser. C, 81, 230-6 (Aug. 1959).

Experimental equipment for study using container for boiling water and high speed motion picture camera; to eliminate influence of gravity, these were mounted on platform which was allowed to fall freely approximately 8 ft; during fall boiling was photographed; results show gravity plays role in boiling process.

177. Smetona, F.

CHARACTERISTICS OF BOILING SOLUTIONS, CE-3510 (March 1945).

178. Smith, L. A. and Ostesgaard, P. C.

BOILING STUDIES USING SPECIAL SUBASSEMBLIES; LOW PRESSURE LOSS OF FLOW, NRTF-ER-40 (1955).

179. Sterman, L. S.

APPLICATION OF DIMENSIONAL ANALYSIS TO HEAT TRANSFER DURING BOILING, KTS (Kirovgrad Alloys Plant), 2, 1948.

180. Sterman, L. S.

INVESTIGATION OF HEAT EXCHANGE IN THE BOILING OF A LIQUID IN PIPES, Translated from: Zhur. Tekh. Fiz, 24, 2046, AERE-Lib/Trans-565 (1954), 8 p.

Experimentally determined effects of pressure, steam content, and velocity on the heat-transfer coefficient and other properties of boiling water are plotted. Five figures. (NSA-9-1238)

181. Sterman, L. S.

ON THE THEORY OF HEAT EXCHANGE ON BOILING IN PIPES, Translated from: Zhur. Tekh. Fiz, 24, 250-257 (1954), AERE-Lib/Trans-579 (1954), 10 p.

A system of differential equations is given which describes, in hydraulic form, heat exchange on boiling in pipes. A general functional relation is established between criteria of similarity. A critical analysis is given of certain relations and criteria previously established by other investigators.

182. Stiefel, J. T.

THE EFFECT OF FINS OR SPACERS ON HEAT TRANSFER, LOCAL BOILING AND PLATE STRESSES IN A SYSTEM WITH WATER FLOWING TURBULENTLY BETWEEN PARALLEL PLATES, WAPD-EM-2 (January 1950), 29 p.

183. Styrikovich, M. A. and Kazakova, E. A.

MECHANISM OF DEPOSITION OF SALTS ON HEATING SURFACES DURING INTENSE VAPORIZATION, Doklady Akad. Nauk S.S.S.R., 68, 851-4 (1949).

Solns. of Na_2SO_4 of 1, 5, 20, and 100 g/l and satd. (at 100°) gypsum soln. were boiled at atm pressure, heat input in most cases being 5-6 x 10^5 kcal/sq m/hr and solns. of Na_2SO_4 of 1 and 5 g/l were boiled under pressure of 32 and 59.5 atm in a steel app. with a reflux condenser, heat input being up to 1.5-2 x 10^6 kcal/sq m/hr. In the case of solns. far from satn., there were no deposits when large vols were boiled at atm or higher pressures. From solns. close to satn., there were no deposits when large vols. were boiled at atm or higher pressures. From solns. close to satn., there was active deposition of salts, the intensity of deposition increasing with heat input. For relatively small heat flows and rare centers of vapor formation, the deposition of salts was on the whole heating surface regardless of the location of vapor bubbles. Deposits of easily sol. salts, observed in high-pressure boilers, are not the result of a considerable increase in concn. of boiler water in the boundary layer, caused by intensive vapor formation. Apparently, the chief cause for these deposits are the unfavorable hydrodynamic conditions of washing over the inner heating surface of the tubes; the origin of these conditions is related to defects in circulation of water in steam boilers.

184. Styrikovich, M. A.

SPECIAL CHEMICAL PROCESSES TAKING PLACE IN BOILERS AT HIGH STEAM PRESSURES, Izvest. Akad. Nauk S.S.S.R., Otdel. Tekh. Nauk, 1137-53 (1950), Chem. Zentr. I, 1646 (1951).

The problems of hydrodynamics and heat exchange in high-pressure boilers are discussed. Contrary to the theory of Hall, no sepn. of salts takes place from unsatd. solns. during normal circulation, even at very high thermal stress. NaCl dissolves appreciably in steam at pressures of 150 atms; the NaCl concn. in the steam amounts to 0.1% that in the boiler water at 170 atm and to 0.6% at 195 atm. The curve showing NaCl content of the steam against NaCl content in the boiler water becomes steeper at high pressures. Although NaCl is very sol. in steam under very high pressure, the soly. of Na_2SO_4, Na_2HPO_4 and Na silicate is slight. No data are available on the soly. of Ca and Mg salts in high pressure steam.

185. Styushchin, N. G. and Sterman, L. S.

THE EFFECT OF VELOCITY OF MOTION OF A FLUID ON HEAT TRANSFER DURING BOILING, Zhur. Tekh. Fiz. 21, 448-52, AEC-tr-1781 (1951).

186. Tippets, F. E.

MODIFICATION OF A 1706-KER LOOP FOR BOILING, HW-41174 (1956), 14 p.

The 1706 KER Recirculation Loops were constructed in order to provide a facility for obtaining experimental data on the operating characteristics, heat transfer, and erosion effects in a recirculating in-pile loop under various conditions of water coolant properties and fuel element types. The system was designed to be cooled by water in the liquid phase, but was to be capable of being later converted in part to allow in-pile boiling experiments to proceed. (NSA-10-11164)

187. Tobe, L. A.

1706-KER BOILING INVESTIGATION, HW-40104 (1955).

188. Tobilevich, N. Yu. and Yeremenko, B. A.

THE STUDY OF THE CHARACTERISTICS OF THE HEAT TRANSFER PROCESS DURING BOILING IN PIPES, V. sb. Gidrodinamika i Teploobmen Pri Kipenii v Kotlakh Vysokogo Davleniya Akad. Nauk S.S.S.R., 186-205 (1955), Translated from Referat Zhur. Mekh. No. 6, 1957. Abstract No. 6840.

189. Urey, H. C.

BOILING WATER EXPERIMENTS RELATIVE TO BOILING REACTORS, CF-51-8-45 (1951), 3 p.

It is pointed out that boiling at higher temperatures and pressures should be more favorable from the standpoint of bubble disengagement per unit of power per volume of liquid.

190. Vanderwater, R. G. and Toyoda, K. G.

BOILING CONSIDERATION AND INSTRUMENTATION STUDY, HW-26549 (1952).

191. Vanderwater, R. G.

BOILING LIMITS, HW-23251 (1952).

192. Vanderwater, R. G.

METHODS TO ALLEVIATE BOILING LIMITS, HW-24957 (1952).

193. Vanderwater, R. G.

TUBE TEMPERATURE RISE LIMITS - BOILING CONSIDERATIONS, HW-23861 (1952).

194. Verschoor, H. and Stemerding, S.

HEAT TRANSFER IN TWO-PHASE FLOW, p. 201-204 in Institution of Mechanical Engineers, London. Proceedings of the general discussion on heat transfer, 11th-13th Sept., 1951, London, 1951.

195. Vos, A. S.

SUPERHEATING AND DISTRIBUTION OF THE TEMPERATURE IN THE LIQUID AND VAPOR OF BOILING LIQUIDS, Ingenieur 71, No. 7 (1959).

Survey of literature presented; 23 references.

196. Walker, K. W.

HEAT TRANSFER TO WATER BOILING UNDER VACUUM, Thesis MIT (1940).

197. Wallis, G. B. and Griffith, P.

LIQUID AND GAS DISTRIBUTIONS IN A TWO-PHASE BOILING ANALOGY, NP-7204 (1958), 74 p.

A description of the design and operation of an experimental apparatus for the analysis of two-phase flows similar to those occurring in boiler tubes at low pressures is presented. Velocity and density profiles of air-water mixtures are determined across a passage in which boiling conditions are simulated by pumping air through porous walls into a water stream. Photographs of the flow patterns are also presented as a qualitative check on the quantitative data. The results obtained include: velocity and concentration profiles of the two phases for various values of the flow rates of each, and a classification of the flow into several patterns or regimes with quantitative data describing each regime. The data are suitable for use in comparing the physical phenomena with mathematical models and for developing a more accurate theoretical treatment of the flow of boiling fluids in heated channels. (NSA, 1959, #7857).

198. Weil, L.

RAPID DETERMINATION OF THE COEFFICIENTS OF EXCHANGE IN BOILING LIQUIDS, J. Phys. Radium 12, 824-5 (1951) (in French).

In order to determine the coefficient of exchange $\alpha = P/\theta$ it is sufficient to measure θ as a function of t, and then to obtain the value of $P = (mc_p/s)(d\theta/dt)$, where P = power given up by a unit of area of the heating element, m = mass of the element, c_p = its specific heat, s = its area, θ = difference between the temperature of the element and that of the liquid, t = time. (Sci. A. 55-1711).

199. Weil, L.

HEAT TRANSFER IN BOILING FLUIDS, Kältetechnik, 5, Heft 12, 349 (1953).

200. Werner, P.

QUANTITATIVE EXPERIMENTS ON BOILING UNDER REDUCED AND INCREASED PRESSURES, A. Physik. Chem. Unterricht 34, 161-4 (1921).

The app. consists of a test-tube partly filled with H_2O and closed with a rubber stopper provided with a thermometer and bent glass tube. The H_2O is boiled at first vigorously to expel all the air, and the test-tube is then connected to a tube 1 m long, which dips into mercury. As the test-tube cools (an extra test-tube is also used in series to serve as a condenser) a partial vacuum forms. The rise of mercury in the tube indicates the extent of reduction of the pressure in the system. One student notes the temp, another dets. the pressure by the mercury gage. The continuation of the boiling is observed under reduced pressures. The test-tube must be cooled by a freezing mixt. to effect large reduction. For increasing pressures, the arrangement is somewhat more complex and the original must be consulted for details. (CA 15-3785-7)

201. Woods, W. K. and Worthington, H.

BOILING IN A PILE, DUH-10169 (1943).

202. Yamagata, K. et al.

BOILING HEAT TRANSFER AT ATMOSPHERIC PRESSURE WITH DISTILLED AND TAP WATER, Mem. Fac. Eng. Kyusku Uni. 15 (1), 97 (1955).

203. Young, G.

STABILITY OF A FIN IN BOILING LIQUID, MDDC-745 (CP-1902) (1945), 9 p.

An idealized discussion of heat transfer in boiling is given, and some calculations of fin performance are made. It is found that infinitely long fins impart stability to a surface being cooled by a boiling liquid.

204. Zmola, P.

INVESTIGATION OF THE MECHANISM OF BOILING IN LIQUIDS, Ph.D. Thesis, Purdue Univ., Lafayette, Ind. (1950).

205. Cambridge University, England

BOILER CIRCULATION RESEARCH, Nuclear Eng., 2, 324-6 (1957).

The circulation of water in boiler tubes at high pressures is a complex subject and most of the theories are based on the supposition that the vapor-water mixture in a boiler tube behaves as a homogeneous fluid; a convenient theory, but one which has some objectionable features. A series of experiments has been performed with 2.54 cm diameter tubes at pressures approaching 210 kg/cm^2, and other experiments on larger, different tubes are in progress. The apparent density of the vapor water is measured by the use of γ rays from a Cs source.

206. Harrison, W. B.

WETTING EFFECTS ON HEAT TRANSFER, Georgia Inst. of Tech. Final Report (for September 1, 1955 through September 30, 1957). 131 p. NP-6508.

The first chapter deals with the general considerations involved in bubble formation and wetting effects. Specific problems related to the copper-stearic acid system also are discussed as background material pertaining to the boiling heat transfer studies described in the second and third chapters. Wetting effects on convective heat transfer are studied with a copper-stearic acid system, reported in the fourth chapter, and a copper-sodium system, reported in the fifth chapter. These convective studies were each made in experimental apparatus which incorporated a region so as to maximize the effect of additional thermal resistance created by nonwetting conditions at the heat transfer surface. In general, the work demonstrated a significant wetting effect on boiling stearic acid from different faces of copper single crystals, but wetting effects were not observed with stearic acid in forced convection past the same crystal surfaces without boiling. The convective studies with sodium were inconclusive, but they leave open the possibility that low and erratic data may be due to nonwetting conditions at the heat transfer surface.

FORCED CONVECTION

207. Alekseyev, G. V., Engineer, Zenkevich, B. A., Candidate of Technical Sciences, Subbotin, V. I., Doctor of Technical Sciences, Professor.

AN INVESTIGATION OF HEAT TRANSFER WHEN WATER IN TUBES BOILS WITH BUBBLE FORMATION, Teploenergetika, No. 4, 74-76 (1962).

Although a good deal of experimental data has been accumulated on heat exchange when water boils in tubes, there are considerable differences between the results of various authors and little work has been done on heat transfer at high steam contents. The present work was undertaken to fill the gap. The experimental section consisted of a pure nickel tube of 12 mm o.d. with a wall thickness of 1.5 mm, electrically heated and with an effective length of 700 mm. The incoming water could be heated either to some definite temperature below the saturation temperature or to a given steam content. Tests were made with the pressure, the specific heat flow and the rate of flow of water (by weight) maintained constant, and the input heat content of the water was determined which gave a set value of steam content in the experimental section. Tests were made with boiling with bubble formation at pressures of 30, 60, 100 and 150 atm with flow rates of 250 to 2000 kg/m^2 sec, with specific heat flow rates up to 0.6 x 10^6 kcal/m^2 hour and steam contents by weight up to 90%. The maximum error of determination of the steam content α ranged from ±20% at a pressure of 30 atm to ±50% at a pressure of 150 atm. The error rises with increase in pressure, because at higher pressures the temperature drops are smaller and the possibilities of error are greater. Forced flow was used and it was found that neither the rate of circulation nor the initial value of the steam content had any influence on the process of heat transfer and, with well-developed surface boiling, the heat transfer coefficient was entirely determined by the specific heat flux and the pressure. The influence of pressure on the heat-transfer coefficient can be allowed for by a criterion K_p. The following empirical formula was derived for heat transfer to a steam/water mixture during boiling with bubble formation:

$$\alpha = 0.1\, K_p^{0.314}\, q^{0.7} \qquad (4)$$

where

$$K_p = \frac{p \cdot 10^4}{\sqrt{\sigma(\gamma' - \gamma'')}} \qquad (5)$$

α - the heat transfer coefficient; q - the absolute pressure, kg/cm^2, σ - the surface tension, kg/m; γ', γ'' - the specific gravity of water and steam on the saturation line at the given pressure, kg/m^3. The maximum deviation of experimental points from this relationship does not exceed ±30%. Results calculated by Eq. (4) are in good agreement with those found by other authors for the case of developed bubble type boiling in water initially below the saturation temperature. The relationship between the heat-transfer coefficient and pressure and specific heat flow is of the same form for boiling with developed bubbling in tubes as in bulk boiling. There are 7 figures.

208. Averin, E. K. and Kruzhilin, G. N.

HEAT TRANSFER IN THE BOILING OF WATER IN CONDITIONS OF FORCED CIRCULATION, Transl. from p. 239-71 of Teploperedachai Teplovoe Modelirovanie, a publication of the Academy of Sciences Press, USSR, Moscow, 1959, 35 p. AERE-Trans-847.

Studies were carried out on the heat transfer from a hot stainless steel surface (slit channel) to boiling water under conditions of forced flow. The water velocity was varied from 0.85 to 5.5 m/sec, the pressure from 1 to 9 kg/cm^2 and the specific heat flux from 0.2 kcal/m^2-hr to the critical value (where burnout of the surface occurs). The data are presented in the form of extensive tables of the above variables for temperature differences between the surface and the water in the range 10 to 70°C, and graphs are given for heat flux and critical heat flux as functions of the above variables. Equations for the heat transfer coefficient and the critical heat flux are given; the critical heat flux is shown to be proportional to the 0.5 power of the water velocity. For small heat fluxes, the heat transfer increases with the water velocity, but for large heat fluxes it decreases. Experiments were also made on the effect of steam content in water on the critical heat flux, which is shown to decrease with steam content up to 0.4 to 0.6 wt. % and thereafter remain constant. This behavior is interpreted in terms of a transition to emulsion flow. Data are also given for heat transfer to boiling water moving in an annular gap.

209. Bergles, A. E. and Rohsenow, W. M.

THE INFLUENCE OF TEMPERATURE DIFFERENCE ON THE TURBULENT FORCED-CONVECTION HEATING OF WATER, J. Heat Transfer, 84, 268-70 (Aug. 1962).

Studies were made of the effects of temperature difference Δt on the forced-convection heating of water. Data indicated that there is no great error introduced by assuming conventional correlations valid for low-temperature water at high Δt. The McAdams correlation equation, $(h/c_{pb}G)(c_p\mu/k)_b^{0.6} = 0.023/GD/\mu_b)^{0.2}$, gave the best results. The subscripts refer to the temperature at which the particular fluid property is evaluated.

210. Bradfield, W. S.

PLANE LAMINAR FORCED CONVECTION FILM BOILING WITH SUBCOOLING, Convair Scientific Research Laboratory, Research Note 35 (1960).

211. Butler, P. A.

MODIFICATION OF A FORCED CONVECTION HEAT TRANSFER LOOP FOR USE WITH BINARY MIXTURES, (thesis), AD-238468 (1960), 50 p.

A project to determine the heat-transfer and pressure-drop characteristics during boiling of a binary mixture in a forced-convection heat-transfer loop is described. A previously used loop was employed, and a description of the modifications of the

loop and the results of the modifications are presented. Thermocouple and orifice calibrations for the loop are described.

212. Butzbach, M.

DETERMINATION EXPERIMENTALE DES COEFFICIENTS DE TRANSMISSION DE CHALEUR, Houille Blanche 12, 69-80 (1957).

Experimental determination of heat transfer coefficients at high heat flux densities in single and two phase media; investigation of forced convection transmission of heat in water with or without surface boiling in nuclear reactors.

213. Casey, D. F.

GRAPHICAL SOLUTIONS OF THE NON-BOILING AND SURFACE BOILING HEAT-TRANSFER EQUATIONS, MTA-10 (1953), 14 p.

The data presented are graphical solutions of the equations recommended by McAdams describing the two phases of forced-convection heat transfer to water, non-boiling and surface boiling. The solutions were obtained for ranges of variables to cover the majority of problems that arise in practice. (CA-48-412b)

214. Chen, S. Y.

HEAT TRANSFER TO BOILING WATER INSIDE TUBES WITH FORCED CIRCULATION, Ph.D. Thesis, Ohio State Univ. (1955).

215. Dwyer, O. E., Horn, F. L. and Weisman, J.

HEAT TRANSFER RATES FOR CROSSFLOW OF WATER THROUGH A TUBE AT REYNOLDS NUMBERS UP TO A MILLION, Part 3: FORCED CONVECTION BOILING AND PRESSURE DROP DATA, ASME Paper No. 54-F-21 (1954).

216. Dwyer, O. E. et al.

HEAT TRANSFER RATES - CROSS FLOW ON WATER THROUGH A TUBE BANK AT REYNOLDS NUMBERS UP TO A MILLION, Ind. Eng. Chem. 48, 1836-46 (1956).

Heat transfer coefficients have been obtained at high Reynolds numbers for cross flow of high temperature, high pressure water through a bank of 200 tubes, 0.810 inch o.d. and spaced on an equilateral triangular grid $1\frac{9}{32}$ inches between centers. In the range investigated, the coefficients were considerably greater than those predicted by extrapolation of the Colburn equation. In the Reynolds number range 10^5 to 10^6, the coefficient varies approximately as the 0.8 power of the Reynolds number instead of 0.6, as indicated by the Colburn equation. The effects of pressure, heat flux, and flow rate on the inception of nucleate boiling and on the heat transfer rate in the transition stage between nonboiling and full surface boiling were studied. Pressure drop results were consistent with data obtained at lower Reynolds numbers.

217. Gouse, S. W.

DESIGN OF A TEST SECTION FOR LOOP 1, BOILING HEAT TRANSFER STUDIES, NAA-SR-MEMO-5651 (1960), 31 p.

Results of a study are presented on aspects of the design, fabrication, and instrumentation of a test section for use in the organic moderated reactor program to study forced convection and sub-cooled boiling of Santowax R.

218. Gunther, F. C.

PHOTOGRAPHIC STUDY OF SURFACE-BOILING HEAT TRANSFER TO WATER WITH FORCED CONVECTION, Trans. ASME, 73, p. 115-123 (1951).

To investigate effect of forced convection on mechanism of heat transfer with surface boiling, high speed, high resolution photographic study was made; test section was transparent channel of rectangular cross section $\frac{3}{16} \times \frac{1}{2} \times 6$ in. with electrically heated metal strip $\frac{1}{8}$ in. wide suspended lengthwise to divide channel into two flow passages. App. Mech. Rev-5-242.

219. Hines, W. S.

FORCED CONVECTION AND PEAK NUCLEATE BOILING HEAT TRANSFER CHARACTERISTICS FOR HYDRAZINE FLOWING TURBULENTLY IN A ROUND TUBE AT PRESSURES TO 1000 psia, R-2059, (Rocketdyne Report) (1959).

220. Hsu, S. T. and Ing, P. W.

EXPERIMENTS ON FORCED CONVECTION SUBCOOLED NUCLEATE BOILING HEAT TRANSFER, American Society of Mechanical Engineers, Preprint Paper No. 62-HT-38, New York (1962), 12 p.

Experiments were performed on subcooled nucleate boiling under forced convection inside an Inconel tube of small diameter and high L/D ratio. The tube itself was used as a resistor for electrical heating. Water was used as the cooling fluid. Investigations included effects of pressure, inlet subcooling, and mass velocity on heat transfer; results of sudden change in heat flux; observations of temperature waves, stability and types of flow; and correlations of heat-transfer data.

221. Huyghe, J. and Mondin, H.

HEAT TRANSFER ON ADMIXTURE OF LIQUID AND GAS BY FORCED TURBULENT CONVECTION WITH SLIGHT VAPORIZATION OF THE LIQUID PHASE, C. R. Acad. Sci. 253, 395-7 (1961).

Flow in double phase, previously considered with respect to thermal characteristics is now treated from the hydraulic standpoint. Modifications of apparatus are discussed for experiments at 100°C. At high turbulence, a thin liquid film is observed on the boundary wall which flows at a speed much lower than that of the gas, and its properties and relationships to the flow are discussed.

222. Huyghe, J., Mondin, H. and Villeneuve, J.

HEAT TRANSFER ON ADMIXTURE OF LIQUID AND GAS BY FORCED TURBULENT CONVECTION WITH SLIGHT VAPORIZATION OF THE LIQUID PHASE, C. R. Acad. Sci. 252, 3015-17 (1961).

Vaporization of a considerable quantity of liquid entrained into a turbulent gaseous flow has previously been suggested as an explanation of the growth of the thermal capacity of the fluid and the improved heat transfer coefficient. This paper shows that the transfer coefficient can be greatly increased even with very little vaporization.

223. Ing, P. W.

FORCED CONVECTION SUBCOOLED NUCLEATE BOILING HEAT TRANSFER INSIDE AN ELECTRICALLY HEATED TUBE OF SMALL DIAMETER AND LARGE L/D RATIO, Dissertation Abstr., 22, 3971 (1962).

A literature survey was made on boiling. This includes bulk boiling, natural and forced convection boiling, two-phase flows, pressure drops, and the stability phenomena. Experiments were performed with special emphasis on the forced convection subcooled nucleate boiling heat transfer inside an electrically heated tube of small diameter and large L/D ratio. Instrumentation was provided to measure temperatures, variations of temperatures, pressures, pressure differentials, mass flow rates, and flow observations. Test results showed the effect of pressure, of inlet subcooling, and of mass velocity on heat transfer. Effects of heat flux on tube wall and fluid temperatures were also observed, particularly in relation to temperature waves and flow stability. Heat transfer correlations were obtained for both the non-boiling and the subcooled nucleate boiling inside the test section.

224. Ivey, H. J. and Morris, D. J.

ON THE RELEVANCE OF THE VAPOUR-LIQUID EXCHANGE MECHANISM FOR SUBCOOLED BOILING HEAT TRANSFER AT HIGH PRESSURE, AEEW-R137 (1962).

225. Kleinhans, A.

STABILITY OF THE FLOW DISTRIBUTION IN HEATING SURFACES WITH FORCED FLOW, Trans. from Archiv für Warmewirtschaft and Dampfkesselwesen 20, 135-8, AEC-tr-1863 (1939), 15 p.

Starting with the pressure drop in a bundle of pipes, a mathematical study is made of the cases in which the flow distribution in a heating surface with forced flow can become unstable. The concept of unstable flow distribution is explained by means of examples.

226. Kreith, F. and Summerfield, M.

INVESTIGATION OF HEAT TRANSFER AT HIGH HEAT-FLUX DENSITIES: EXPERIMENTAL STUDY WITH WATER OF FRICTION DROP AND FORCED CONVECTION WITH AND WITHOUT SURFACE BOILING IN TUBES; PROGRESS REPORT No. 4-68, NP-1213 (JPL-PR-4-68) (1948), 44 p.

Heat-transfer and nonisothermal pressure drop data are presented for water flowing in stainless-steel tubes 0.528 and 0.587 in. ID in a horizontal and vertical position, respectively. The tubes were heated by passing alternating current at low voltage through them. The surface coefficients of heat transfer between the inner wall and the liquid were determined by measuring the fluid inlet and outlet temperature, the energy dissipated, and the temperature of the outer tube surface. The inner surface temperature was calculated by means of a theoretical equation, which is derived in detail in an appendix. The friction data indicate that the over-all friction drop at equivalent mass flow rates of water may decrease up to 16% under forced-convective heat-transfer conditions when compared with isothermal flow. The heat-transfer friction drop can be predicted by the use of a viscosity-ratio correction factor. Surface coefficients of heat transfer for non-boiling forced convection were correlated within ±5% for heat-flux densities from 0.5 to 2 Btu/(in.^{2})(sec) in the Reynolds no. range from 50,000 to 200,000 by the conventional Colburn equation for heat transfer in tubes. In the forced convection region where the surface temperature exceeded the boiling temperature of the liquid, it was found that the conventional equations for forced convection were not applicable, because in this region the surface temperature was primarily a function of the liquid pressure. When the liquid film adjacent to the wall exceeded the boiling temperature, the wall temperature was relatively insensitive to a reduction in velocity or an increase in heat flux and never exceeded the boiling temperature more than 70°F. Experimental data were obtained at mass flow rates of about 0.80 and 1.45 lb/sec [3.0 and 5.4 lb/(sec)(in.^{2})] in the heat-flux range from 0.7 to 2.8 Btu/(in.^{2})(sec) and at pressures from 20 to 200 psia. For a given mass flow rate and pressure the results were correlated by plotting the heat flux vs. the difference in temperature between the wall and the boiling point of the liquid. The maximum heat that could be removed at a given pressure and flow rate was limited by an unsteady flow phenomenon caused by the accumulation of vapor bubbles in the liquid near the outlet end of the tube. When this condition was reached, the test section began to vibrate violently and a further decrease in mass flow caused the tube to melt near the outlet end. 13 references.

227. Kutateladze, S.S., Doctor of Technical Sciences, Professor.

INFLUENCE OF RATE OF CIRCULATION ON THE HEAT-TRANSFER COEFFICIENT DURING BOILING IN TUBES, Energomashinostroyeniye, No. 1, pp. 12-15 (1961).

This article integrates the results of other authors and proposes a simple interpolation formula to allow for the combined influence on the intensity of heat transfer of forced convection and the process of steam generation.

In steam boilers, atomic reactors and other steam-raising equipment, the process of boiling in tubes takes place under conditions of a certain speed of circulation of the liquid. It has been known for a long time that under certain conditions the rate of circulation and the process of steam generation have a mutual influence on the heat-transfer coefficient.

However, many workers have shown that with a high rate of heat flux the speed of circulation has practically no influence on the intensity of heat transfer during boiling. Under conditions of natural circulation there is an optimum condition of operation of an evaporator for which practically the whole of the heating surface is generating steam and the heat-transfer relationships are close to those of developed boiling in a large volume. Many authors have found that speed of flow either has no influence or was automatically allowed for by coefficients of proportionality. Formulae given by a number of authors are quoted to bear out this statement.

Thus, there is a region of rate of heat flow in which the heat-transfer coefficient during boiling is practically independent of the rate of flow of liquid, at any rate when it does not depend on the steam content of the flow. This region is termed the region of developed boiling. In this case heat transfer during boiling in tubes is determined by a system of criteria, as per Eq. (8).

As the process of boiling develops, its influence on the boundary layer becomes more and more important. Finally, the movement of liquid in the layer adjacent to the walls, due to the formation, growth and breakaway of steam bubbles, becomes much more important than the effect of the mean flow of the steam-liquid mixture as a whole.

It has been proposed, to a first approximation, to assess the influence of forced circulation and the process of steam formation by the ratio of the heat-transfer coefficient corresponding to convective heat exchange without boiling (α_0) to that for convective heat exchange with developed boiling (α_∞). A simple interpolation formula that satisfies the necessary conditions is of the form:

$$\frac{\alpha}{\alpha_0} = \sqrt[n]{1 + \left(\frac{\alpha_\infty}{\alpha_0}\right)^n} \quad . \qquad (12)$$

Experimental results are quoted for particular conditions of flow in pipes combined with heat transfer which, if expressions (7) and (12) are valid, should lie on straight lines in the system of coordinates given by expression (14).

The results are plotted in Fig. 3 and it will be seen that the linearity is satisfactory for practical purposes when n in Eq. (12) is 2.

Further results are then quoted and it is concluded that the combined influence of rate of circulation and the process of boiling on the heat-transfer coefficient may be represented by the interpolation formula (12). The existing limited experimental data on the boiling of water in tubes indicates that the value of n in this formula equals 2, which is convenient for practical calculations. The heat-transfer coefficient during developed boiling in tubes is described by expression (7), which is of the same type as those applicable to boiling in a large volume. There is need for further careful experimental study of how the combined influence of organized flow of liquid in the process of steam formation affects the heat transfer.

Acknowledgments are made to T. G. Filippova and Ya. A. Mitsel' for assistance in calculations. There are 6 figures and 15 references: 14 Soviet and 1 non-Soviet.

228. Ladiev, R. Ya.

COMPARISON OF HEAT TRANSFER TO BOILING SOLUTIONS OF NH_4-NO_3 IN A VERTICAL CIRCUIT WITH ARTIFICIAL AND NATURAL CIRCULATION, Izvest. Kiev. Politekh. Inst. 30, Pt. 1, 120-33 (1960).

During boiling in a circuit with artificial circulation, 2 modes of changes in heat transfer of the vapor formation process occur: "free," where the heat-transfer coeff. $\alpha_2 = f(q)$ and "constrained," where $\alpha_2 = f(q,\omega)$(q = heat flux, kcal/sq m sec and ω = circulation velocity). The velocity corresponding to the change of one mode of vapor formation into the other is the transient velocity, ω_0; this is detd. exptl., and for H_2O and aq. solns. of salts $\omega_0 d$ - 0.0133 = const.

229. Leninger, H. A. and Veldstra, J.

HEAT TRANSFER IN A VERTICAL EVAPORATOR TUBE IN FORCED CIRCULATION AND WITH SURFACE BOILING, Chem.-Ing. Tech. 34, 417-22 (1962).

Expts. are reported which are an extension of the natural convection studies (CA 56, 11391d). In forced circulation, the effect of temp drop upon heat transfer is less than with natural circulation. When surface boiling is used, where no vapor is allowed to form in the tube, the heat transfer increases with the recirculating velocity.

230. Levy, S.

STEAM SLIP - THEORETICAL PREDICTION FROM MOMENTUM MODEL, Trans. ASME, Jour. of Heat Trans. 82, Series C, 113 (1960).

Theoretical equations governing slip effects in forced circulation of boiling water are derived. The equations indicate that steam slip is dependent upon channel geometry, inlet water velocity, and rate of heat addition. A simplified momentum model is postulated which leads to equal friction and head losses of two phases. The model gives good agreement with available experimental results in horizontal and vertical test sections with and without heat addition at pressures from 12 to 2000 psia. Discussion of the model in terms of nonquasi steady-state unbalances of friction and head losses of the two phases explains experimental deviations from the predictions and the previously noted effects of water inlet velocity. It also gives trends for the effects of channel geometry and rate of heat addition. Application of the simplified model to calculating two-phase pressure drops is included.

231. Logan, L. A., Fragen, N., and Badger, W. L.

LIQUID FILM HEAT TRANSFER COEFFICIENTS IN A VERTICAL TUBE FORCED CIRCULATION EVAPORATOR, Ind. Eng. Che. 20, 1044-1047 (1934).

Coefficients for liquids in forced convection through 8 ft, 0.75 in. internal diam vertical copper tubes have

been measured directly in semi-commercial evaporator and correlated by equation; eq. applied with accuracy within plus or minus 10%, between stated limits.

232. McLain, Stuart

QUARTERLY PROGRESS REPORT ON REACTOR DEVELOPMENT, 4000 PROGRAM, ANL-5594 (1956), 66 p.

Experimental Boiling Water Reactor, EBWR. Specifications have been completed for tne forced circulation equipment. Excessive O_2 and H_2 was detected in EBWR steam. The possibility of controlling the O_2 content, and the effects of excessive O_2 on corrosion are being studied. In-pile and out-of-pile corrosion tests on Al-Ni alloys are being evaluated. A lower in-pile corrosion rate is indicated. Fast Power Breeder Reactor, EBR-II. Working-model operations are reviewed. Electromagnetic pump and auxiliary equipment operation continued to be satisfactory. Shutdown cooler analysis and installation for the EBR model was reviewed. The operation of this cooler was extrapolated for application to the EBR-II. Thermal cycling tests on U fuel alloys, 3 and 5% fissium, indicate desirable thermal stability. Heat transfer coefficients were measured in the liquid metal loop for local fluxes up to 6×10^6 Btu/ft^2-hr.

233. Massier, P. F.

A FORCED-CONVECTION AND NUCLEATE BOILING HEAT-TRANSFER TEST APPARATUS, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif., JPL-TR-32-47 (1961), 28 p.

For most liquid propellants used in rocket engines, the ability to cool thrust-chamber walls locally is established by the upper limit of nucleate boiling. An experimental apparatus utilizing electrically heated tubes to obtain boiling heat-transfer characteristics of numerous propellants is described. The effects of deposition and electrically conducting fluids on heat-flux measurements, as well as precautions that must be considered when testing monopropellants, are discussed. Comparisons are made of variable-property and constant-property equations for computing temperature difference across an electrically heated tube wall. (NSA 15: 11127)

234. Menashi, L.

INCIPIENT BOILING AND THE BUBBLE BOUNDARY LAYER FORMATION OVER A HEATED PLATE FOR FORCED CONVECTION FLOW IN A PRESSURIZED RECTANGULAR CHANNEL, Dissertation Abstr., 23, 585 (Aug. 1962).

The inception of bubbles for forced convection flow over a heated plate in a pressurized channel and their consequent mutual interaction in the formation of a bubble boundary layer was investigated. A high pressure closed loop was designed to permit visual observation of boiling over a heated plate and to provide temperature measurements of the boiling fluid. The plate, which is 0.050 in. wide and 9.48 in. long, was vertically oriented in a 0.50 x 0.46 in. rectangular channel. Photographs and temperature profile measurements were obtained for forced convection boiling of distilled water at pressures of 200 to 1000 psia, velocities of 1 to 6 ft/sec, subcoolings of 50 to 300°F and heat flux of 0.14×10^6 to 1.5×10^6 Btu/hr-ft^2. A correlation equation for the incipient heat flux (the flux necessary to initiate observable bubbles) was obtained. The equation predicts incipient heat flux to within ±15%. The bubble boundary layer thickness was correlated to within ±20% by a dimensionless equation. Temperature profiles at various locations from the leading edge were measured. The mean temperature at the single-phase core-bubble boundary layer interface was found to approach inlet temperature as heat flux is increased toward its maximum value. Large temperature fluctuations were detected in both the single-phase core and the bubble boundary layer. The temperature fluctuations indicate the existence of subcooled liquid at the inlet temperature along the single-phase core-bubble boundary layer interface. It was also observed that the amplitude of temperature fluctuations near the heated surface decreases as the heat flux is increased. This suggests that burnout is characterized by the formation of a stagnant layer of superheated vapor near the surface. (NSA-62-33138)

235. Mumm, J. F.

HEAT TRANSFER TO BOILING WATER FORCED THROUGH A UNIFORMLY HEATED TUBE, ANL-5276 (1954), 57 p.

An electrically heated, horizontal, Type 347 stainless steel tube (0.465 in. ID by 0.505 in. OD by 7 ft long) was used to obtain local coefficients of heat transfer in the region of net steam generation. The maximum weight fraction evaporated was 0.60. The investigation covered a range of pressures from 45 to 200 psia, of heat fluxes from 50,000 to 250,000 Btu/(hr)(sq ft), and of flow rates from 70 to 280 lb/(sec)(sq ft). The data were correlated by means of the dimensionless equation

$$\frac{hD_c}{k} = \left[4.3 + 5.0 \times 10^{-4}\left(\frac{V_{fg}}{V_f}\right)\right]^{1.64}\left[\frac{q''}{Gh_{fg}}\right]^{0.464}\left[\frac{GD}{\mu_f}\right]^{0.808}$$

with a root mean square deviation of 10%. (NSA-9-1804)

236. Perkins, H. C. and Leppert, G.

FORCED CONVECTION HEAT TRANSFER FROM A UNIFORMLY HEATED CYLINDER, J. Heat Transfer, 84, 257-63 (Aug. 1962).

Forced convection heat transfer from a cylindrical heating element with crossflow occurs in many situations of practical interest, but heat-transfer coefficients for liquids were previously reported in the literature only for Reynolds numbers below 200. New data taken with water and ethylene glycol at Reynolds numbers from 40 to 100,000 and Prandtl numbers from 1 to 300 were correlated. The effects of temperature differences large enough to produce significant changes in viscosity across the boundary layer were also investigated and are correlated in terms of a viscosity ratio.

237. Profos, P.

DYNAMIC BEHAVIOUR OF FORCED-FLOW EVAPORATOR SYSTEMS, Sulzer Tech. Rev., 42, 5-12 (1960).

The dynamic control behavior of forced-flow evaporator systems is of considerable importance in the control of once-through forced-circulation boilers and drum-type boilers with steaming economizers. It plays a large part in deciding the character of the feed control system, and to some extent it also affects the properties of the boiler as a whole. A combined graphical and mathematical method is developed by which the transfer characteristics can be determined from the design data of the steam generator. This incidentally permits a clear picture to be gained of the complicated processes taking place in a heating system of this kind under transient conditions.

238. Quittenton, R. C.

THE DIRECT MEASUREMENT OF THE FILM COEFFICIENT OF HEAT TRANSFER TO MOLTEN SODIUM METAL IN FORCED CONVECTION, Arvida, Quebec, 1953.

References: p. 37-9.

239. Rachko, V. A.

EFFECT OF THE VELOCITY CIRCULATION ON THE COEFFICIENT OF HEAT TRANSFER IN BOILING WATER, Journal of Technical Physics (USSR), No. 9, 16, 993-1004 (1946).

240. Rankin, S.

HEAT TRANSFER TO BOILING LIQUIDS UNDER CONDITIONS OF HIGH TEMPERATURE DIFFERENCE AND FORCED CONVECTION, Final Technical Report, UD-FB-13 (1958), 94 p.

Heat transfer coefficients have been determined for forced convection film boiling under conditions of high temperature difference. The results should be of value in design of cooling systems where large and variable heat fluxes are encountered. The studies were made with two different liquids, Freon-113 and methanol. The liquid flowed vertically upwards inside a 4-ft length of steam jacketed Everdur pipe of 1.06 in. inside diameter. The liquid entering the test section was slightly above 1 atm pressure and a few degrees below its boiling point. Data were obtained at entering liquid velocities of from 1.0 to 8.5 ft/sec, and with wall-to-fluid temperature differences which ranged from a maximum of 320 deg. F. down to values around 80 deg. F. where nucleate boiling was encountered. Peak heat flux data and pressure drop data were also obtained in most cases. The heat transfer coefficients varied from around 58 Btu/(hr)(deg.F.)(sq ft) at the lowest temperature differences to around 44 Btu/(hr)(deg.F.)(sq ft) at the highest temperature differences. The effect of entering liquid velocity was quite small; at any given temperature difference the velocity differences affected the magnitude of the heat transfer coefficients by no more than plus or minus 10%. An equation has been derived for prediction of the coefficients of heat transfer for this case. The derivation assumes the presence of a continuous smooth core of liquid surrounded by an annular film of vapor flowing upward in laminar motion under the influence of buoyant forces. However, the experimental results yield heat transfer coefficients which are about twice as large as those predicted by the derived equation. This seems to indicate that the flow of vapor in the vapor film was turbulent. The degree of stability of the vapor film has also been examined in this report. A mathematical derivation is presented to show that vapor repulsion forces are sufficient to provide for a stable interface under any velocity condition.

241. Rao, C. V.

EFFECT OF LOCAL BOILING ON HEAT TRANSFER RATES INSIDE A VERTICAL ANNULUS WITH COOLANT MIXTURES OF DIFFERENT COMPOSITIONS UNDER LAMINAR AND TURBULENT FLOW CONDITIONS, Dissertation Abstr. 22, 3567 (Apr.1962).

The design and optimum operation of cooling jackets for liquid-cooled aircraft engines and rocket motors require an understanding of the heat-transfer characteristics of different types of coolant under various operating conditions. Because of the impracticability of obtaining fundamental heat-transfer data by the use of actual full-scale engines, a bench-rig apparatus designed for the simulation of the range of heat fluxes encountered in aircraft engines was employed to study local boiling as well as non-boiling heat-transfer rates under both laminar and turbulent flow conditions. The heat exchanger consists essentially of a thick-walled 1.635-in. OD by 0.98-in. ID copper tube 14.25 in. long surrounded by a 2.01-in. ID glass jacket by means of which visual observations could be made. The coolant flowing upward through the annulus was heated by steam condensing on the inside of the copper tube. The coolants studied were methanol, water and their mixtures. For nonboiling conditions, the turbulent flow data obtained could be fairly well correlated by the equation employed by Carpenter et al., predicted values being about 10% higher. Correlation of the laminar flow data required the use of a specially derived theoretical equation based on the actual velocity distribution in annuli. The laminar flow equation used by Carpenter et al., predicted values 25 to 30% higher. In the case of local boiling data obtained, when the local boiling effects were large in comparison with the convective heat-transfer effects, the heat-transfer rates were found to be independent of flow rates, coolant pressures, and degrees of subcooling and depend only on the temperature excess and coolants employed. With small local boiling effects, heat transfer rates were found to be affected by all of the operating variables mentioned above. The local boiling laminar flow data could empirically be correlated in a simple manner. A mechanistic picture of bubble formation, growth and collapse was proposed for the interpretation of local boiling data in general.

242. Rohsenow, W. M. and Clark, J. A.

PROGRESS REPORT NO. 5, DIC Project 6627, NP-3461 (1950), 17 p.

Included are 11 curves which present the initial results of forced convection boiling heat transfer

studies. Heat transfer data are given for water at 2000, 1500, and 200 psia flowing at 12 to 20 ft/sec through an electrically heated 0.180 in. ID vertical Ni test section. Test section pressure drop data are given for the 200 psia run. Also given are curves showing the axial distribution of temperature and heat flux in the test section at 1500 and 2000 psia at 12 and 20 ft/sec. For most of the reported runs the data is given for a heat transfer surface contaminated with a scale deposit. Interpretation of heat transfer data from the contaminated surface is given, and a method is proposed for evaluating the effect of the scale deposit. Fluid bulk temperature and heat flux (q/A) are calculated as functions of test section length by a method given in the appendix. Two test section failures or burnouts are discussed and photographed. It appears from the boiling data obtained that the dynamic or stirring effect of the bubbles on the rate of heat transfer is significant at 1500 and 2000 psia.

243. Rohsenow, W. M. and Clark, J. A.

THE MECHANISM OF BOILING HEAT TRANSFER, Trans. Am. Soc. Mech. Engrs. 73, 609-20 (1951).

An analysis of the heat required to form a vapor bubble in a liquid is presented. High-speed motion pictures of boiling heat transfer in forced convection showing bubbles departing from a heated surface are analyzed and the net heat transferred to the bubbles is compared with the total heat transferred from the heated surface. It is found that the heat transferred to the moving liquid by the condensation of the bubbles is a negligible part of the total convective heat transfer. Therefore, it is proposed that the high rate of heat transfer assocd. with surface boiling in a subcooled liquid is due primarily to the violent agitation of the quiescent layers of liquid adjacent to the heated surface resulting from the motion of vapor bubbles being generated there.

244. Sabersky, R. H. and Mulligan, H. E.

ON THE RELATIONSHIP BETWEEN FLUID FRICTION AND HEAT TRANSFER IN NUCLEATE BOILING, Jet. Prop. 25, 9-12 (1955).

Von Karman [Trans. ASME 61, 705-10, 1939] has shown that the friction and heat-transfer coefficients on the basis of Reynolds analogy are related by the equation $C_F/2 = C_H$ when the Prandtl number is unity. The same relation is assumed for turbulent flow without a laminar boundary layer. The authors conducted experiments to determine if any relationship exists between the friction and heat-transfer coefficients in the region of nucleate boiling with forced convection.

Tests were made with distilled water flowing through a $\frac{3}{8}$-in. diam stainless-steel tube, the tube itself serving as an electrical resistance heater. Authors' test results confirm the above equation to a first approximation. Reviewer believes that further research is needed to show that the above equation is independent of other parameters. The present test data suggest a definite pressure effect, and some uncertainty exists in the temperature predicted at the inside surface of the tube. Reviewer agrees with the authors that the first-order effect of the bubbles is a hydrodynamic one, leading to an increase in heat exchange as well as momentum exchange.

245. Schaefer, J. W. and Jack, J. R.

INVESTIGATION OF FORCED-CONVECTION NUCLEATE BOILING OF WATER FOR NOZZLE COOLING AT VERY HIGH HEAT FLUXES, NASA-TN-D-1214 (1962), 47 p.

The nonuniform axial heat-flux distribution typical of a very high temperature flow nozzle was simulated by resistance heating of variable-wall-thickness Inconel tubes. The coolant water flowed through the constant-inside-diameter test sections at flow rates ranging from 0.45×10^4 to 1.27×10^4 lb/(sq ft)(sec) (inlet velocities of 73 to 204 ft/sec). Results are presented for nonboiling forced convection, nucleate-boiling forced convection at local heat fluxes up to 11,200 Btu/(sq ft)(sec) [40.3×10^6 Btu/(sq ft)(hr)], burnout, and pressure drop. All results are compared with existing correlations. The solution for the temperature distribution in a resistance-heated variable-wall-thickness tube and the appropriate heat-transfer relations are derived.

246. Schrock, V. E. and Grossman, L. M.

FORCED CONVECTION BOILING STUDIES. FINAL REPORT ON FORCED CONVECTION VAPORIZATION PROJECT, TID-14632 (1959), 123 p.

Local heat transfer coefficients and pressure gradients were measured for bulk boiling of water in forced flow in round tubes with internal diameter ranging from 0.1162 to 0.4317 in. and lengths of 15 to 40 in., heat fluxes of 6×10^4 to 1.45×10^6 Btu/hr ft^2, mass fluxes of 49 to 911 lb/sec ft^2, exit qualities of 5 to 57% and at pressures ranging from 42 to 505 psia. The pressure gradients are correlated within 30% in terms of modified Lockhart-Martinelli parameter, while the Nusselt number is correlated within 40% by a combination of the Lockhart-Martinelli X_{tt} and a parameter called the boiling number, $Bo = (q/A)/(Gh_{fg})$. Apparently X_{tt} expresses the effect of forced convection while the boiling number relates to the nucleate boiling contribution. A study of the influences of nucleate boiling of a subcooled liquid on the pressure gradient in forced flow was also conducted.

247. Schrock, V. E. and Grossman, L. M.

LOCAL PRESSURE GRADIENTS IN FORCED CONVECTION VAPORIZATION, Nuclear Science and Engineering, 4, 245-250 (1959).

An experimental study of pressure drop in forced convection vaporization was made in a heat transfer loop designed for the investigation of local heat transfer coefficients and local pressure gradients for water flowing vertically upward in an electrically heated tube. Data presented are for $\frac{1}{8}$-in. i.d. 347 stainless steel tubes of 15 and 20-in. lengths with mass fluxes of 200 to 700 lb/sec ft^2, heat fluxes of 1 to 8×10^5 Btu/hr-ft^2, qualities at the exit up to 50% and with pressures ranging from 50 to 400 psia. A correlation of the local pressure gradients as a function of the Martinelli parameter X_{tt} was obtained to

within ±15% and a design procedure for calculating over-all pressure drop from this correlation is suggested.

248. Schrock, V. E. and Grossman, L. M.

FORCED CONVECTION BOILING IN TUBES, Nuclear Sci. and Eng., 12, 474 (1962).

Local heat transfer coefficients and pressure gradients were measured for bulk boiling of water in forced flow (vertically upward) in round tubes with internal diameters ranging from 0.1162 to 0.4317 in., lengths of 15 to 40 in., heat fluxes of 6×10^4 to 1.45×10^6 Btu/hr ft^2, mass fluxes of 49 to 911 lb/sec ft^2, exit qualities of 5 to 57%, and at pressures ranging from 42 to 505 psia. The local heat transfer coefficients expressed in the form of the Nusselt number were correlated in terms of Reynolds and Prandtl numbers and two dimensionless groups characterizing forced convection vaporization, the Lockhart-Martinelli parameter X_{tt}, and the boiling number, $Bo = (q/A)/Gh_{fg}$. For large values of the latter, nucleate boiling predominates and the dependence of the heat transfer on X_{tt} is small. Conversely, at the small values of Bo, convective flow effects are dominant, and there is a strong dependence on X_{tt}.

249. Schweppe, J. L. and Foust, A. S.

EFFECT OF FORCED CIRCULATION RATE ON BOILING HEAT TRANSFER AND PRESSURE DROP IN A SHORT VERTICAL TUBE, Chem. Eng. Progr. Symposium Series, Heat Transfer, Atlantic City 49, No. 5, 77 (1953).

Results of boiling-film coeffs. were measured and reported to streams of boiling water at incipient boiling conditions, in about a 10-in. section of 3 different diams. The test section was intentionally small in order to measure point conditions, and the liquid was carefully introduced at the b.p., so that the influence of the turbulence of the stream on the behavior at incipient boiling would be accurately measured. The results do not confirm earlier results of Austin (Z. Ver. deut. Ing. 46, 1890 (1902), that at high rates of agitation the coeffs. become independent of the temp. drop. An influence of agitation continued with increasing velocity up to the highest velocity measured, which was approx. 40 ft/sec. The inversion in pressure gradient, which was found at mass velocities to be between 200 and 300 lb/sq ft sec, was a rather surprising phenomenon. This corresponds to an entering liquid velocity of approx. 3 linear ft/sec, beyond which there is a range in which the pressure gradient decreases with increasing velocity. At higher velocities the pressure gradient increases as would be expected. This phenomenon is explained on the basis of sonic choking at the end of the tube, which is characteristic of high-velocity flow in a straight section. The velocity of sound in the mixt. of water and its equil. vapor is presented, and the values are startlingly low at low b.ps. The sonic choking results in a suppression of vaporization so that in this region of inversion, where there is actually a decrease in pressure gradient, there is a corresponding decrease in linear velocity even though the mass velocity is increasing. (CA-47-7837d)

250. Silvestri, M. et al.

GAS-LIQUID AND VAPOR-LIQUID MIXTURES AS COOLING AGENTS, Centro Informazioni Studi Esperienze, Milan. A/Conference 15/P/1367 (1959), 22 p.

Physical properties of gas-liquid and vapor-liquid mixtures are suitable, in many cases, for forced convection heat transfer, all the more so because of the very high apparent heat capacity when the liquid component has a high latent heat of vaporization. Pressure drops were determined for different gas-liquid mixtures, in different experimental conditions, keeping the gas in turbulent flow and the liquid both in viscous and in turbulent flow. The following parameters were varied: tube diameter, total pressure, liquid and gas flow rates, and liquid viscosity. Experimental data can be correlated by quite simple relationships. Heat transfer properties were studied on steam-water and gas-water mixtures. In electrically heated tubings heat transfer coefficients for steam-water mixtures were determined at various pressures, at different specific flow-rates and for different liquid-to-steam flow-rate ratios, up to burn out conditions. Maximum values of the heat transfer coefficients are of the same order of magnitude as those obtained in pressurized water systems, whereas the density of the mixtures, also in the very high pressure range, are much lower than liquid densities. These properties seem to give to gas-liquid or vapor-liquid mixtures some interest as cooling agents for nuclear reactors.

251. Slesser, C. G. and Cleland, D.

SURFACE EVAPORATION BY FORCED CONVECTION. I. SIMULTANEOUS HEAT AND MASS TRANSFER., Internat. J. Heat Mass Transfer (GB), vol. 5, 735-49 (Aug. 1962).

The evaporation of liquid from a moving belt of liquid-impregnated synthetic fibre was studied as a problem in simultaneous heat and mass transfer by forced convection in a system which comprises several identical elements. The novel apparatus is described which provides means of studying a variety of parameters under steady-state conditions. Expressions for heat- and mass-transfer rates are given, the equivalence of j-factors is demonstrated, and the index of the Schmidt number is shown to be 0.576. All results were correlated statistically.

252. Stiushin, N. G., and Sterman, L. S.

EFFECT OF THE VELOCITY OF A MOVING AND BOILING LIQUID ON HEAT EXCHANGE, Zhur. Tekh. Fiz. 21, 448-452 (1951) (In Russian)

The role of the velocity of forced circulation on heat transfer in a boiling liquid is experimentally evaluated. The intensity of the heat exchange grows with the velocity. This effect of the velocity is a function of the thermal-flow value. The results are worked out in dimensionless coordinates. (NSA-5-5641)

253. Stiushin, N. G.

INVESTIGATION OF THE INFLUENCE OF RATE OF FORCED MOVEMENT OF FLUID ON HEAT EXCHANGE IN BOILING UNDER PRESSURE, Zh Eksperim.i Teor. Fiz. 25 1920-30 (1953).

254. Torikai, K., Hori, M., and Yamasaki, T.

THE FLUID FLOW RESISTANCE THROUGH THE ROUND TUBE IN NET BOILING, J. Atomic Energy Soc. Japan 2, 671-681 (1960).

The fluid flow resistance through round tubes in boiling is different from two-phase flow, but it is not well identified. It is definitely shown from semi-theoretical analysis and experiments in net boiling of forced flow in 20 ϕ tube at 3 to 13 m/sec, 2 to 150 atm, and in 1 to 4 x 10^5 kcal/m^2hr, turbulence of flow by turbulent energy based upon the detachment from the tube wall and growth of the bubbles is generated, and the fluid flow resistance is also changed. But this turbulence is not larger than the turbulence of normal flow in tubes except in cases of low flow velocity or low pressure, and this effect is negligible in practice. Then the coefficient of frictional flow resistance through the round rough tube in normal turbulent flow is available in high velocity flow at high pressure in net boiling too.

255. Wright R. M.

DOWNFLOW FORCED CONVECTION BOILING OF WATER IN UNIFORMLY HEATED TUBES (thesis), UCRL-9744 (1961) 216 p.

Local heat transfer coefficients and local, total two-phase pressure drops were measured in the downflow forced-convection (net) boiling of water in electrically heated tubes. The tubes used were 0.719 and 0.472 in. ID, with lengths of 5.67 and 4.69 ft, respectively. The flow variables cover the following ranges: mass flux G, 110 to 700 lbm/sec-ft^2; heat flux q, 13,800 to 88,000 Btu/hr-ft^2; quality (mass fraction vapor) x, 0 to 19%; boiling number $(=q/h_{fg}G)$ B_o, 0.24 to 1.9 x 10^{-4}; pressure, 15.8 to 68.2 psia. Boiling heat transfer results are compared to the correlations of Dengler, Mumm, and Schrock and Grossman. New boiling heat transfer correlations are derived, the skeleton of these being $h_B \propto G^{0.6}q^{0.3}x^{0.4}$. Large effects due to two-phase thermal entrance phenomena were observed. These effects are discussed with reference to previous experiments in forced-convection boiling. Local, total two-phase pressure gradients are correlated by the method of Schrock and Grossman. Individual pressure gradients are also predicted by several methods. On the basis of heat transfer and pressure drop observations, the flow and vaporization mechanisms are discussed. A design procedure is derived and typical results are discussed.

256. Zenkevich, B. A.

THE GENERALIZATION OF EXPERIMENTAL DATA ON CRITICAL HEAT FLUXES IN FORCED CONVECTION OF SUBCOOLED WATER, J. Nuclear Energy, Part B: Reactor Technology, 1 130-133 (1959).

An equation in dimensionless groups has been proposed by the author on the basis of experimental data on critical heat fluxes in forced convection of sub-cooled water at pressures between 100 and 210 atm. A simplification of this equation at low pressures is predicted from theory. It is shown that the dimensionless equation previously given is valid over a wider range of pressures, namely from 35 to 210 atm. The reduction of published experimental data concerning q_{cr} at low pressures confirms the theoretical conclusion that the functional relations between one group to be determined and two determining groups become degenerate at water pressures near atmospheric and therefore that the dimensionless equation simplifies in this case. From this equation a formula is derived which can be used for calculations at pressures between 1 and 15 atm.

257. Zenkevich, B. A. and Subbotin, V. I.

CRITICAL HEAT FLUXES IN SUBCOOLED WATER WITH FORCED CONVECTION BOILING, J. Nuclear Energy, Part B: Reactor Technology 1, 134-40 (1959).

Reports the study of critical heat fluxes for water flowing in vertical tubes, heated to temperatures up to the saturation temperature, in the range of pressures from 140 to 220 atm.

258. Zenkevich, B. A., Subbotin, V. I. and Troyanov, M. F.

CRITICAL HEAT FLUXES FOR A BUNDLE OF TUBES COOLED IN PRESSURIZED WATER, J. Nuclear Energy, Part B. 1, 197-199 (1960).

Object was to investigate the critical phenomena in the regimes of boiling when a bundle of tubes, representing a possible type of fuel element, were cooled by pressurized water flowing parallel to the axis.

259. Academy of Sciences, Moscow

HEAT TRANSFER AND THERMODYNAMIC MODELING, NP-tr-702 (1959), 554 p.

Heat transfer of boiling water in forced convection; steam-content measurements in boiling with subcooling; determination of heat transfer coefficients for vapor condensation of viscous substances; heat transfer in steam condensation on vertical tubes; similarity conditions of molecular processes; generalization of experimental data on viscosity and heat conduction of steam.

NATURAL CONVECTION

260. Akin, G. A. and McAdams, W. H.

BOILING HEAT TRANSFER IN A NATURAL CONVECTION EVAPORATOR, Ind Eng Chem 31, 487-491 (1939) [Also in A.I.Ch.E. Trans. 35, 137-55 (1939)].

Results of experiments with natural convection boilers; several sizes and arrangements of heating surface used; effect of wetting agents; model 60-tube evaporator used to boil distilled water at atmospheric pressure with overall temperature differences ranging from 20 to 100°F; distribution of heat flux-various rows.

261. Allen, C. F.

BOILING OF FREON-114 IN A THREE FOOT STRAIGHT TUBE EVAPORATOR, K-1487 (1961), 21 p.

Experimental determinations of heat flux were made with Freon-114 flowing by natural circulation through a steam-heated vertical tube with and without swirl promoters. The heated length of the $\frac{7}{8}$ inch outside diameter copper tube was 35 inches, the saturation temperature of Freon-114 at test-section flow exit 160°F, and the heat flux range from 7,000 to 70,000 Btu/hr/sq ft. Heat flux measurements at specified conditions were compared to determine the degree of fouling and the effect of swirling flow on heat transfer efficiency. Experimental data showed that the circulation of water-saturated Freon-114 at 200°F for 2 $\frac{1}{2}$ hours did not produce sufficient steel corrosion products to foul the surface of the evaporator. Swirl promoters were effective in reducing dry-wall vapor binding at the higher heat loads. The 50% increase in maximum heat flux observed was limited by the low liquid-to-vapor ratio of the bulk Freon leaving the evaporator. An increase in input flow to the evaporator by forced circulation or increased liquid heat should produce an additional increase in maximum heat flux.

262. Anderson, R. P., et al.

AN ANALOG SIMULATION OF THE TRANSIENT BEHAVIOR OF TWO-PHASE NATURAL CIRCULATION SYSTEMS, A.I.Ch.E. Preprint 27a, New York (1962), 22 p.

The design of high-performance natural circulation boiling systems requires that the behavior of the systems be characterized under transient conditions. In order to accomplish this, the time and space dependent continuity, energy, and momentum equations for a natural circulation system are written. The resulting set of equations are solved simultaneously, utilizing an analog computer. A set of criteria that the analytical model has to satisfy is: (1) the model must provide an accurate steady-state calculation of the recirculation rate and vapor volume fraction for various power inputs; (2) it must reproduce the experimental transient behavior during varying power inputs; and (3) the model must accurately predict the inception of oscillations in a natural circulation system. The resulting equations are compared with experimental results at various pressures with two geometries in boiling water systems. The equations meet the established criteria, and the analytical model is useful for predicting the behavior of two-phase natural circulation systems during transients. The model accurately predicts the point at which such systems exhibit oscillatory behavior. The results were found to be very sensitive to the vapor-liquid velocity ratio (slip ratio) used in the computation. The velocity ratio correlation used in the model is presented.

263. Bogdanov, F. F.

INVESTIGATION OF NATURAL CIRCULATION OF AN ORGANIC HEAT CARRIER WITH HIGH BOILING POINT, AEC-TR-2881 (1950), 10 p.

The results are given of an investigation of useful pressures developed by the vapor-liquid mixture of an organic coolant in a 56 to 70 mm tube under natural circulation.

264. Bondar, A. G.

EXPERIMENTAL INVESTIGATION OF HEAT EMISSION FROM A BOILING SOLUTION OF CAUSTIC SODA IN A VERTICAL TUBE WITH NATURAL CIRCULATION, Izvest. Kiev. Politekhn. Inst., 17, 83-97 (1956).

Results of investigations in the determination of heat emission with boiling solutions of caustic soda, NaOH, in a vertical tube with natural circulation are presented. The object of this research was to obtain data for reliable calculation of heating surfaces in equipment for the evaporation of NaOH solutions and to establish optimum operating conditions. A system of specially designed experimental equipment is described. The methods of measurement and of processing the experiments are described in detail. In particular, the specific heat flow q was determined by the quantity of condensate formed on the surface of the boiling tube at separate sections, the quantity of heat necessary for dehydration being taken into account. It is claimed that the relative error in the determination of α_2 for the minimum and maximum heat load (q equal to 1700 and 74,200 kcal/m^2hr, respectively) fell within the range of five to eight %. The determination of optimum hydrodynamic conditions for the boiling of NaOH solutions for required concentrations was performed through a series of experiments, differing in the apparent level of the boiling solution in an oxidized steel tube (diameter 32/38 mm, length 1500 mm). Experiments were conducted under these conditions with the object of determining values of α_2, the coefficient of heat transfer for boiling solutions of NaOH of various concentrations, and of establishing the dependence of α_2 upon q and the physical properties of the solutions under secondary vapor pressures equal to atmospheric pressure for 5, 10, and 20% solutions, and varying in the range of 0.62 to 0.76 kg/cm^2 for 15, 30, and 40% solutions. It is claimed (within the range of the parameters of these experiments) that α_2 is proportional to q by the power n = 0.564 to 0.620. The results obtained are in accord with the data of other authors. In particular, it is emphasized that, with identical heat flow, the coefficients of heat emission to water are greater than to the solution. The quantity α_2 to the solution decreases with increased temperature. Using a special movable thermocouple, the author shows that in the boiling of solutions in a vertical contour with natural circulation, a considerably greater amount of

super-heating (~2°) takes place than in large-scale boiling. It is pointed out that under optimum conditions the solution is at the greatest temperature, as a rule, at the initial region of the evaporating tube.

265. Born, J. H., Jr., and Jones, M. L.

EFFICIENCY OF A HIGH TEMPERATURE VAPORIZER, Chem. Eng. Progr., 56, No. 7, p. 39-44 (1960).

To obtain basic information on the performance and operation of the vapor generator or vaporizer a series of tests were carried out in a natural circulation vaporizer, employing Dowtherm as the heat transfer medium, operating with a vapor temperature close to 700°F.

266. Brooks, C. H., and Badger, W. L.

HEAT TRANSFER COEFFICIENTS IN THE BOILING SECTION OF A LONG-TUBE, NATURAL-CIRCULATION EVAPORATOR, Trans. Am. Inst. Chem. Engrs., 33, 392-416 (1937).

Heat transfer coefficients reported apply only to boiling sections; method used to determine boundary between two sections is that suggested by R. M. Boarts.

267. Chang, Y. P.

THE ANALYSIS OF HEAT TRANSFER IN NATURAL CONVECTION AND IN BOILING, Trans. A.S.M.E. 79, 1501-1509 (1957).

The 2 cases of fully developed turbulent flow passing a flat plate at zero incidence, and through a tube are considered. The laminar sublayer whose thickness is usually considered as const. at a given Reynolds no. is postulated to vary with the heat flow. The effect of natural convection is taken into account, despite its minor importance in predicting the heat transfer by forced convection in the turbulent region. A general formula for Nusselt no. is obtained as a function of Prandtl, Reynolds, and Grashof nos. The heat transfer by natural convection alone becomes only a particular case and the Nusselt no. is readily found by dropping out the term contg. the Reynolds no. Calcd. results agree with expts. as conducted by previous investigators for fluids with Prandtl nos. within the range of 0.60 to 40.

268. Chernobylskii, I. I.

CALCULATION OF THE HEAT-TRANSFER EMISSION COEFFICIENT DURING BOILING OF BINARY MIXTURES, Khim. Prom., No. 6, 362-3 (1957).

Heat transfer measurements were made with vertical stainless-steel bayonet tubes, 3/8 to 3/4 in. outer diam. with lengths from 2.6 to 6.5 in. The heat source was steam. The boiling film T ranged from 154° to 314°F. for 3 org. liquids and from 547° to 788°F. for N_2 all at 1 atm. No forced convection was used. C_6H_6, CCl_4, and N_2 on the longer tubes had heat-transfer coeffs., h, 2 or 3 times greater than that predicted by the Bromley equation (CA 44, 5653i); however, the Reynolds nos. were found to exceed 2000. N_2 on the 2.6 in. length obeyed the equation; the Reynolds nos. were less than 2000. MeOH is an anomaly; although the Reynolds nos. were less than 2000, the flow was proved by photography to be turbulent and the h values were much higher than those predicted for viscous flow. A correlation is given which fits all the data except for MeOH. It shows that a vertical orientation is superior to the horizontal for liquids boiling outside tubes.

269. Chernobylskii, I. I., and Tananaiko, Iu. M.

HEAT EXCHANGE DURING BOILING OF LIQUIDS IN NARROW ANNULAR TUBES, Zhur. Tekh. Fiz., 26, 2316 (1957) (English Trans. Soviet Physics 1, No. 10, 2244, 1957).

In this article we consider problems associated with the possible intensification of boiling in a narrow annular tube ("annular slit") given natural circulation and moderate thermal loads.

270. Cook, W. H., and Marchaterre, J. F.

SINGLE AND MULTI-CHANNEL NATURAL CIRCULATION BOILING AT 600 PSIG, p. 60, Reactor Engineering Division Quarterly Report (for) October, November, December 1955. Section I. (Apr. 1956), 169 p., ANL 5561.

Supporting and Alternate Design Research and Development. Boiling heat transfer studies were made. Riser studies indicate that riser height is not too important a parameter in influencing the ratio of velocities of steam and liquid. Data are given on the pressure drop resulting from 2-phase flow. The transient behavior of the multi-channel natural circulation loop is discussed. Single-channel unrestricted and restricted natural circulation boiling studies are summarized in detail. Data showing the relationship between power density, voids, quality, recirculation flow, pressure, and geometry for boiling systems are given in both tabular and graphical form. Pressure drop measurements are included, and an analytical method of calculating natural circulation performance is outlined. The sources of error in steam void measurements are evaluated.

271. Danilova, G. N., Candidate of Technical Sciences and Bel'skiy, V. K., Engineer

EXPERIMENTAL INVESTIGATION OF THE HEAT EXCHANGE DURING THE BOILING PROCESS OF FREON-22, Kholodil'naya tekhnika, no. 1, 7-13 (1962).

The experimental results obtained when investigating the heat exchange during the bubble boiling of Freon-22 under natural convection conditions, are discussed. The experiments were conducted at the department of the theoretical principles of thermo- and refrigeration technology of the Leningradskiy tekhnologicheskiy institut kholodil'noy promyshlennosti (Leningrad Technological Institute of the Refrigeration Industry). The test unit consisted of a steam generator and a condenser connected by a piping system. Brass and nickel test tubes with the following parameters were used: nickel tube: diameter - 2 mm; working length - 156 mm; wall thickness - 0.15 mm; brass tube: diameter - 2.9 mm; working length - 155 mm;

wall thickness - 0.54 mm. After a vacuum was created in the unit, 2/3 of the steam generator was filled with Freon-22, the refrigerator switched on, the required temperature set in the thermostat of the condenser, and current conducted through the tube. The current intensity in the tube, the voltage drop on its ends, and the electromotive force of the thermocouples were measured. The current intensity was measured with an astatic ammeter of the electromagnetic system of class 0.5, connected through the YTT -6 (UTT-6) current transformer. The following results were obtained: (1) Hysteresis was observed in the case of the brass tube at "q" of up to 5,500 (q - - specific heat flow) and in the case of the nickel tube at "q" of up to 9,500 kcal/m^2 · hour; (2) the brass and nickel tubes had different heat-emission coefficients; at small heat flows, the deviation was especially large, at "q" >100,000 kcal/m^2 · hour, the latter considerably decreased; (3) the obtained heat emission coefficients were several times larger than those calculated according to the criterion equations of S.S. Kutateladze (Ref. 1: Osnovy teorii teploobmena. [The bases of the theory of heat exchange], Mashgiz, 1957) and G.N. Kruzhilin (Ref. 2: Izvestiya AN SSSR, OTN, 1949, no. 5; Izvestiya AN SSSR, OTN, 1955, no. 10, Ye. K. Averin, co-author), developed using various liquids especially water. The heat emission coefficient can also be calculated using the V.I. Tolubinskiy formula (Ref. 3: Izvestiya vysshikh uchebnykh zavedeniy, "Energetika," 1959, no. 1); (5) the heat-emission coefficients of boiling Freon-22 are greater than of Freon-12; (6) the validity of the proposed method for measuring the temperature and heat flows was proved by using it in the case of water; the obtained results correlated well with those calculated according to S.S. Kutateladze's equation. There are 4 figures and 4 Soviet-bloc references.

272. Guerrieri, S. A., and Talty, R. D.

A STUDY OF HEAT TRANSFER TO ORGANIC LIQUIDS IN SINGLE-TUBE, NATURAL-CIRCULATION, VERTICAL TUBE BOILERS, CEP Symp. Ser. No. 18, 52, 69-77 (1956).

A study of heat transfer to boiling cyclohexane, methanol, benzene, pentane, and heptane has been carried out in two single-tube natural-circulation vertical boilers which were oil-heated brass tubes 0.75-in. I.D. by 6 ft. long and 1.0-in. I.D. by 6.5 ft. long, respectively. Wall and fluid-core temperatures were measured at 6-in. intervals along the length of each tube. Point heat transfer coefficients and the amount of vapor generated in each 6-in. section were calculated. Heat flux ranged from 2,170 to 17,400 Btu/(hr.)(sq.ft.); vapor at tube outlet, from 2.8 to 11.6%; boiling film coefficient, from 224 to 1,172 Btu/(hr.)(sq.ft./°F.); boiling film temperature drop, from 6.1° to 24.2°F.

The results of the investigation indicate that the transfer of heat in tube boilers occurs simultaneously by two processes; by convection and by nucleate boiling. The convection process increases in importance with increasing vapor concentration, whereas the nucleate boiling process predominates at low percentage vapor and decreases in importance with increasing vapor concentration. An analysis is presented which accounts for both processes, and a correlation, based on this analysis, is presented which permits the evaluation of the heat transfer coefficient for these two processes.

273. Hammar, O. G., and Jung, R.

THE EFFECT OF DECREASING BOILER PRESSURE ON NATURAL CIRCULATION IN WATER TUBE BOILERS,Combustion, 27, 47-55 (September 1955).

Tests showed that limiting value of pressure time gradient which will avoid disturbing circulation depends primarily upon initial boiler pressure and water velocity in downtakes; if latter is high and riser tubes are heated at their lower part, circulation will be less affected.

274. Haywood, R. W.

RESEARCH INTO THE FUNDAMENTALS OF BOILER CIRCULATION THEORY, Inst. of Mech. Engrs., (London), - American Society of Mechanical Engineers, Gen. Discussion on Heat Transfer, Proceedings, Sept. 11-13, pp. 20-2 (1951).

275. Jameson, A. S., and Lottes, P. A.

NATURAL CIRCULATION BOILING OF WATER FLOWING UPWARD THROUGH AN ANNULUS, p. 150-157 of Reactor Engineering Div. Quarterly Report for Sept. 1, 1953 through Nov. 30, 1953. Argonne National Lab., ANL 5208 (Del.)

276. Kaiser, F.

TUBE FAILURES THROUGH FLUCTUATION LOADS, Tech. Überwachung, 1, 105-106, and 113-115 (1940).

Results of investigation of cracks in tubes of vertical tube boiler; steam forming in downcomer interfered with boiler circulation; phenomena could be followed more closely on glass model; based on experiences with this boiler, recommendations for design and operation of boilers with natural water circulation are given.

277. Kruzhilin, G. N.

HEAT TRANSMISSION FROM A HEATING SURFACE TO A BOILING ONE-COMPONENT LIQUID AT FREE CONVECTION, Transl. from Izvest. Akad. Nauk S.S.S.R. Otdel. Tekh. Nauk, 967-80, AEC-tr-2060 (1948), 20 p.

It is indicated that the coefficient of heat transfer and the critical heat load characterizing the heat transfer at boiling do not depend directly on the physical characteristics of the liquid or the pressure. Equations to determine the values of the criteria of similarity of these coefficients are presented. 18 references.

278. Kruzhilin, G. N.

GENERALIZATION OF THE EXPERIMENTAL DATA ON THE HEAT TRANSMISSION AT THE BOILING OF LIQUIDS UNDER THE CONDITIONS OF FREE CONVECTION, Transl. from Izvest Akad Nauk S.S.S.R. Otdel. Takh. Nauk, 701-12, AEC-tr-2000 (1949) 16 p.

The results of the generalization of the known experimental data on the heat transmission at the boiling of various one-component liquids at free convection are discussed. The generalization is made on the basis of dimensionless equations obtained by analysis of the problem according to the method of similarities.

279. Labuntsov, D. A.

GENERALIZED RELATIONSHIPS OF CRITICAL THERMAL LOAD DURING BOILING OF LIQUIDS UNDER CONDITION OF FREE MOTION, Teploenergetika 7, 76-80 (1960).

Comparison of equation obtained with those commonly used, and with experimental data.

280. Labuntsov, D. A.

CRITICAL HEAT LOADS WITH BOILING OF NON-HEATED WATER AT NON-STATIONARY HEAT DOMAINS, Inzh. Fiz. Zh. 4, No. 9, 83-85 (1961).

Results are given of an experimental measurement of critical heat fluxes in conditions of fast (linear in time) increase in heat load, i.e. non-stationary heat conditions. Experiments were conducted in subcooled and boiling water with free convection.

281. Ladiev, R. Ya.

APPLICATION OF APPROXIMATE THERMODYNAMIC ANALOGY FOR ESTABLISHING THE RELATIONS GOVERNING HEAT RELEASE DURING BOILING, Izv. Kiyevsk. politekhn. in-ta, 30, 175-187 (1960).

In evaluating experimental data on the coefficient of heat release during boiling of large volumes of liquid with natural circulation, numerous authors use the following dependence on the heat flux (q):

$$\alpha_2 = A_2 q^n$$

A_2 - function of the physical properties of the liquid depending on pressure. Calculation of A_2 is complicated due to the fact that for each pressure the values of a number of physical constants are required which are frequently unknown. By analyzing the differential equation of the process the author derives a criterial relation into which the pressure function $f(p/p_{cr})$ is introduced, where p_{cr} is the critical pressure for the given substance. By writing the criterial equation for two pressures (one of which is the atmospheric pressure) and dividing one by the other, the author obtains the dependence $f(p/p_{cr})$ in an explicit form. The calculation formulae for the heat release coefficient is given as follows (whereby the symbols have their usual meanings):

$$\alpha_2 = A_2 \frac{\gamma - \gamma''}{\sigma} \quad q^{0.6} = A_2 \frac{q^{0.6}}{\sigma^2} \text{ kcal/m}^2\cdot\text{hour}\cdot{}^\circ\text{C}$$

where

$$A_2 = 1.69 \frac{\lambda_1}{\gamma_1} \left(\frac{\nu_1''}{r_1 \gamma_1'' \delta_1^2} \right)^{0.6}$$

A_2 does not depend on pressure; the index 1 indicates that the values refer to atmospheric pressure. The following is given in the paper: a comparison of the obtained relation with experimental data and values of $A_2 \cdot 10^6$ for water, ethyl alcohol, heptane, pentane, benzol, respectively, for the power index n equalling 0.6-66; 17.3, 15.2, 11.2, 10.5 and for n equalling 0.7-21: 5.5, 4.6, 3.2, 3.1. It is shown that reliable extension of the obtained criterial relation to other liquids, and in the first instance to strongly associated liquids, depends on whether at the saturation line these substances comply with the law of the states on which the study made in the paper is based. 14 bibliographic references.

[Note: The above text is a full translation of the original Soviet abstract.]

282. Laird, A. M., Scott, A. W. and Thomson, A. S. T.

NATURAL CIRCULATION INVESTIGATIONS ON EXPERIMENTAL TWO-TUBE BOILER, North East Coast Instn Engrs & Shipbldrs-Trans 74, pt 6, 311-40 (1958); Discussion pt 8, D97-108 (1958).

Plant at British Shipbldg Research Assn; max pressure 1500 psi, max heat input rate 120,000 Btu-hr per sq ft; influence of tube diameter, pressure, and heat input; effects of restricting orifices in circuit, nonuniform heating of riser, shortening heated length and rapid drop in boiler pressure; gamma ray determination of density and flow pattern in riser tube. 43 refs.

283. Lang, D. C.

TWO-PHASE FLOW IN A NATURAL CIRCULATION BOILER, S. B. Thesis, M.I.T., M. E. Department (1957).

284. Latyshev, L. A.

CALCULATING THE TEMPERATURE FIELDS IN AN INSUFFICIENTLY HEATED LIQUID UPON BOILING UNDER CONDITIONS OF FREE CONVECTION, Translated from Izvest. Vysshikh Ucheb. Zavedenii, Aviatsion. Tekh, No. 3, 74-9 (1960), 9 p.

The convection patterns in a vertical container of liquid with lateral weak heating surfaces are examined, and it is found that turbulent upward and downward flows cause a microvortex structure to appear on the surface of the liquid. A potential-field model

is developed for calculating the temperature distributions in this type of flow, and the results obtained with the model are compared with the observed temperature distributions and microvortex structure.

285. Leniger, H. A., and Veldstra, J.

HEAT TRANSFER IN A VERTICAL EVAPORATOR TUBE WITH NATURAL CONVECTION, Chem. Ingr. Tech. 34, 21-6 (1962).

The effects of apparent liquid level, temp. drop, and boiling temp. on the heat transfer coeff. were investigated in tubes 1 and 2 m. long and 18 and 47 mm. in diam. Many data are reported in graphical form, and the various effects are analyzed critically. 21 references.

286. Levy, S., and Beckjord, E. S.

HYDRAULIC INSTABILITY IN A NATURAL CIRCULATION LOOP WITH NET STEAM GENERATION AT 1000 PSIA, GEAP-3215 (1959).

The performance of a natural circulation loop was studied at 1000 psia. Tests were performed with rods heated electrically inside a pipe. Test results reveal that flow instability occurs at lower steam qualities and higher flows as the inlet subcooling is increased. Oscillatory conditions were obtained for calculated exit void fractions ranging from 0.6 to 0.9. Data are included on several instability conditions for fixed systems at given pressures, and their variations with heater and system geometry. 47 p.

287. Lewis, W. Y. and Robertson, S. A.

THE CIRCULATION OF WATER AND STEAM IN WATER-TUBE BOILERS AND THE RATIONAL SIMPLIFICATION OF BOILER DESIGN, Proceedings of the Institution of Mechanical Engs., London 143, 147-181 (1940).

The authors stress the need for a sound theory of circulation in water-tube boilers, to enable weight and space to be saved and efficiency and reliability to be increased. They establish, as a standard of excellence with which other boilers may be compared, a single boiler consisting of a single drum and a single U-tube.

The paper consists of three parts. Part I describes the nature of the changes from water to steam. Particularly interesting is the labeled diagram of the change from water to steam in a vertical tube. In Part II the flow in the simple U-tube boiler is calculated, and in Part III the features of various departures for the standard U-tube, met in practice, are discussed. An improved type tube is evolved, allowing a simplification in boiler design.

288. Liu, Han-Chou.

HEAT TRANSFER COEFFICIENTS FOR BOILING LIQUIDS IN EVAPORATORS, Hua Kung Hsuch Pao 1, 62-3 (1958).

For liquids boiling inside tubes $Nu = f_1[(c\Delta t)/r, p\delta/\sigma, Re, An, (ART)/R, Al/r, \delta/l, h/l, d/l, \mu'/\mu, \gamma'/\gamma]$, where Nu = Nusselt no., c = sp. heat of liquid, Δt = temp. difference, r = latent heat of vaporization, p = local static pressure during the formation of a bubble, $\delta = \sqrt{\sigma/(\gamma-\gamma')}$, σ = surface tension, Re = Reynolds no., $An = (g\delta^3)/\nu^2$, ν = kinematic viscosity of liquid, A = reciprocal of mech. equiv. of heat, R = gas const., T = abs. temp., l, d = length and diam. of an evaporator tube, resp., h = height of liquid surface, μ and μ' = viscosity of liquid and gas, resp., γ and γ' = sp. wt. of liquid and gas, resp. For natural convection in evaporators, the above relation was simplified by neglecting the terms Re, d/l, and δ/l. This simplified expression was claimed to be correct after checking against Kirschbaum's exptl. data (cf. C.4.49, 10677a) on H_1O, NaCl, and sugar solns. The empirical formula given by Kirschbaum was considered to be very limited and incomplete. Based on the same data and the simplified expression, the resulting formula, $Nu = 8.6 \times 10^{-10}\ [(c\Delta t/r)An]^{1.5}(P\delta/\sigma)^{0.1}(1000\gamma'/\gamma)^{1.15}(\mu/\mu')^{0.5}$, was considered to be applicable as a general equation. CA-13692

289. Lottes, P. A.

EFFECTS OF CHANNEL GEOMETRY ON THE POWER DENSITY OF A NATURAL CIRCULATION BOILING CHANNEL AT 300 psia, p. 5-6 of Argonne National Laboratory Quarterly Rept., Jan-Mar. 1955. ANL-5462.

290. Lottes, P. A., and Flinn, W. S.

A METHOD OF ANALYSIS OF NATURAL CIRCULATION BOILING SYSTEMS, Nuclear Sci. and Eng. 1, 461-76 (1956).

The analysis presented has been developed for use in designing natural circulation boiling water nuclear reactors. Preliminary experimental information is given on density of steam water mixtures, velocity ratios of steam to water, and two phase friction factors for boiling in a vertical channel with uniform heat input. Experimental results of a natural circulation 600 psi boiling facility are compared with analytical results using this method.

291. Lottes, P. A., et al.

EXPERIMENTAL STUDIES OF NATURAL CIRCULATION BOILING AND THEIR APPLICATION TO BOILING REACTOR PERFORMANCE, P/1983, Second International Conference on Peaceful Uses of Atomic Energy, Geneva, 7, 784-800 (1958).

292. Marchaterre, J. F., et al.

NATURAL AND FORCED-CIRCULATION BOILING STUDIES, ANL-5735 (1960), 47 p.

The tabulated local steam volume fraction data from an investigation of natural and forced-circulation boiling systems are presented. The experimental equipment is described and the correlation of the experimental data is briefly discussed. The data were taken from natural and forced circulation in 1/4 by 2 by 60 in., and 1/2 by 2 by 60 in. rectangular channels over a velocity range of 1 to 6 ft/sec. and a quality range of 0 to 6%.

293. Markson, A. A., Ravese, T., and Humphreys, C. G. R.

A METHOD OF ESTIMATING THE CIRCULATION IN STEAM-BOILER-FURNACE CIRCUITS, Trans. Am. Soc. Mech. Engrs., 64, 275 (1942).

294. O'Donnell, J. F.

HEAT TRANSFER TO BOILING LIQUIDS IN NATURAL CIRCULATION EVAPORATION, Cambridge, Mass. Institute of Technology, Thesis (1950).

295. Piret, E. L., and Isbin, H. S.

TWO PHASE HEAT TRANSFER IN NATURAL CIRCULATION EVAPORATION, Chem. Eng. Progr. 50, 305-11 (1954).

Boiling heat transfer coefficients for electrically heated 1-in. tube vertical, natural circulation evaporator measuring for water, isopropyne and n-butyl alcohols, carbon tetrachloride, 50% potassium carbonate solutions; data are well correlated by use of either empirical Dittus-Boelter form of equation or one based on bubble Reynolds and Nusselt numbers.

296. Rathbun, A. S., et. al.

NATURAL CIRCULATION OF WATER AT 1200 PSIA UNDER HEATED LOCAL BOILING AND BULK BOILING CONDITIONS, TEST DATA AND ANALYSIS, WAPD-AD-TH-470 (1958), 50 p.

The natural circulation tests performed and analyzed in this report were conducted at 1200 psia on the Bettis Natural Circulation Loop, No. 29. The tests were run with two different single channel test sections (0.101 in. x 1 in. x 27 in. long and 0.210 in. x 1 in. x 27 in. long). Heat fluxes ranged from 50,000 Btu/hr ft^2 to departure from nucleate boiling and inlet subcooling was fixed at 109°F. The results show that there is no difference between natural and forced circulation pressure drop and riser density. (Other tests recently completed but not reported here show similarly that there is no difference between forced circulation and natural circulation DNB providing there are no large deviations of flow due to instabilities.) The tests also show that loop circulating flows in Loop No. 29 can be predicted quite accurately in single-phase flow. Circulation rates with two-phase flow can be accurately predicted if two-phase entrance and exit losses and steamwater slip ratios are known. Further, flow instabilities were noted under certain conditions and occurred before DNB. With the 0.101 in. x 1 in. x 27 in. long test section these instabilities were large enough to cause a DNB. However, at the same conditions no apparent instability was noted with the 0.210 in. x 1 in. x 27 in. long test section. Some data for slip ratios in two phase flow at inlet velocities less than 1 ft/sec were obtained. Additional tests with other channel sizes and at other pressures have been completed and data reduction is in progress.

297. Reveal, W. S.

HEAT TRANSMISSION STUDIES IN A NATURAL CIRCULATION EVAPORATOR, Ph.D. Thesis, Univ. of Minnesota (1946).

298. Rosenkranz, H.

INVESTIGATIONS ON THE WATER CIRCUITS IN BOILING WATER REACTORS WITH NATURAL CIRCULATION, Kernenergie, 4, 784-92 (1961) In German.

In the study of the water circuits in boiling water reactors, a literature evaluation was first carried out on the steam-water relative velocities and on the calculation of pressure losses in two-phase mixtures. An equation for the density distribution is then given. In conclusion, a method for the calculation of the water circuits and the results of the calculation are discussed.

299. Rychkov, A. I.

CORRELATION OF HEAT TRANSFER COEFFICIENTS FOR NATURAL CONVECTION BOILING, Chem. Age India 10, 185 (1959).

The proposed equation is based on the results of studies in heat transfer to boiling liquids: $E_s = 0.19(q/q_{kp})0.25(P/P_{kp}0.33$ and is suggested for pressures up to $P = 0.35\ P_{kp}$ where E_s = a dimensionless const., a combination of values called the ebullioscopic criterium, hE/q, E = ebullioscopic const. of the liquid at pressure P, h = heat transfer coeff., kcal./sq. m. hr. °C., q = heat flux, kcal./sq. m. hr., q_{kp} = crit. flux, kcal./sq. m. hr., P_{kp} = crit. pressure of the substance, atm. Exptl. data show that the above equation is followed by mixts. of miscible liquids. The case of heat exchange discussed was independent of the shape, size, and location of the heating surface. This would indicate the absence of a distinct geometric factor. However, the geometric factor is taken into account, indirectly, in the term q_{kp}. The conclusions are based on natural convection cases. When natural convection is influenced by an artificially created forced movement, the q_{kp} term of the equation should reflect the influence of the forced convection.

300. Schmidt, E.

EXPERIMENTS CONCERNING WATER CIRCULATION IN BOILERS, V. D. I. Zeit., 73, 1151-1155 (1929).

It is shown by experiment that self-evaporation is cause of frequently observed reversed water circulation; theory of water circulation has to take self-evaporation and relative velocity into consideration.

301. Schurig, W.

WATER CIRCULATION IN STEAM BOILERS AND MOVEMENTS OF LIQUID-GAS MIXTURES IN TUBES, Forschungsheft 365- Ausgabe B 5, 13-23 (1934).

Experiments made in mechanical laboratory of Institute of Technology in Danzig; results in tables and curves. Bibliography.

302. Seidel, H.

CALCULATION OF WATER CIRCULATION IN BOILER BANKS AND ITS SIGNIFICANCE FOR THE DESIGN OF WATER TUBE BOILERS, Z. Bayer. Revis-Ver., 35, 211-16, 225-31, 240-42 (1931).

Calculation of speed of circulation; pressure in boiler; circulation diagram; calculation of loss; influence of flue-gas circulation on water cycle; conclusions.

303. Shunichi, E. H. and Uchida, S.

NATURAL CONVECTION BOILING IN VERTICAL PIPES, Che. Eng. (Japan), 15, 311 (1951).

304. Sorokin, A. F.

HEAT EXCHANGE DURING BOILING OF SOLUTIONS UNDER CONDITIONS OF FREE CONVECTION, Sb. Nauchn. Tr. Ivanovsk. Energ. Inst. No. 9, 90-8 (1959).

The heat transfer coeffs. for H_2O, NaCl soln., sugar soln., KNO_3, and NH_4NO_3 solns. were detd. For pure liquids, $\alpha^* = \alpha/\alpha_0 \cdot (p/p_0)^m$ (α^* = transfer coeff., α = transfer coeff. at p, α_0 = transfer coeff. at p_0). For the solns. studied, the formula $\alpha^*(p/p_0)^{0.4}$ is useful. The general formula is $\alpha_0 = \alpha\phi(b) = Aq^{0.7}p^{0.4}\phi(b)$. For the solutions studied $\phi(b) = 1.0 - a\,b/100$, where a is a const. for each soln.

305. Styrikovich, M. A. and Kholodovskii, G. E.

AN INVESTIGATION OF CIRCULATION IN STEAM GENERATING TUBES AT HIGH STEAM PRESSURES, Transl. from Izvest. Akad. Nauk S.S.S.R., Otdel. Tekh. Nauk, 506-28, AEC-tr-1433 (AEC-tr-1440) (1951), 33 p.

306. Tolubinskii, V. I.

HEAT TRANSFER WHILE BOILING WITH FREE CONVECTION, Transactions of the Institute of Heat Engineering, Academy of Sciences of the Ukranian Soviet Socialist Republic, 2, 1950.

307. Troy, M.

NATURAL CONVECTION OF WATER AT 2000 PSIA WITH BOILING IN VERTICAL RECTANGULAR CHANNELS UNDER CONDITIONS OF ZERO-NET THROUGH FLOW, WAPD TH 456 (1958), 25 p.

Tests were run on water at 2000 psia under conditions of zero-net flow in vertical rectangular channels to determine the maximum heat flux that could be dissipated under such restricted conditions without resulting in an excessively high metal surface temperature.

308. Van Brunt, J.

A STUDY OF CIRCULATION IN HIGH-PRESSURE BOILER AND WATER-COOLED FURNACES, American Soc. of Mech. Engrs. Trans. 63, 339-48 (1941).

Discussion of elements of boiler and furnace design dealing with problem of obtaining adequate circulation for higher pressure now demanded by current practice; action within simple evaporating circuit explained; procedure in analyzing water wall circuits and calculating circulation in boiler tubes.

309. Veneraki, I. E.

HEAT TRANSFER RATES DURING THE BOILING OF WATER AND SUGAR SOLUTIONS IN VERTICAL AND HORIZONTAL TUBES UNDER CONDITIONS OF FREE CIRCULATION, Izvest. Kiev. Politekh. Inst. 18, 344-57 (1955).

The investigation was carried out with water and with sugar solns. with concns. from 0 to 60° Br. at a pressure p from 1 to 0.1 atm. and q from 4×10^3 to 55×10^3 kcal./sq. m. hr. A brass pipe in a vertical and horizontal position was used as the heat transfer surface. The coeff. of heat transfer α was correlated by the equation $\alpha = cq^n p^m$, where the value m depends on the boiling liquid and on the position of the heating surface.

310. Westmoreland, J. C.

A STEADY STATE DYNAMIC ANALYSIS OF THE S3G/S4G NATURAL CIRCULATION STEAM GENERATOR SYSTEM, KAPL-M-SMS-13 (1956), 32 p.

An analysis of the S3G/S4G natural circulation steam generator has been made to facilitate the prediction of certain dynamic characteristics of the system in terms of its pertinent geometric parameters. A simple two-phase annular flow model is proposed to permit analytical solutions for the thermal driving head and friction pressure-loss in the riser. This model has been reduced to data for which existing two-phase theories are based and a favorable comparison is presented. The equations from the analysis have been programed for solution by the IBM 650 digital computer and two steam generator configurations have been studied with regard to geometric parameters and also thermodynamic operating state.

311. Westmoreland, J. C.

NATURAL CIRCULATION STEAM GENERATORS FOR NUCLEAR POWER, Nucl. Sci. and Eng. 2, 533-546 (1957).

Analysis of generator to facilitate prediction of certain dynamic characteristics of systems in terms of their pertinent geometric parameters; simple two-phase annular flow model to permit analytical solutions for thermal driving head and friction pressure loss in riser.

312. Zinzen, A.

DER WASSERUMLAUF IN ROHRENKESSELN, Brennstoff-Waerme-Kraft 3, No. 7 (1951).

313. Zinzen, A. and Schubert, F.

NEW APPROACH FOR EVALUATING EXPERIMENTS ON NATURAL WATER CIRCULATION IN BOILERS, Brennstoff-Waerme-Kraft 10 no. 5, 216-18 (1958).

Observations show that bubbles rising in water carry with them considerable amounts of water; new equation developed takes this factor into account; qualitative agreement of test results obtained.

314. Zysina-Molozhen, L. M., and Kutateladze, S. S.

THE EFFECT OF PRESSURE ON THE MECHANISM OF STEAM FORMATION IN A BOILING LIQUID, Zhur. Tekh. Fiz. 20, 110-16 (1950) (in Russian).

An experimental study of the mechanism of formation of vapor bubbles in a boiling liquid, under conditions of free circulation, showed the inadequacy of formulas frequently used for the calculation of the intensity of heat exchanges emanating from the German school of workers (Fritz, Physik. Z., No. 11 (1935); Jacob and Linke, ibid., No. 8 (1936)); these formulas do not reflect the true role played by pressure in the mechanism of boiling. (NSA-5-5643)

315. Academy of Sciences, Moscow

HEAT POWER ENGINEERING, PART I, Transl. from Teploenergetika Vypusk 1, AEC-tr-4496 (1959), 178 p.

Discussions are included on studies of the generalization of experimental data on the circulation of water in steam boilers, regions of forms of flow of a steam-water mixture in an inclined pipe, steam and gas content during the bubbling process, pressure pulsations during the flow of gas-liquid mixtures in pipes, flow of a steam-water mixture in pipes by the γ-irradiation method, temperature field in combustion chambers, steam boiler of a solar heat power station, radiant heat exchange in gray-body systems, and use of the methods of indefinite coefficients in the solution of nonlinear problems of mathematical physics.

FILM

316. Allingham, W. D., and McEntire, J. A.

DETERMINATION OF BOILING FILM COEFFICIENT FOR A HEATED HORIZONTAL TUBE IN WATER SATURATED WICK MATERIAL, J. Heat Transfer 83, 71-6 (1961).

The use of an absorbent wick material satd. with a coolant has become attractive from a design standpoint for some missile-cooling applications, but published data for predicting film coeffs. are very limited. Boiling film coeffs. for a 1.0-in. (outside diam.) Cu tube embedded in water-satd. ceramic fiber-wick material were correlated over a heat flux range from 1000 to 10,000 Btu./hr./sq. ft. by a dimensionless equation (given). The presence of wick material next to a heat-transfer surface decreases turbulence in the region near the surface, increases the effective surface area, and provides active sites for bubble formation. This produces a higher film coeff. at low heat flux than occurs with pool boiling. At higher heat flux, the wick-boiling film coeff. was lower than for pool boiling.

317. Banchero, J. T., and Barker, G. E.

STABLE FILM BOILING OF LIQUID OXYGEN OUTSIDE SINGLE HORIZONTAL TUBES AND WIRES, Chem. Eng. Progr. Symposium Ser. 51, No. 17, 21 (1955).

Heat transfer coefficients for liquid oxygen boiling outside single horizontal tubes and wires were measured in the stable film boiling region. The difference between the heated-surface and the saturation temperatures of the liquid was varied from 100° to 700°F., pressure was varied from 5 to 500 lb./sq. in. abs., and the diameters used ranged from 0.025 to 0.750 in. The Bromley correlation was found to predict the effects of temperature difference and pressure for the entire range of variables but does not correctly predict the effect of diameter over the entire range. The experimental values of the coefficient were found to vary as $(1/D + \text{constant})$.

318. Berenson, P. J.

FILM-BOILING HEAT TRANSFER FROM A HORIZONTAL SURFACE, ASME Transactions, Series C, Journal of Heat Transfer 83, 351-358 (1961).

Taylor-Helmholtz Hydrodynamic Instability and its significance with regard to film boiling heat transfer from a horizontal surface is discussed. It is shown that near the minimum film-boiling heat flux, the bubble spacing and growth rate is determined by Taylor Instability neglecting the effect of fluid depth and viscosity. Utilizing a simplified geometrical model, an analytical expression for the heat-transfer coefficient near the minimum in film pool boiling from a horizontal surface was derived. Combining this equation with the available correlation for the minimum heat flux yields an analytical equation for the temperature difference at the minimum, which defines the location of the minimum point. The above equations agree with the available experimental measurements made on n-pentane and carbon tetrachloride within ± 10 percent.

319. Bergelin, O. P., et al.

HEAT TRANSFER TO BOILING LIQUID UNDER CONDITIONS OF HIGH TEMPERATURE DIFFERENCE AND FORCED CONVECTION, UD-FB-7 (1956), 24 p.

The experimental results of this project to date may be summarized as follows: 1) Surface roughness is shown to have a definite effect upon heat flux in the transitional region between nucleate and film boiling. This effect apparently continues into the film boiling region. 2) As the surface roughness increases, the rate of boiling increases. 3) Photographs of film boiling show irregular wavy roughness of the interface between liquid and vapor. The interface appears to become smoother as the temperature driving force

increases. Within the transitional zone, as roughness increases, there is a greater tendency for the boiling to fluctuate between nucleate and partial film boiling.

320. Borishanskii, V. M.

EFFECT OF PRESSURE AND THE PROPERTIES OF THE LIQUID ON THE TERMINATION OF FILM BOILING AT FREE CONVECTION IN A LARGE VOLUME, Voprosy Teploobmena pri Izmenenii Agregatnogo Sostoyaniya Veshchestva (Moscow-Leningrad: Gosenergoizdat), Sbornik 1953, 108-17; Referat. Zhur., Khim. 1955 No. 8811.

The transition from film boiling to bubble boiling was investigated. The app. consisted of a steel drum filled with the investigated liquid and having along its axis a cylindrical C rod of approx. 2.2 mm. diam. and 50 mm. long heated by an elec. current. The liquids investigated were water, benzene, isooctane, and CCl_4. At certain heat loads on the heating surface (q_{cr1}) bubble boiling changed into film boiling. A reversed transition from film to bubble boiling was accompanied by disruption of the steam layer at some heat load on the heating surface (q_{cr2}) detd. by the properties of the liquid and satn. pressure. The end of film boiling was detd. visually from the disappearance of the steam layer on the surface, and the appearance on this surface of conditions characteristic of bubble boiling. The relation between satn. pressure (p) and q_{cr_2} was established. The curve $q_{cr2} = f(p)$ passed through a max. at $p/p_{cr} < 0.5$ and converged toward 0 at the crit. point (p_{cr} is crit. pressure). The values of q_{cr_2} depended largely on the phys. properties of the liquid. Cf. CA-50-6119d.

321. Borishanskiy, V.

EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER IN FILM BOILING ON HORIZONTAL AND VERTICAL TUBES IN A LARGE VOLUME OF LIQUID, Kutateladze, S.S. ed., Voprosy teplootdachi i gidravliki dvukhfaznyk sred; sbornik statey, Moscow, Gosenergoizdat, 128-138 (1961).

A preliminary experiment was necessary to determine the range of heat loads of the heating surface in which film boiling takes place. This was done by taking high speed photographs (4000 exposures per second) from which the nature of boiling could be judged. The central tube was heated with a low voltage current and the air temperature inside it (equal to the temperature of the inner surface) was measured by a thermocouple fixed in the center. In a similar apparatus for tests with vertical tubes, this thermocouple was movable. When the heat load was varied on the tube, the pressure in the boiler was controlled by use of the compensating heater or the cooler. In testing octanes above 7 kg/cm^2 the tube was rapidly carburized, and no results at all could be obtained for normal hexane because of soot formation. The coefficient of heat transfer was calculated in the usual way. Heat transfer in film boiling of ethyl alcohol on a horizontal tube having an external diameter of 5.91 mm is given for 5 different pressures. Similar results with horizontal tubes were obtained for octane, iso-octane and carbon tetrachloride. The plots show that the effect of heat load on heat transfer is smaller at higher pressures. In film boiling on a vertical tube, the heat transfer for ethyl alcohol is given. Similar tests were carried out on ethyl ether, normal octane and benzene. Regions of stable and unstable film boiling can be distinguished. Other conditions being equal, coefficients of heat transfer on horizontal and vertical tubes are close in the stable region. There are 12 figures and 5 references: 4 Soviet-bloc and 1 non-Soviet-bloc. The reference to the English-language publication reads as follows: Bromley, Chemical Engineering Progress, 46, 5, 1950.

322. Bosworth, R. C.

DEMONSTRATION OF FILM AND NUCLEAR BOILING, J. Proc. Roy Soc N.S. Wales 80 20-1 (1946).

A Cu block heated to dull redness with min. oxide formation and dropping into MeOH or EtOH with care is rendered clean and bright. Boiling on the surface proceeds by the film mechanism. On cooling, boiling decreases to a definite temperature at which nuclear boiling sets in with a great increase in rate of boiling. Simultaneously, the rate of cooling accelerates and the temperature falls rapidly below the b.p. CA-42-10.

323. Bradfield, W. S., Barkdoll, O., and Byrne, J. T.

FILM BOILING ON HYDRODYNAMIC BODIES, Convair Scientific Laboratory, Research Note 37, NP-10317 (1960), 35 p.

Free and forced convection quenching studies of hydro-dynamic shapes are presented. Effects of subcooling and surface condition on heat flux and vapor layer stability are included. Motion picture studies of characteristics of vapor-liquid interface configurations are discussed. These include vapor layers generated by sublimation and with a chemically reacting surface in combination with film boiling. Forced convection heat transfer and friction drag measurements in water are presented and compared with theoretical predictions. Large friction drag reductions were observed.

324. Bradfield, W. S., Barkdoll, R. O., and Byrne, J. T.

SOME EFFECTS OF BOILING ON HYDRODYNAMIC DRAG, Int. J. Heat Mass Transfer, 5,615-622 (1962).

Experiments at velocities up to 20 ft/s on a hemisphere-cylinder model heated to high temperature demonstrate a large reduction in friction drag. The drag reduction is due to formation of a stable vapor layer at the solid surface by film boiling of the liquid. An analysis of the phenomenon predicts the effect of surface temperature and water temperature on the drag reduction. Comparative measurements for nucleate boiling, subliming, and non-wetting surfaces are presented.

325. Breen, B. P., and Westwater, J. W.

EFFECT OF DIAMETER OF HORIZONTAL TUBES ON FILM BOILING HEAT TRANSFER, A.I.Ch.E. Preprint 19, New York (1962), 27 p.

Tests were made to discover the limiting range of diameters for which the theoretical equation of Bromley for film boiling on horizontal cylinders is valid. Prior tests showed the equation to be adequate in the diameter range of roughly $\frac{1}{4}$ to $\frac{3}{4}$ inch, but not for electrically-heated wires of very small diameters. In the present study the range of tube diameters was extended up to 1.895 inch, using steam-heated, stainless steel tubes in a pool at atmospheric pressure. The liquids were at saturation conditions. Freon-113 was boiled at ΔT values (tube-to-liquid) from 190 to 350°F, and isopropanol was used at ΔT from 150 to 280°F. At each ΔT, the heat transfer coefficient decreased with increasing tube diameter until a critical diameter was reached. Further increases in tube diameter caused slight increases in the heat transfer coefficient. For Freon-113 the minimum h occurred at a critical diameter of about 0.48 in., whereas for isopropanol the value was about 0.66 in. Photography shows that, with large tubes, the pattern of bubble release is similar to that for film boiling on horizontal flat plates. It is not the narrow-slit pattern of vapor release which was Bromley's model. The critical tube diameter was found to be that which permits the development of hydrodynamic waves of the Taylor instability type on the top portion of the tubes. All available pool film boiling data for the entire range of diameters from 0.004 to 1.895 in. can be correlated well by an equation which includes the critical wave length from hydrodynamic theory. The Bromley equation is applicable for the range, $\lambda_c/D = 0.8$ to 8.

326. Bromley, L.

HEAT TRANSFER IN FILM BOILING FROM HORIZONTAL TUBE, BC-86 (1947).

327. Bromley, L. A.

HEAT TRANSFER IN STABLE FILM BOILING, UCRL-122 (1948).

328. Bromley, L. A.

HEAT TRANSFER AND STABLE FILM BOILING, Chm. Eng. Prog. 46, 221-227 (1950) (see also MDDC-1628).

By the use of equations, which are derived from a few simple premises and well verified by extensive exptl. data, it is possible to calc. coeffs. of heat transfer to be expected in natural convection stable film boiling from a horizontal tube. The method employed for the derivation can be applied to derive equations for heat-transfer coeffs. to be expected in film boiling from any other shape. Equations are derived for the case of film boiling from a vertical tube or a vertical plane surface.

329. Bromley, L. A., LeRoy, N. R., and Robbers, J. A.

HEAT TRANSFER IN FORCED CONVECTION FILM BOILING, Ind. Eng. Chem. 45, 2639-46, UCRL-1894 (Aug. 1, 1952) (1953).

A theory is developed for predicting heat transfer coeffs. in forced convection film boiling from a horizontal tube. Values calcd. from the equations given are within ±40% of the exptl. coeffs. obtained by continuously circulating liquid at its b.p. past a tubular graphite heating element. The graphite tube diams. range from $\frac{3}{8}$ to $\frac{5}{8}$ in., and the liquids used include hexane, CCl_4, EtOH, and C_6H_6. (CA-48-2423g)

330. Carter, J. C.

THE EFFECT OF FILM BOILING, ANL-4766 (1952), 25 p.

Evidence is presented that a boiling film has the characteristics of a boundary layer phenomenon by showing how the principal variables affect polytropic forced flow. A technique employing high-speed photography is suggested for taking data from which generalized equations may be evolved to define the state and energy transformation at any condition.

331. Cess, R. D., and Sparrow, E. M.

FILM BOILING IN A FORCED CONVECTION BOUNDARY LAYER FLOW, J. Heat Transfer 83, 370-6 (1961).

An analysis has been made to det. the heat transfer and friction characteristics in forced-convection film boiling on a flat plate. The resulting 2-phase flow problem can be formulated easily within the scope of laminar boundary-layer theory. Solutions covering the parameter range of practical interest have been obtained by a combined anal.-numerical method. Heat-transfer and skin-friction results are presented both graphically and as simple, closed form anal. expressions. Relative to the case of pure liquid flow, the skin friction is substantially reduced due to film boiling. The heat transfer increases as $(\Delta T)^{1/2}$, a much smaller dependence than in other convection phenomena.

332. Cess, R. D., and Sparrow, E. M.

SUBCOOLED FORCED CONVECTION FILM BOILING ON A FLAT PLATE, J. Heat Transfer 83, 377-9 (1961).

The analysis given in the preceding abstr. is extended to include the effects of a subcooled liquid. An exact boundary layer formulation is used and results provided for liquids of all Prandtl nos. Subcooling appreciably affects the film-boiling results, causing an increase in both heat transfer and skin friction. The effect will be most severe for low Prandtl no. liquids (liquid metals).

333. Chang, Y. P.

WAVE THEORY OF HEAT TRANSFER IN FILM BOILING, ASME Transactions, Series C, J. of Heat Trans. 81, 1-12 (Feb. 1959).

This paper is an extension of a previous one[1] in which heat transfer has been analyzed by the wave theory for natural convection and for nucleate boiling in detail and for film boiling in principle. In the present paper, heat transfer in saturated and subcooled film boiling from horizontal and vertical surfaces is analyzed from the viewpoint of the previously presented idea. By means of the concept of equivalent thermal diffusivity a generalized Prandtl number is recommended. Thus a general formula is obtained for both convection and boiling. The predicted results agree well with the experiments of previous investigators.

334. Church, J. W., and Cobb, H. G.

STUDY OF THE FILM COEFFICIENT OF HEAT TRANSFER BETWEEN A METAL AND A BOILING LIQUID, Chem. Eng. Thesis, Mass. Inst. Tech. (1922).

335. Cryder, D. S., and Gilliland, E. R.

HEAT TRANSMISSION FROM METAL SURFACES TO BOILING LIQUIDS, Ind. Eng. Chem., 24, 1382-7 (1932).

Direct measurements of boiling liquid-film coefficients of heat transmission, by means of experimental evaporator consisting of electrically heated brass tube suspended in boiling liquid; widely varying temperature differences between pipe surface and boiling liquid measured for eleven different liquids; equations correlating heat transmission coefficients with physical properties of boiling liquids.

336. Cryder, D. S., and Finalborgo, A. C.

HEAT TRANSMISSION FROM METAL SURFACES TO BOILING LIQUIDS. EFFECT OF TEMPERATURE OF THE LIQUID ON THE LIQUID FILM COEFFICIENT, Trans. Amer. Inst. Chem. Eng., 33, 346-361 (1937).

Film coefficients determined for eight different liquids at boiling points both above and below atmospheric pressure, using electrically heated brass tube; apparatus and procedure illustrated and described.

337. Drayer, D. E.

AN EXPERIMENTAL INVESTIGATION OF THE HEAT TRANSFER COEFFICIENTS FOR BOILING AND CONDENSING HYDROGEN FILMS, Dissertation Abstr. 22: 3129 (Mar. 1962).

Relationships between boiling, condensing, and overall heat transfer coefficients of hydrogen and the variables of temperature difference and heat flux were investigated. The apparatus utilized a smooth, vertical brass tube. Film condensation of hydrogen vapors took place within the tube whereas nucleate boiling of liquid hydrogen occurred on the outside of the tube. The hydrogen boil-off rate served as a measure of the heat transferred. Individual film temperature differences were obtained from thermocouple readings and thermal resistance calculations. Boiling heat transfer coefficients were determined for a Δt of 0.06 to 1.17°F and a heat flux range of 23 to 978 Btu/hr-ft^2 of boiling surface area. The values of the boiling coefficients obtained varied from 360 to 800 Btu/hr-ft^2-°F. Of the various theoretical and empirical equations for predicting boiling coefficients that were examined, the Forster-Zuber theory agreed within 12% with the data obtained at a temperature difference of 1.17°F. Other theories examined, however, showed less agreement with the experimental values. Condensing heat transfer coefficients were determined for the steady-state condensation of hydrogen vapor under laminar flow conditions. The range in Δt studied was 0.31 to 4.69°F and the corresponding heat flux range was 31 to 1310 Btu/hr-ft^2 based on the condensing surface area. The resulting condensing film coefficients varied from 90 to 300 Btu/hr-ft^2-°F and were all lower than those predicted by Nusselt's theory over this same Δt range. This is not surprising,however, since compliance with all of the numerous, idealized assumptions of Nusselt's theory may not have been completely possible in this investigation. Over-all heat transfer coefficients were determined for a temperature range of 0.38 to 6.06°F and a heat flux range of 23 to 978 Btu/hr-ft^2, based on the boiling surface area. These experimental values ranged from 44 to 146 Btu/hr-ft^2-°F and were approximately 16% larger than those predicted by a combination of the Forster-Zuber and Nusselt theories.

338. Farber, E. A., and Scorah, R. L.

HEAT TRANSFER TO WATER BOILING UNDER PRESSURE, Trans. ASME 70, 369-384 (1948).

The film coeff. of heat transfer from a hot metal surface to a boiling liquid was estd. from expts. with an electrically heated wire submerged in the liquid. The heat-flow rate was given by the consumption of elec. energy. The temp. drop through the film was taken as the difference between the surface temp. of the wire and the mean temp. of the liquid. The surface temp. of the wire was estd. by a small thermocouple. The graph of film coeff. as a function of temp. drop through the film is called the "boiling" curve. As the temp. drop increased, the film coeff. first rose to a max., then fell to a minimum, from which it rose steadily as the temp. drop continued to increase. When water was boiled at atm. pressure, different heated metals gave different boiling curves; preliminary data are given for Ni, W, chromel A and C. When water was boiled at different elevated pressures, the same heated metal gave different boiling curves; data are given for Ni and chromel at 0, 25, 50, 75, and 100 lb per sq. in. (CA-42-4006i).

339. Frederking, T., and Grassmann, P.

FILM BOILING OF LIQUEFIED GASES ESPECIALLY OF LIQUID HELIUM I., Bull. Inst. Internat. Froid, Annexe, 1958-1, 317-22.

Experimental results for the heat transfer coefficient as a function of the temperature excess of heated Pt wires of various diameters between 5 and 50 μ over the boiling temperature of liquid He I and N_2 at atmospheric pressure are presented. The results can be expressed by Nu = 2.5 $(Gr\ Pr)^{0.11}$ where $10^{-7} < (Gr\ Pr) < 10^{-1}$.

340. Frederking,T.

FILM BOILING OF HELIUM I AND OTHER LIQUIFIED GASES ON SINGLE WIRES, A.I.Ch.E. Journal 5, 403-6 (1959).

Heat-transfer coeffs. were obtained for natural-convection boiling of He I on single wires with a diam. of 5-50 μ. The measurements covered temp. differences of 30-1000°K. between the heating surfaces and the satd. liquid under atm. pressure. The results are correlated in dimensionless form (Nusselt no. vs. the product of the Grashof and Prandtl nos.) and compared with data for N and measurements of other investigators on film boiling of liquified gases.

341. Hosler, E. R.

FILM BOILING ON HORIZONTAL PLATES, Ph.D. Thesis, U. of Ill., 97 pp. (1961).

342. Hosler, E. R., and Westwater, J. W.

FILM BOILING ON A HORIZONTAL PLATE, ARS (Am. Rocket Soc.) J., 32, 553-8 (1962).

Film boiling is studied for water and Freon-11 (CCl_3F) at atmospheric pressure on a flat horizontal aluminum heating surface 8 in. square. High speed motion pictures were taken from which interbubble distances, bubble periods, breakoff diameters, and geometric arrangement of bubbles were determined. The results show that the minimum heat flux in film boiling from a horizontal surface is definitely a type of Taylor hydrodynamic instability. A new experimental technique was developed for obtaining film boiling on a large area without the necessity of using huge heat fluxes to go over the peak of the boiling curve. Once film boiling was established, the film boiling region could be traversed by changing the heat output from the gas burner beneath the slab.

343. Hsu, Y. Y., and Westwater, J. W.

FILM BOILING FROM VERTICAL TUBES, presented at the ASME-AIChE Heat Transfer Conf., Penn. State Univ., Univ. Park, Pa., Paper No. 57-HT-24, Aug. 1957; also A.I.Ch.E. Journal 4, 58-62 (1958).

Heat-transfer measurements were made with vertical stainless-steel bayonet tubes, $\frac{3}{8}$ to $\frac{3}{4}$ in. outer diam., with lengths from 2.6 to 6.5 in. The heat source was steam. The boiling film ΔT ranged from 154° to 314°F. for 3 org. liquids and from 547° to 788°F. for N_2, all at 1 atm. No forced convection was used. C_6H_6, CCl_4, and N_2 on the longer tubes had heat-transfer coeffs., h, 2 or 3 times greater than that predicted by the Bromley equation (C.A. 44, 5653i); however, the Reynolds nos. were found to exceed 2000. N_2 on the 2.6-in. length obeyed the equation; the Reynolds nos. were less than 2000. MeOH is an anomaly; although the Reynolds nos. were less than 2000, the flow was proved by photography to be turbulent and the h values were much higher than those predicted for viscous flow. A correlation is given which fits all the data except for MeOH. It shows that a vertical orientation is superior to the horizontal for liquids boiling outside tubes.

344. Hsu, Y. Y.

FILM BOILING ON VERTICAL SURFACES, Ph.D. Thesis, Univ. of Illinois (1958).

345. Hsu, Y. Y., and Westwater, J. W.

APPROXIMATE THEORY FOR FILM BOILING ON VERTICAL SURFACES, Chem. Eng. Prog. Symp. Series No. 30, 56, 15-24 (1960).

A new equation is presented for film boiling at a vertical surface for saturated liquids in the absence of forced flow. The principal approximations are that vapor flow near the low end of the heating surface is viscous and Bromely's equation is valid there, turbulence develops where the local Reynolds number reaches about 100, and in the turbulent region of the heating surface thermal resistance is due entirely to the laminar sublayer. Tests with five liquids on tubes having lengths between 2 and 6.3 in , and a range of ΔT from 200° to 780°F, show that the equation is reliable to within an average error of about ±32%.

346. Karetnikov, Iu. P.

INVESTIGATION OF THE HEAT TRANSFER TO A FILM OF BOILING LIQUID, Zh. tekh. Fiz. 24, 193- (1954).

347. Koh, J. C. Y.

ANALYSIS OF FILM BOILING ON VERTICAL SURFACES, ASME Transactions, Series C, J. of Heat Trans. 84, 55-62 (Feb. 1962).

The two phase flow problem in laminar film boiling on a vertical flat plate is analyzed. The shear stress and vapor velocity at the vapor-liquid interface are taken into account. The problem is treated by solving simultaneously the boundary-layer equations for the vapor and liquid phases. In contrast to the film-condensation problem where the heat transfer is independent of the $\rho\mu$ ratio, and where the interfacial shear can be neglected for a Prandtl number of unity or larger, it is shown that the $\rho\mu$ ratio is an important parameter in the film-boiling heat transfer, and that the interfacial shear is quite different from zero.

348. Leyse, C. F.

A PROPOSAL FOR AN IN-PILE FILM BOILING EXPERIMENT IN THE MTR, IDO-16118 (1953), 26 p.

Consideration is given to what information is necessary in order to permit operation of the MTR in the film boiling region. Several types of experiments are

discussed briefly and an in-pile film boiling experiment is proposed for the L-42 position of the MTR.

349. Leyse, C. F.

PERMISSIBLE MTR POWER LEVELS WITH AND WITHOUT FILM BOILING, IDO-16064 (1953), 23 p.

Considering only the heat transfer situation in the active lattice, it is permissible to increase substantially the power level at which the MTR is operated. It is recommended that the power level not exceed that shown by the lower curve representing the maximum power levels that can be attained without inducing film boiling. If the bulk water temperature adjacent to the hottest part of the hottest fuel element can be maintained below 150°F, the power level could be increased to about 40 megawatts. The possibility of maintaining this temperature depends on the heat removal capabilities of the process water cooling system, which have not yet been investigated. Present evidence is not sufficient to permit recommending the operation of the MTR with film boiling.

350. McDonough, J. B., Milich, W., and King, E. C.

PARTIAL FILM BOILING WITH WATER AT 2000 PSIG IN A ROUND VERTICAL TUBE, Technical Report No. 62, NP-6976 (1958), 48 p.

A study of the partial film boiling region of water at 2000 psig was made in a $\frac{1}{4}$ in. OD vertical Inconel-X tube, 0.152 in. ID x $12\frac{1}{2}$ in. long. The water parameters were: mass flow rates approximately 0.4×10^6 to 1.5×10^6 lb/hr sq ft, and inlet enthalpies of ~ 377 to 614 Btu/lb. NaK, a liquid metal, was used as the heating medium. The wall temperatures measured in the nucleate boiling region agreed within approximately ±10°F of Jens & Lottes correlation. The burnout heat flux results reported agree within approximately ±25% of WAPD (Bettis Plant) correlation. The film boiling data do not appear to yield to correlation over the range investigated in this experiment. The partial film boiling coefficients found in this experiment range from approximately 100 to 10,000 Btu/hr sq ft-°F.

351. McDonough, J. B., Milich, W., and King, E. C.

AN EXPERIMENTAL STUDY OF PARTIAL FILM BOILING REGION WITH WATER AT ELEVATED PRESSURES IN A ROUND VERTICAL TUBE, Chem. Eng. Prog. Symp. Series No. 32, 57, 197-208 (1960).

A study to determine the surface flux in the partial-film-boiling region of water at 800, 1200, and 2000 lb/sq in. abs. was made in a $\frac{1}{4}$ in. O.D. vertical Inconel-X tube, 0.152 in. I.D. x $12\frac{1}{2}$ in. long. The water parameters were: mass flow rates approximately 0.2 to 1.5×10^6 lb./(hr)(sq ft) at inlet enthalpies of about 200 to approximately 670 Btu/lb. NaK, a liquid metal, was used as the heating medium.

The experimental techniques by which the data were obtained and a description of the experimental loop, test section, sample data reduction method, and analysis of experimental errors are described.

The range of variables applicable to the correlation made are tabulated within the report.

352. McFadden, P. W., and Grosh, R. J.

HIGH-FLUX HEAT TRANSFER STUDIES: AN ANALYTICAL INVESTIGATION OF LAMINAR FILM BOILING, ANL-6060 (1959), 59 p.

An analysis was made of stable, laminar, free convection, film boiling from isothermal vertical plates and horizontal cylinders surrounded by a saturated liquid, where radiation was only of minor importance. The mathematical techniques of boundary layer theory were used and the boundary layer equations were reduced to ordinary differential equations by means of a transformation similar to those used in free convection and condensation. The equations were solved for: (1) compressible flow with variable specific heat, (2) variable specific heat and density variations considered only in the evaluation of the buoyant force, and (3) the case of constant properties. Numerical results were obtained for: (1) near critical water at 2800 and 3100 psia with wall to liquid temperature differences of 250, 500, and 1000°F; (2) for fluids with Prandtl numbers of 2/3, 1, and 2; and (3) for mercury and methanol film boiling at one atmosphere, considering constant properties. The results obtained by assuming constant properties were compared to: (1) the results obtained by considering variable properties, (2) experimental results, and (3) the comparable case of laminar film condensation. It was shown that the method of considering density variations only in the evaluation of the buoyant force is not valid in film boiling. It was also shown that the constant-property solutions for heat transfer did not always agree with solutions obtained considering compressible flow and variable specific heat. An approximate analysis of a non-isothermal wall, including the effects of radiation, was presented. It was shown that for high emissivity walls at high temperature, radiation is the controlling factor in film boiling heat transfer.

353. McFadden, P. W., and Grosh, R. J.

AN ANALYSIS OF LAMINAR FILM BOILING WITH VARIABLE PROPERTIES, Inter. J. of Heat and Mass Tran. 1, 325-335 (1961).

Analysis is made of stable, laminar, free convection, film boiling from isothermal vertical plates and horizontal cylinders surrounded by saturated liquid; equations are solved for compressible flow with variable specific heat; numerical results are presented for near critical water at 2800 and 3100 psi with wall to liquid temperature differences of 250, 500 and 1000 F; results for heat transfer, velocity distribution and temperature distribution are included.

354. Marx, J. W., and Davis, B. I.

FILM-BOILING TERMINATION MECHANISM, J. Appl. Phys. 23, 1354-1357 (1952).

It is suggested that free molecule heat conduction provides the critical energy transfer that just precedes the collapse of the vapour blanket in the film boiling process. An expression for the extreme possible values of the heat transfer coefficient, as a function of pressure, is derived for solid-boiling

liquid systems and numerically evaluated for water. The wetting temperature is given in terms of measurable parameters of the system, and experiments are suggested. (Sci. Abst. 56-793).

355. Mendler, O. J.

ESTIMATED FILM BOILING HEAT TRANSFER COEFFICIENTS, WAPD-TH-404 (1958), 16 p.

A method is presented for estimating conservative values of film boiling heat transfer coefficients as a sum of a convection coefficient and a radiation coefficient. The convection coefficient is calculated by assuming pure conduction through a maximum sustainable laminar vapor layer. The radiation coefficient is estimated using the expression for thermal radiation between two parallel walls. 6 references.

356. Motte, E. I.

FILM BOILING OF FLOWING SUBCOOLED LIQUIDS, UCRL-2511 (1954), 139 p.

Heat transfer coefficients across the vapor film were evaluated from the rates of heat transfer in upward-flow forced convection from outside single horizontal tubes to four liquid systems: ethyl alcohol, benzene, hexane and carbon tetrachloride. These heat transfer coefficients were found to be markedly increased by subcooling the liquids. It has previously been shown that, since the vapor film is in laminar flow in forced convection film boiling, heat is transferred across the vapor film by conduction and radiation. In this study it has been further shown that, if the liquid is subcooled, heat is transferred from the vapor liquid interface into the liquid by eddy conduction and the effect of thermal conduction is negligible.

357. Motte, E. I., and Bromley, L. A.

FILM BOILING OF FLOWING SUBCOOLED LIQUIDS, Ind. Eng. Chem. 49, 1921-1928 (1957).

Heat transfer coefficients outside single horizontal tubes were measured for upward flow forced convection film boiling of ethyl alcohol, benzene, hexane, and carbon tetrachloride. These coefficients were found to be increased markedly by subcooling the liquids below their boiling points. It has been shown previously that heat is transferred across the vapor film by conduction and radiation in forced convection film boiling. Forced convection film boiling occurs when the dimensionless group U gD is greater than 2. In this study it has been further shown that, if the liquid is subcooled, heat is transferred from the vapor-liquid interface into the liquid mainly by eddy conduction. Heat transfer by thermal conduction into the liquid appears to be important only at low liquid velocity.

358. Nakagawa, Y., and Yoshida, T.

FILM STATE BOILING AT RAPID COOLING: I. EFFECTS DUE TO CONDITIONS OF COOLANTS, Chem. Eng. (Japan) 16, 74-82 (1952).

The phenomena in film boiling due to the quenching of a steel rod (2 cm. in diam. and 12 cm. long) were observed, by using 22 kinds of stagnant liquids with different phys. properties. The film heat-transfer coeffs. calcd. from the cooling curves (the initial temp. of the rod was kept const. = 720°) were correlated by an empirical dimensionless equation as follows:

$$\alpha R/\lambda = 407200(\sigma/\gamma R^2)^{1.275}(Pr)^{-0.331}[(u_R - u_0)/(u_2 - u_0)]^{-2.446}$$

where $\alpha R/\lambda$ is Nusselt no., R is radius of the rod, Pr, σ, γ, are, resp., Prandtl no., surface tension, and sp. wt. of cooling liquids at the bulk temp. u_0, u_R, and u_2 are, resp., surface temp. of specimen and b.p. of liquids. (CA-46-3808E).

359. Nakagawa, Y., and Yoshida, T.

FILM-STATE BOILING ON RAPID COOLING: II. EFFECTS DUE TO CONDITIONS OF HEAT-TRANSFER SURFACES, Chem. Eng. (Japan) 16, 104-10 (1952).

Heat-transfer coeffs., α in the boiling produced on quenching of steel rod were measured under the various conditions of the test specimen. High values of α can be obtained by lowering the initial temp. of test bars and by increasing the roughness of their surfaces. Effects of the diam. of test bars on the values of α are not cleared in their present expts. (CA-46-5900a).

360. Nishikawa, K.

PHOTOGRAPHIC STUDIES OF SATURATED FREE CONVECTION STABLE FILM BOILING, Japan Soc Mech. Engrs. Bul. 4 no 13, 115-23 (1961).

Bubble dynamics in stable film boiling was studied; it is found that behavior of bubble generation presents different aspects according to difference of emissivity of heating surface, even if total heat fluxes remain same; necessity of introduction correlating equation to take into consideration vapor film stirring effect of generating bubbles.

361. Polomik, E. E., Levy, S., and Sawochka, S. G.

FILM BOILING OF STEAM-WATER MIXTURES IN ANNULAR FLOW AT 800, 1100, and 1400 PSI, ASME Preprint 62-Wa-136.

362. Posey, W. J.

PROGRESS REPORT NO. 40 FOR APRIL AND MAY, 1957, 26 p., Mine Safety Appliances Co., Callery, Pa., NP-6338.

Hydrodynamic testing of CVR flow channels continued. Other pressurized-water reactor studies reported are: small-scale radioactive leaks in cooling system, simulation of a major pressurized water system rupture, unstable film boiling with water inside tubes, fission product release during core meltdown simulation, radioactivity associated with crud particle size ranges, and chromate formation in high temperature water systems. (For preceding period see NP-6260.)

363. Posey, W. J.

PROGRESS REPORT NO. 51, FOR FEBRUARY AND MARCH, 1959, 21 p., MSA Research Corp., Callery, Penna., MSAR-59-52.

Engineering. Studies were continued on film boiling with water inside tubes with heat transfer runs at 2000 and 1200 psia. Subassembly cooling at decay heat power levels is being investigated. Experiments were initiated to investigate the cooling effectiveness of spraying water upon an inductively heated subassembly at decay heat power levels. Pressure buildup in the vapor container during loss of coolant accident is being investigated. A test to evaluate the actual pressure peak and compare it with the theoretical calculated pressure is reported. Chemistry. Fission product release during core meltdown is being investigated. The mode of meltdown and characteristic distribution of released fission products was studied to provide safeguard information for nuclear power plants. The reaction of sodium sulfite and dissolved oxygen in boiler water and feed water is being studied as a function of temperature, oxygen concentration, pH, and Cu^{2+} concentration. (For preceding period see NP-7252.)

364. Posey, W. J.

PROGRESS REPORT NO. 54 FOR AUGUST AND SEPTEMBER 1959, 50 p., MSA Research Corp., Callery, Penna., MSAR-59-117.

Work continued on film boiling with water inside tubes. Sodium silicate was used in combination with insulating materials to investigate its usefulness as an inhibitor to chloride stress corrosion. The corrosion specimens were 1-in. Sch 40 Type 304 stainless steel pipe which were stressed, insulated and thermally cycled from ~200 to 650°F by periodic heating and emersion in sea water. Stressed, uninsulated 1-in. Sch 40 Type 304 stainless steel pipe specimens were exposed to a high humidity simulated sea water-air environment for a 1000 hr period to investigate the occurrence of chloride stress corrosion. The purpose of the BTF Pressurizer Blowdown Test was to obtain vessel blowdown data to establish that the specific application of the mathematical model used to describe the reactor blowdown is conservative for the size of the pressure vessel. The pressure buildup in the vapor container during loss of coolant accident in a reactor is being studied. The reaction rates of sodium sulfite and dissolved oxygen in boiler water and feed water are being studied as a function of temperature, oxygen concentration, sulfite concentration, phosphate concentration, pH, and copper concentration. Potassium pentaborate is being considered as a chemical poison to reactor shutdown. (For preceding period see MSAR-59-89.)

365. Posey, W. J.

PROGRESS REPORT NO. 56 FOR DECEMBER 1959 AND JANUARY 1960, 48 p., MSA Research Corp., Callery, Pa., MSAR-60-16.

Engineering. The experiment on film boiling with water inside tubes was terminated. An investigation of the caustic stress corrosion of austenitic stainless steel at high heat flux was begun. A project is reported to investigate the ability of 1-inch Sch 40 Inconel piping to withstand stress corrosion at conditions found to be harmful to austenitic stainless steel. Chemistry. The reaction rates of sodium sulfite and dissolved oxygen in boiler water and feed water were studied as a function of temperature, oxygen concentration, phosphate concentration, pH, and copper concentration. A study of decontamination of radioactive components is being made to provide information for a decontamination handbook. (For preceding period see MSAR-59-136.)

366. Posey, W. J.

PROGRESS REPORT 57 FOR FEBRUARY AND MARCH, 1960, 34 p., MSA Research Corp., Callery, Pa., MSAR-60-49.

Experiments are reported in which Inconel pipe specimens were exposed for 1000 hours in a high-humidity sea water-warm air compartment. Constant-temperature specimens were held at 400, 200, 165, and 125°F while cyclic specimens were varied between 550 and 125°F. Results indicate that Inconel is a better choice for piping material for use in high salinity and humidity than is stainless steel. Blowdown tests to determine where flashing occurs and to study the effects of various orifice lengths where the flashing occurs are scheduled. Other investigations for which reports have been published include investigations on film boiling and solution rates of gases in water systems. Data from an evaluation of decontaminating solutions used for electrolytic descaling indicate that citric acid used as an electrolyte was less effective than sulfuric acid or an alkaline cleaner. Other cleaning and decontaminating procedures involving solutions, abrasive slurries, and ultrasonics are discussed and evaluated. (For preceding period see MSAR-60-16.)

367. Rao, R. D., Desai, H. S., and Gogate, D. V.

A NOTE ON HEAT TRANSFER AND FILM BOILING, Indian J. Phys. 34, 456-460 (1960).

Heat transfer between electrically heated metal wires and different boiling liquids was studied and characteristic boiling curves were obtained by plotting the heat flux q/A against the excess of temperature Δt of the wire over the boiling point. The relation between the heat transfer coefficient h and Δt was also studied. The values of maximum heat flux and critical temperature difference are calculated for the different wires and liquids used in this investigation.

368. Rumford, R.

HEAT TRANSFER THROUGH BOILING LIQUID FILMS, J. Soc. Chem. Ind. (London) 66, 309-12 (1947).

The rate of heat flow from a metal wall to a boiling fluid has been measured for water, toluene, ethyl alcohol and nitric acid. It has been shown that, where more than about 10% of the feed liquid is converted to vapour, the rate of heat transfer is not affected by mass velocity. It is also shown that boiling is not confined to any one zone in a vertical tube

evaporator, but probably extends throughout the tube length. (Sci. Abst. 51-1224).

369. Scherrer, V. E., et al.

BOILING STUDIES, p. 30-34 in NRL QUARTERLY ON NUCLEAR SCIENCE AND TECHNOLOGY, Progress Report for the Period October-December 1955, Jan. 1, 1956, 44 p., NP-5876.

Preliminary results are reported on film boiling about a 1-mil W wire immersed in water. Preliminary design values are given for a barge-mounted nuclear power plant.

370. Schmidt, K. R.

THERMODYNAMIC INVESTIGATIONS OF HIGHLY LOADED BOILER HEATING SURFACES, Transl. from Mitt. Ver. Grosskesselbesitzer, No. 63, 391 (1959), 24 p., AEC-tr-4033.

The mechanics of film boiling for a system with a given heat transfer and for a system with a given temperature are discussed. The parameters affecting thermal flow are considered. The dependence of a boiler on operational parameters such as flow rate, diameter of the inner tube, direction of the flow, pressure, inlet enthalpy, and heat loading was investigated. Measurements of the excess temperatures of the tube walls, pressures, and temperatures of the tube walls, pressures, and temperatures at the inlet and outlet of the tube were made on tubes of various diameters with varying flow velocities. The effect of increasing the flow velocity on film boiling revealed a leveling of the maxima and shifting of the beginning point of the partial film boiling after higher enthalpies. The dependence of the temperature of the inner wall tube at different thermal loadings on the enthalpy of water is shown graphically. Heat transmission by a tube wall to water and to overheated steam was analyzed.

371. Sparrow, E. M., and Cess, R. D.

THE EFFECT OF SUBCOOLED LIQUID ON LAMINAR FILM BOILING, ASME, Paper Ht., 61-SA-29.

Heat-transfer results for film boiling in the presence of a subcooled liquid have been determined analytically for the case of the isothermal vertical plate. The two-phase flow and heat-transfer problem which arises has been formulated exactly within the framework of boundary-layer theory, and free convection within the liquid has been accounted for. At a fixed temperature difference between surface and saturation, the effect of subcooling is to increase the heat transfer from the plate surface, with the magnitude of the increase being controlled by five physical parameters. Graphical presentation of the heat-transfer results is made for parametric values which correspond to water, but this information may be applied to other fluids having similar parameter ranges. For large subcooling, the heat transfer is essentially equal to that for pure free convection (no boiling), and the limits for this condition are given.

372. Stroebe, G. W., Baker, E. M., and Badger, W. L.

BOILING-FILM HEAT TRANSFER COEFFICIENTS IN A LONG-TUBE VERTICAL EVAPORATOR, Ind. & Eng. Chem., 31, 200-206 (1939).

Film coefficients are given for water, sugar, and "Duponol" solutions, boiling in a long-tube vertical evaporator, equipped with a single 20-foot tube, under a wide range of conditions. From the data obtained, an empirical correlation of the coefficients is derived, expressing the coefficients in terms of the Prandtl number, surface tension of the liquid, specific volume of the vapor, and average temperature drop across the liquid film; all of these are based on the average temperature of the boiling liquid. A relation between the average liquid temperature and the vapor temperature is derived, from which the average liquid temperature can be predicted from variables usually known to the commercial designer. An explanation for the effect of the several variables is given in the light of this and previous investigations, and of certain known factors affecting the mechanism of boiling in the tube.

373. Tachibana, F., and Fukui, S.

HEAT TRANSFER IN FILM BOILING TO SUBCOOLED LIQUIDS, p. 219-23 of "International Developments in Heat Transfer. Part II" New York, ASME, 1961.

The cooling rate of quenching depends upon the heat transfer by both film and nucleate boiling to a subcooled liquid. The rate of heat transfer in film boiling to the subcooled liquid was calculated theoretically considering that the boundary layer of the liquid exists outside the vapor film. As a result of the tests on electrically heated nichrome wire in distilled water, alcohol, and carbon tetrachloride, a marked effect of the degree of subcooling on the heat transfer rate in film boiling was found. The experimental results agreed fairly well with the calculated results.

374. Timmerhaus, K. D., Drayer, D. E., and Dean, J. W.

AN EXPERIMENTAL INVESTIGATION OF OVER ALL HEAT TRANSFER COEFFS. FOR CONDENSING AND BOILING HYDROGEN FILMS, p. 270-8 of "International Developments in Heat Transfer. Part II." New York, ASME, 1961.

Over-all heat transfer coefficients for condensing and boiling hydrogen films were determined for temperature gradients ranging from 0.38 to 6.06°F for a single smooth vertical brass tube. Temperature difference between the condensing and boiling films was regulated and observed by changes in vapor pressure. Over-all heat transfer coefficients under these experimental conditions were plotted not only as a function of the temperature difference but also of the heat flux and were compared as far as possible with known values in the literature and with computations based on the conventional design

equations available in the standard texts. The latter comparison indicated that the computational values may in certain cases be off by as much as a factor of two to three. Consequently further investigations are being conducted to evaluate the over-all heat transfer coefficients and to check previously reported individual heat transfer coefficients especially with regards to the effect of surface conditions on these coefficients.

375. Ulrich, A. J.

THERMIONIC ENERGY CONVERSION DIODE USING A FILM BOILING LIQUID METAL ANODE, Progress Report from February 1961 to September 1961, 11 p., ANL-6465.

The conventional plasma thermocouple or thermionic energy conversion diode has a solid metal anode. Cs vapor at a pressure of a few millibars or less is widely used to provide ions for electron space charge neutralization. Usually, conditions are such that a monolayer of Cs coats the anode, so that electrically the anode appears to be Cs. This suggests the use of a diode with a liquid metal anode material such as Cs, Rb, or K, and their alloys. Recent experiments showed that a diode, consisting of a hot cathode and a liquid metal anode separated by the vapor film created in film boiling, can be produced. Data are given. Experiments investigating the electrical characteristics of film boiling using water are described.

376. Zielinski, E.

FILM-BOILING ON BOILER SURFACES, Combustion 29, 47 (June 1958).

Basic experiment on causes of film boiling; fundamental conditions in modern high rate boilers; experimental findings; it is concluded that as long as a nucleate boiling is maintained independently of flow of heat flux but within indicated range, overtemperature of tube wall on evaporating side could never become greater than 75°F.

377. Naval Research Lab., Washington, D. C.

NUCLEAR POWER PROBLEMS, Progress Report for the Period Aug. 15, 1956 to Oct. 1, 1956, 15 p. NRL-4854.

Results of studies of corrosion products formed by the action of H_2O and oxygenated solutions on low carbon steel at room temperature are tabulated. Some qualitative studies of fouling of the test section of the diphenyl loop with the high tar fluid are discussed. Heat transfer data in the stable film boiling region are plotted. (For preceding period see NRL-4813.)

378. Naval Research Lab., Washington, D. C.

NUCLEAR POWER PROBLEMS, Progress Report for the Period Oct. 1, 1956 to Dec. 1, 1956, 13 p., NRL-4876.

Specific heat values are included for diphenyl, m-terphenyl, m-m-quaterphenyl, and one of the high tar samples over the temperature range, 200 to 500°F. Results of studies of corrosion products formed by the action of H_2O and oxygenated solutions on low carbon steel during treatment at room temperature and 600°F are given. Additional data were obtained in the stable film boiling region for a heated stainless steel rod under static conditions in a pool of H_2O at atmospheric pressure. (For preceding period see NRL-4854.)

379. Columbia University

BASIC STUDIES IN HEAT TRANSFER AND FLUID FLOW, Quarterly Progress Report for Period October 1, 1960-December 31, 1960, 36 p. TID 11549.

Transient vaporization experiments were conducted to determine the usefulness of conductive-film heaters in boiling experiments and the qualitative functional relation between surface temperature and time during boiling. Discussions are given of results on the influence of liquid conductivity on the performance of conductive films, the visual characteristics of heat transfer from conductive films, and temperature measurements on conductive films. Graphical representations are given of the results for the electrical heat-generation rate, and relative change, in electrical resistance as functions of pulse time. A series of concentric heat-transfer and pressure-drop experiments was completed using a nickel heater tube. The pressure-drop results are shown as friction factors as a function of Reynolds number with a standard curve for comparison. The concentric heat-transfer tests covered heat-generation rates to 500,000 Btu/hr-ft^2 and water velocities of 2 to 25 fps.

Local(See Nucleate)

NUCLEATE AND POOL

380. Askaryan, G. A.

ON THE DENSITY OF BUBBLES ALONG THE TRACK OF AN IONIZING PARTICLE IN AN OVERHEATED LIQUID, Zhur. Eksp. Teor. Fiz. 103, 610-11 (1956).

The elementary theory of induced boiling based on the electrodynamic model of stimulated disturbance of superheated liquids was developed. Qualitative results of the theory were the separation of the variables which characterize the ionizing particles and the variables which characterize the state of the medium and the linear dependence of the boiling density on the ionizing power of the particles.

381. Aladév, I. T., et al.

NEW METHODS OF STUDYING HEAT LOSS DURING BOILING OF LIQUIDS, Dokl. Akad. Nauk. SSSR, 90 No. 5, 775-776 (1953).

382. Aladév, I. T.,et al.

EFFECT OF THE WETTABILITY ON THE HEAT EXCHANGE DURING EBULLITION (WITH SUMMARY IN ENGLISH) Inzh -Fiz. Zhur. 1, 11-17 (July 1958).

383. Bankoff, S. G., Colahan, W. J., and Bartz, D. R.

SUMMARY OF CONFERENCE ON BUBBLE DYNAMICS AND BOILING HEAT TRANSFER AT THE JET PROPULSION LABORATORY, June 14 and 15, 1956, December 1956, JPL-MEMO-20-137 (1956), 52 p.

A meeting was held to bring together recent contributors in the field of boiling heat transfer. The major subjects covered were nucleation, bubble dynamics theory, boiling heat transfer, and nucleate peel boiling from a horizontal surface. The points of agreement and difference in the several analyses and correlations reported in the literature were discussed, and the areas which require more extensive experimentation and theoretical treatment were indicated. 57 references.

384. Bankoff, S. G.

ON THE MECHANISM OF SUBCOOLED NUCLEATE BOILING, JPL-MEMO-30-8 (1959), 52 p.

The mechanism of heat transfer in forced convection subcooled nucleate boiling is considered. A three-step model is proposed. First, the heat flows from the wall into the adjacent liquid by two parallel paths: (a) the portion of the wall area which is periodically covered by bubbles is primarily cooled by quenching, due to colder liquid rushing in as the bubbles collapse; (b) over the remainder of the wall area, convective heat transfer is induced primarily by the stirring effect of the bubbles. Secondly, heat flows through the two-phase wall layer, partly by turbulent convection in the liquid between the bubbles, and partly by latent heat transport within the bubbles themselves. Finally, the heat flows by turbulent convection from the edge of the two-phase wall layer into the turbulent core. Simplified expressions are deduced for the first and third steps, which give reasonable agreement with Gunther's data. The relative importance of latent heat transport is as yet uncertain, but it is shown to be very likely significant in comparison with the heat flow through the liquid between the bubbles. Expressions are deduced for the quenching heat flux and the mean velocity induced by the bubbles. The liquid temperature at the edge of the two-phase wall layer is computed for Gunther's data and is found to rise sharply towards the saturation temperature as burnout is approached. This signifies that the maximum heat flux coincides with the appearance of a fairly thick layer of warm water next to the wall, possibly due to the inability of the turbulent core liquid to remove the heat as fast as it is transmitted through the two-phase wall layer. The heat flow expressions which have been derived are quite approximate; considerably more data on the local parameters in subcooled nucleate boiling are required before they can be put on a firm footing. On the other hand, the three-step model is not considered to be speculative; it is, in fact, a simple statement of the physical situation in highly subcooled nucleate boiling.

385. Bankoff, S. G.

THE PREDICTION OF SURFACE TEMPERATURES AT INCIPIENT BOILING, Chem Eng Prog Sym Ser 55, No. 29 (1959).

The superheat conditions required for bubble nucleation in ebullition are considered. It is shown that "cavity-type" surfaces may require relatively low superheats which are determined by the cavity dimensions, but that grooves, which are the more common type of primary roughness element, are ineffective vapor traps unless very poorly wetted or steep-walled. An approximate theory is derived for predicting superheats required for initiation of ebullition at low pressures, based on a limiting real solution of the equations for the rate of penetration of the liquid into the capillary roughness element. Agreement is shown with the literature within the experimental uncertainties involved. These observations should also be pertinent to cavitation phenomena.

386. Bankoff, S. G.

ON THE MECHANISM OF SUBCOOLED NUCLEATE BOILING, PART I: PRELIMINARY CONSIDERATIONS Chem. Eng. Prog. Symp. Series No. 32, 57, 156-163 (1961).

A sequential rate process model for heat transfer in forced-convection subcooled nucleate boiling is proposed. The model divides the heat flow into three sequential steps: 1) from the heating surface to the inner portion of the two-phase wall layer, 2) from the inner to the outer portion of the two-phase layer, and 3) from the outer portion of the two-phase layer to the single-phase turbulent core liquid. Expressions are deduced for the quenching heat flux and for the mean amplitude of the velocity fluctuation in the liquid between the bubbles.

387. Bankoff, S. G.

ON THE MECHANISM OF SUBCOOLED NUCLEATE BOILING, PART II: SEQUENTIAL RATE PROCESS MODEL, Chem. Eng. Prog. Symp. Series No. 32, 57, 164-172 (1961).

In this part temperature distributions through the single-phase turbulent core are calculated for Gunther's data. On the assumption that the Reynolds analogy holds all the way to the wall, the liquid temperature at the edge of the two-phase wall layer is found to rise sharply toward the saturation temperature as burnout is approached. This signifies that the third step of the sequential rate processes may be controlling near the maximum heat flux. Separate contributions to the heat flux are deduced for the first and third steps, which are in good agreement with Gunther's data. More information is necessary concerning the relative importance of latent heat transport before the second step can be described.

388. Bankoff, S. G.

LATENT HEAT TRANSPORT IN NUCLEATE BOILING, A.I.Ch.E. Journal 8, 63-5 (1962).

A simple 1-dimensional transport calcn. is made which indicates that latent heat transport, by simultaneous evapn. and condensation at different portions of the bubble surfaces, can account for the major portion of the total heat flux in the neighborhood of the departure from subcooled nucleate boiling (burnout). This differs from the previously held view that the stirring action of the bubbles accounted for most of the heat flow in subcooled nucleate boiling. Other evidence is discussed which favors the latent heat transport theory. 22 references.

389. Batch, J. M., and Toyoda, K. G.

EXPERIMENTALLY DETERMINED BOILING CURVES, HW-42469 B (1956).

390. Baumier, J., et al.

HEAT TRANSFER WITH HIGH HEAT FLUX DENSITY BETWEEN A WALL AND WATER WITH LOCAL BOILING AT THE WALL (IN FRENCH), CEA-846 (1958), 28 p.

The aim of the present study was to determine the relationship between the temperature of a hot wall and that of a cooling fluid under conditions where this fluid is subject to local boiling at the wall. Attention was directed particularly to the aspect of the phenomenon in the transition region between the classical turbulent convection and the convection with local boiling. The tests were carried out with water at an average temperature of 50°C circulating in an annular space, the heat flux deriving from the inside tube. The flux region used corresponds to a transmission by normal turbulent convection and by convection with the appearance of local boiling. The results obtained in the field of normal convection follow the classical laws; the results in the zone where local boiling appears are in correct agreement with the formulas proposed by other authors for higher heat fluxes.

391. Beatty, K. O.

ANALYSIS AND INTERPRETATION OF THE SHAPE OF THE BOILING HEAT TRANSFER CURVE, Fourth National Heat Transfer Conf. A.I.Ch.E-A.S.M.E., Buffalo, New York, August 14 to 17, 1960.

392. Benjamin, J. E.

BUBBLE GROWTH IN NUCLEATE BOILING OF A BINARY MIXTURE, Ph.D. Thesis, University of Illinois (1960), 84 p.

393. Benjamin, J. E., and Westwater, J. W.

HIGH SPEED MICROSCOPIC STUDY OF PHASE CHANGES, Proceedings of the Fifth International Congress on High Speed Photography, (Accepted for Publication).

394. Benson, P. R.

EFFECTS OF DISSOLVED NITROGEN ON SUBCOOLED NUCLEATE BOILING IN SANTOWAX R, NAA-SR-6891 (1961), 22 p.

Ten heat transfer tests were made using Santowax R coolant samples, eight being continued to the burnout point. Tests were made at pressures of 90 and 150 psia and bulk coolant temperatures ranging between 500 and 650°F. Tests were made with both vertical and horizontal heaters. Results showed that: the onset of nucleate boiling was affected to a large extent by the concentration of dissolved nitrogen, being reduced by as much as 195°F when saturated with nitrogen at 90 psia pressure, the critical heat flux was the same for coolants containing low or high dissolved nitrogen content, with evidence that the coolant was partially degassed when it contacted the heater even though there was no observed change in bulk gas concentration, and pool boiling may be a useful method for checking saturation temperature vs. pressure data obtained by other methods and for establishing approximate equilibrium relationships for systems not examined by P-V-T methods.

395. Bogart, N. T., et al.

HEAT TRANSFER TO BOILING LIQUIDS UNDER PRESSURE, Thesis MIT (1939).

396. Bonilla, C. F., and Cichelli, M. T.

HEAT TRANSFER TO LIQUIDS BOILING UNDER PRESSURE IN HEAT TRANSFER LECTURES, Volume II, pp. 150-186, NEPA-979 (1949), 345 p.

The following 15 lectures were presented at the NEPA Heat Transfer Symposium Oak Ridge, Tennessee, Dec. 8-13, 1947.

397. Borishanskiy, V. M.

GENERALIZATION OF EXPERIMENTAL DATA ON CESSATION OF BUBBLE FORMATION IN THE BOILING OF LARGE VOLUMES OF LIQUID, Tsentral. Nauch.-Issledovatel. Kotloturbin. Inst. im. I. I. Polzunova No. 28, 169-81 (1955).

From fluid mech. considerations, equations are developed for the prediction of cessation of bubble formation as a function of pressure in large vols. of liquid near the crit. point. The resultant equations satisfactorily represent the data in the literature.

398. Borishanskiy, V. M.

AN EQUATION GENERALIZING EXPERIMENTAL DATA ON THE CESSATION OF BUBBLE BOILING IN A LARGE VOLUME OF LIQUID, J. of Tech. Physics of the USSR, 26, 452-6 (1956), English Translation in: Soviet Physics-Technical Physics, 1, 438-2 (1956).

Experimental data are examined as the basis of an improved equation for calculating critical heat loads during boiling in large volumes of liquid.

399. Borishanskiy, V. M., and Kozyrev, A. P.

GENERALIZATION OF EXPERIMENTAL DATA ON HEAT TRANSFER IN NUCLEATE BOILING ON THE BASIS OF THERMODYNAMIC SIMILARITY, Inzhenerno-fizicheskiy zhurnal, v. 5, no. 12, 1962, 3-8.

In a previous paper (V. M. Borishanskiy, Voprosy teplootdachi i gidravliki dvukhfaznykh sred - Problems of heat transfer and hydraulics of two-phase media, Gosenergoizdat, 1961, p. 18) the formula $\alpha^*_p = \alpha^*_{p^*} F_1(p/p_{cr})$ was derived for the case of nucleate boiling where $\alpha^* = \alpha/q^n$, α is the heat transfer coefficient, q the thermal load of the heating surface. This formula makes it possible to allow for the pressure effect on the heat transfer of a medium over strongly varying physical properties in a wide range of pressures. Formula

$$\alpha = B\left(\frac{g}{M}R\right)^{1/6} \frac{p_{kp}^{1/3}}{T_{kp}^{5/6}} q^{2/3} F_3\left(\frac{p}{p_{kp}}\right) \quad . \qquad (5)$$

(p_{kp} - critical pressure, T_{kp} - critical temperature) is derived with the aid of thermodynamic similarity (I. I. Novikov, Voprosy teplootdachi i gidravliki dvukhfaznykh sred - Problems of heat transfer and hydraulics of two-phase media, Gosenergoizdat, 1961, p. 7 and 14), allowing for the experimentally proved fact that the heat transfer coefficient α is a function of the thermal load q and of the physical parameters of the medium when a nucleate boiling occurs with free convection. The function $F_3(p/p_{kp})$ is universal for thermodynamically similar substances and characterizes the effect of reduced pressure on the heat transfer. The shape of this curve is determined graphically by a method due to Borishanskiy. Formulas

$$\alpha = 600 \frac{p_{kp}^{1/3}}{T_{kp}^{5/6} M^{1/6}} q^{2/3} \left(0{,}37 + 3{,}15 \frac{p}{p_{kp}}\right) \text{npH} \frac{p}{p_{kp}} \leq 0.2;$$

$$\alpha = 600 \frac{p_{kp}^{1/3}}{T_{kp}^{5/6} M^{1/6}} q^{2/3} \exp\left[1{,}85\left(\frac{p}{p_{kp}} - 0{,}2\right)\right] \text{npH} \frac{p}{p_{kp}} \geq 0{,}2. \qquad (6)$$

are given for practical application. Only p_{cr}, T_{cr} and M of the medium need to be known in order to calculate the heat transfer coefficient at increased pressure and with free convection. The results obtained with these formulas agree with the experimental data given in a large number of papers within ±30%. There are 2 figures and 2 tables.

400. Boyd, L. R.

TEMPERATURE EFFECTS OF NUCLEATE BOILING, KAPL-M-LRB-2 (1956), 12 p.

The temperature behavior of a heating surface and the adjacent coolant water with varying degrees of nucleate boiling was investigated for the purpose of devising means of detecting the presence of nucleate boiling in the S3G. For the experiment, a small water channel, constructed of clear plastic, was used. A thin metal diaphragm formed one side of the channel. A portion of this diaphragm was heated electrically. Thermocouples were used to monitor the time average temperatures and the temperature fluctuations, both on the air side surface of the heated area of the metal diaphragm and in the water above and downstream from the heated area. The clear plastic construction permitted seeing the boiling on the heated surface.

401. Boyd, L. R.

NUCLEATE BOILING DETECTION SYSTEM DESIGN DESCRIPTION, KAPL-M-SSD-46 (1957), 9 p.

The proposed instrumentation system for the detection of local nucleate boiling in the S3G reactor core is described. Boiling will be detected by ion chambers inserted into thimbles which enter the core.

402. Braunlich, R. H.

POOL BOILING OF LIQUIDS AT REDUCED PRESSURES, M. S. Thesis, MIT (1941).

403. Carl, R., and Picornell, P.

LOCAL BOILING OF WATER IN AN ANNULUS, M. S. Thesis, M.I.T., Cambridge (1947).

404. Chang, Y. P., and Snyder, N. W.

HEAT TRANSFER IN SATURATED BOILING, Chem. Eng. Prog. Symp. Ser., 56, No. 30, pp 25-38 (1960).

This paper considers the heat transfer by boiling liquid from a horizontal surface. The presence of vapor bubbles contributes three effects to the heat transfer: destruction of the wave motion adherent to natural convection; increase of the effective thermal conductivity due to the eddy motion, or agitation effect; and change of specific heat capacity due to change of phase, or latent heat effect. The agitation effect is assumed to extend to the whole regime of nucleate boiling; whereas the latent heat effect starts to become significant only when the condition corresponding to the peak heat flux is approached. Six-dimensional parameters are found from the equations of momentum and energy. An equivalent thermal diffusivity of boiling liquid is defined and correlated from these six parameters.

A general equation of heat transfer coefficient is obtained in both convection and nucleate boiling. Peak heat flux and its corresponding temperature difference are determined according to the

mechanism of agitation and latent heat transport. Calculated results agree well with test data of previous investigators for dependence on both temperature and pressure.

405. Chang, Y. P.

AN EXPERIMENTAL MODIFICATION OF NUCLEATION THEORY AND ITS APPLICATION TO BOILING HEAT TRANSFER, ANL-6304 (1961), 34 p.

From the equations of momentum and energy and by the aid of established experimental phenomena, the problem of heat transfer in nucleate boiling was reduced to one consisting of three parameters: the first represents the Stanton number; the second, bubble growth; and the third, nucleation. With an empirical modification of the nucleation theory as developed by Volmer and Eyring from the Maxwell-Boltzmann distribution law, an equation was obtained for the heat transfer in vigorous boiling: $(qH\sqrt{\sigma/\rho c_p}\ \theta_s N_A (kT_s)^{3/2}) = C \exp\left[-n(16\pi/3)(\sigma/\Delta p)^2 (\sigma/kT_s)\ (\rho c_p\ \theta_s/\rho_v \lambda)^{-m}\right]$, where m = 1 and 2 for organic and inorganic liquids (including liquid metals), respectively. The symbols C and n represent dimensionless numbers whose values depend on the liquid and surface condition of the heater. Application of this equation is restricted to the following cases of boiling: saturated pool boiling from either smooth or rough surfaces; saturated and subcooled forced convection boiling from rough surfaces; and early stage of saturated and subcooled forced convection boiling from smooth surfaces. The validity of this equation for vigorous boiling was tested for more than a dozen different liquids under different pressures and different surface conditions. By introducing an eddy thermal diffusivity, a general equation was obtained, valid for the whole range of nucleate boiling.

406. Chang, Y. P.

SOME POSSIBLE CRITICAL CONDITIONS IN NUCLEATE BOILING, American Society of Mechanical Engineers, Preprint Paper No. 62-HT-37, New York (1962), 11 p.

Certain basic ideas from which several critical conditions are derived were introduced into boiling heat transfer. The heat transfer in nucleate boiling is considered as being limited by the maximum rate of bubble generation from a unit area of the heating surface. With certain simplified assumptions, an equation was obtained for the first critical heat flux of nucleate boiling with and without forced convection and subcooling.

407. Clark, H. B., Strenge, P. S., and Westwater, J. W.

ACTIVE SITES FOR NUCLEATE BOILING, Preprint 13, Sec. Nat. Heat Trans. Conf. AIChE-ASME, Chicago, Aug. 18-21, 1958, Chem. Eng. Progr. 29, 95-102 (1959).

Photography during and after nucleate boiling was used to identify active bubble-producing sites. Ether and pentane were tested on vertical surfaces of pure zinc and an aluminum alloy at atmospheric pressure. Numerous still photographs at magnifications between 160X and 864X and a few electron micrographs at a magnification of 25,000X were obtained. These plus high-speed motion pictures having a magnification on the negative of 13X show definitely that pits with diameters between 0.0003 and 0.003 in. are very active nucleation sites. Some scratches, a plastic-metal interface, and a mobile speck of unidentified material were active sites also. In no case did bubbles form at grain boundaries. No difference in activity could be found for the various crystal faces of zinc, an anisotropic material.

408. Cole, Robert

INVESTIGATION OF TRANSIENT POOL BOILING DUE TO SUDDEN LARGE POWER SURGE, NACA-TN-3885 (1956), 44 p.

The transient heat-transfer characteristics of a system composed of a nickel ribbon immersed horizontally in a pool of water were determined at atmospheric pressure for average heat-generation rates of 3, 10, and 20 x 10^5 Btu/(hr)(sq ft), and fluid bulk temperatures from 76° to 203°F. The power surge duration was limited to 30 milliseconds. Analyses show that convective heat transfer in the nonboiling region was negligible within the time limits employed. Comparison was made between determined ribbon temperatures and those occurring had the ribbon been completely insulated. Transient heat-transfer coefficients had critical-heat-flux values are tabulated.

409. Cole, Robert

A PHOTOGRAPHIC STUDY OF POOL BOILING IN THE REGION OF THE CRITICAL HEAT FLUX, A.I.Ch.E. Journal, 6, 533-8 (1960).

A photographic study was made to investigate the boiling phenomena in the neighborhood of the critical heat flux. Results indicate that at high heat fluxes the primary forces acting on a bubble leaving the surface are the buoyancy and drag forces.

410. Colver, C. P.

MEASUREMENTS OF THE TEMPERATURE PROFILES ADJACENT TO THE SURFACE DURING THE NUCLEATE BOILING OF WATER AND METHANOL, MS Thesis Univ. of Kansas (1960).

411. Corty, C., and Foust, A. S.

SURFACE VARIABLES IN NUCLEATE BOILING, Chem. Eng. Prog. Symp. Ser., 51 No. 17 (1955).

Measurements were made of the nucleate boiling coefficients of ether, normal pentane, and Freon 113 from a horizontal heated surface. Profilometer measurements of roughness and photo- and electron-micrographs of the surfaces were taken. Boiling bubbles were photographed in profile, and active centers were counted.

The experiments indicate a major influence of microroughness on the ΔT necessary to sustain nucleate boiling at any given heat flux. This furnishes an answer to the wide variation in slopes of boiling

coefficient curves from superficially similar systems, which however may have a wide range of nucleus effectiveness.

A pronounced hysteresis effect was observed. While increasing heat flux, the ΔT is higher than that necessary to accommodate the same heat transfer when the flux is being decreased. This hysteresis is due to uneven activation of the surface during increase of the flux. The observance of stable "patch-wise" boiling furnishes an additional clue to the divergent results which have been reported.

Based on these observed phenomena, a vapor-trapping mechanism of nucleate boiling has been postulated.

412. Costello, C. P., and Tuthill, W. E.

EFFECTS OF ACCELERATION ON NUCLEATE POOL BOILING, Chem. Eng. Prog. Symp. Series No. 32, 57, 189-196 (1961).

This paper presents the results of an investigation undertaken to determine the effects of accelerations produced by centrifugal effects on pool boiling heat transfer to distilled water. The investigation was instigated to better understand the mechanisms of boiling heat transfer, as well as to obtain data for accelerating systems. It was found that boiling heat transfer coefficients are adversely affected by acceleration directed away from the heat surface. The significance of this is discussed in terms of boiling mechanisms and equations.

413. Diskind, T., et. al.

BASIC STUDIES IN HEAT TRANSFER AND FLUID FLOW, TID-6035 (1960), 88 p.

A summary of research activities in nucleate boiling heat transfer, transient vaporization, film boiling, forced convection boiling, convection heat transfer in noncircular ducts, and transient heat transfer in reactor coolant channels is presented. Research proposals for study of the transient vaporization of liquid at a solid surface and for investigation of flow patterns in forced-circulation boiling flow are included as appendixes.

414. Dorsey, N. E.

QUIET BOILING, Phys. Rev. 55, 594 (1939).

The use of more or less rounded points for reducing the severity of such bumping as occurs when air-free water is boiled in clean glass vessels is common practice, but the results so obtained are seldom satisfactory. It seems not to have been recognized that if the material of which the points are made is such that it is perfectly wetted by the liquid at the temperature considered, then the point cannot be efficacious, as it will have no effect whatever upon the form or size of the incipient bubble of vapor. On the other hand, the presence in the liquid of a substance that is completely unwetted by the liquid at the temperature concerned will be efficacious, whatever its shape. Since in this case the contact angle is 180, the curvature of the incipient bubble at its very beginning will be slight and will at first increase as the volume increases; the first facilitates the formation of the initial bubble, the second stabilizes the initial stages of its growth. Among such substances for water are the stearates of zinc and of aluminum. Each of these is very effective. A simple mechanical device for the prevention of bumping will be described.

415. Drew, T. B., and Mueller, A. C.

BOILING, Trans. Am. Inst. Chem. Eng. 33, 449-71 (1937).

State of art of boiling reviewed; with submerged steam coil, it is found that at overall steam-to-liquid temperature differences of 30 to 50 C, "spheroidal state" develops, liquid no longer maintains contact with heating surface, and rate of heat transfer decreases for further increase in temperature difference; data presented to show significance of this effect in practical ranges for several organic liquids. Bibliography. (CA-31-8259-8).

416. Duch, G.

CONTRIBUTION TO THE STUDY OF THE PHENOMENON OF BOILING UNDER CONSTANT PRESSURE, J. Chim. Phys. 33, 414-26 (1936).

From a consideration of forces between two neighboring mols. when there is a rupture in a "film" formed by mols. pulling out from the surface during boiling under const. pressure, a relation $\phi = (3/2\pi)(A/r)$ is obtained in which π is the centered force of attraction, A is the surface tension under the conditions set up and r is the mol. radius. r is given approx. by the formula $r = [(3/4\pi N)(M/D)]^{1/3}$ in which M is the mol. mass, D is the abs. d. and N the Avogadro-Planck no. ϕ seems to have a nearly const. value of 2.7×10^8 and therefore a substitution of equations gives $M = A^3 D.8 \times 10^{-2}$. The product of ϕ by the reduction factor γ, which is (log Tc-log Te)/log Tc gives an expression of the force of mol. attraction $\phi\gamma = f(1/r)$. The graphic representation of this gives a straight line which appears to converge for most org. compds. toward a nodal point of coördinates $(\phi\gamma)_0 = 0.0854$ and $[1/r]_0 = 0.248 \times 10^{-8}$ c.g.s. The change of $\phi\gamma$ and $1/r$ is a linear function expressed by $d\phi\gamma - k_1(1/r^2)dr$. A study of the "dynamic" line of the benzene series gives a relation among surface tension, b.p. and crit. temp. which is $A/\gamma = \psi$ = const. In this A and γ have the values as before. Also for most org. groups, a graphic representation of $A^P_{te} = f(1/r)$ gives a series of straight lines converging toward a new nodal point, P, of coördinates $A_p = 14.3$ and $1/rp = 0.248$. For homologs of an org. family A and $1/r$ increase linearly and therefore the differential equation $dA = -k_2(1/r^2)dr$ is obtained in which k_2 is a const. for the particular substance considered. Combining differential equations gives $dA/d\phi\gamma = k_2/k_1$ = const. = k_3. Values of D,.A, Tc, Te, $1/r, \phi\gamma, \phi$, γ, $\Delta(1/r), \Delta\phi\gamma$, k_1, k_2, k_3 and ΔA are given for 17 org. compds.

417. Dunn, P. S., and Vincent, A. D.

STUDY OF HEAT TRANSFER FROM A HORIZONTAL METAL SURFACE TO BOILING LIQUID, Chem. Eng. M.S. Thesis, MIT (1931).

418. Dutkiewicz, R. K.

PRELIMINARY STUDIES INTO BOILING HEAT TRANSFER, S. African Mech. Engr. 7, 231-4 (Mar. 1958).

Phenomena associated with heat transfer process from heating surface to liquid, during boiling of liquid; experiments dealing with effect of pre-treatment of surface on boiling curve; results of photographic tests on boiling of water on platinum wire.

419. Edwards, D. K.

THE ROLE OF INTERPHASE MASS TRANSFER IN THE MECHANISM OF NUCLEATE BOILING, M.S. Thesis, U. of Calif. (Berkeley) (1956).

420. Eggleton, P. and Kermack, W. O.

BOILING AND BUBBLING, Chem. Products 8, 75-80 (1945).

A discussion of the practical importance of bubble formation, exptl. investigations, superheating, theories of superheating and supersatn., significance of nuclei in bubble formation, and crit. vols.

421. Faneuff, C. C., McLean, E. A., and Scherrer, V. E.

SURFACE BOILING, J. Appl. Phys. 29, 80-4 (1958).

An experiment is described in which the growth of vapor bubbles at a surface is followed in detail. Growth curves are obtained and shown to agree, within experimental error, with current theories of growth under idealized conditions, provided an average superheat present at the initiation of growth is used in the calculation. A criterion is proposed to permit estimation of a delayed time for vapor formation. The estimated delays are found to be in qualitative agreement with those measured.

422. Farber, E. A.

FREE CONVECTION HEAT TRANSFER FROM ELECTRICALLY HEATED WIRES, J. App. Phys. 22, 1437 (1951).

In this paper the author discusses the heat transfer by free convection from electrically heated wires (copper and iron) to distilled water between freezing and boiling, to water boiling at atmospheric conditions and to air at room temperature. The wire surface temperatures needed for the heat transfer determination are calculated from the theoretical temperature distribution in the wire. The experimental results show maximum heat transfer rates of about 2,200,000 Btu/hr, ft^2 near freezing and 450,000 Btu/hr, ft^2 near boiling. For boiling water, as the temperature difference between the wire surface and water is increased, the heat transfer coefficient first increases reaching a maximum, then decreases reaching a minimum and increases again (because of radiation) until the wire fails by melting. For copper the maximum film coefficient of 9100 Btu/hr, ft^2, °F is observed at 49 degrees temperature difference and the minimum of 136 Btu/hr, ft^2, °F, at a temperature difference of 690 degrees F. Corresponding values for iron are 12,300 Btu/hr, ft^2, °F at a 33 degree temperature difference and 142 Btu/hr, ft^2, °F at a 620 degree difference. When air at room temperature surrounds the wire the heat transfer coefficient for copper with an oxide film varies from 0 to 30 and for iron from 0 to 26 Btu/hr, ft^2, °F as the surface temperature of the wires is raised until failure occurs.

423. Forster, H. K., and Zuber, N.

DYNAMICS OF VAPOR BUBBLES AND BOILING HEAT TRANSFER, J. of AIChE, 1, 531-5, NSA-10-2698 (1955).

Analytical expressions for bubble radii and growth rates are applied in an analysis of surface boiling at high heat transfer rates. It is shown that the product of bubble radius and radial velocity is a constant, independent of the bubble radius. This circumstance permits the formulation of a Reynolds number for the flow in the thin superheated liquid layer adjacent to the heating surface. The result of the analysis is then applied to maximal heat transfer rates in pool boiling.

424. Forster, K. E.

BOILING, Jet Propulsion, 27, 1104-06 (1957).

425. Forster, K. E., and Greif, R.

HEAT TRANSFER TO A BOILING LIQUID: MECHANISM AND CORRELATION, ASME Paper No. 58-HT-11. Journal of Heat Transfer 81, 43-53 (1958).

Various heat transfer mechanisms, previously proposed, are analyzed in light of recent experiments; evidence presented in favor of vapor-liquid exchange mechanism and against widely accepted "microconvection" mechanism; "Reynolds Analogy" for nucleate boiling presented; calculation of superheat at which liquid bulk velocity ceases to contribute to heat flux; expression for growth of vapor bubble in highly superheated liquid. 20 refs.

426. Forster, K. E.

GROWTH OF A VAPOR-FILLED CAVITY NEAR A HEATING SURFACE AND SOME RELATED QUESTIONS, Phys. of Fluids (USA), vol. 4, No. 4, 448-55 (Apr. 1961).

The growth of a vapour bubble on a heating element immersed in a liquid which is at saturation temperature or subcooled far from the heating surface but which is superheated near the heating surface, is treated as a problem of heat conduction with evaporation on a boundary. The results show, in agreement with experiment, that in a liquid at saturation temperature the radius grows as $t^{1/2}$ at first (t is time) and as $t^{1/4}$ for $t \to \infty$; for a subcooled liquid the radius as a function of time is given as an infinite series in terms of a quantity H, later identified with the thickness of the thermal boundary layer. Several relations between boundary layer thickness in a boiling liquid, maximum radius attained by the cavity before collapse and superheat and subcooling are derived and compared with experiment. For large subcooling the boundary layer thickness is shown to be about one-half (or less) the size of the maximum radius. Physical considerations concerning the mechanism of heat transmission to a boiling

liquid lead to the definition of a heat diffusivity, the exchange diffusivity $a^* = M^2 a$, with M the dimensionless ratio of enthalpies of superheated liquid and of saturated vapour. The dimension of the thermal boundary layer is shown to be the diffusion length for the exchange diffusivity.

427. Fritz, W., and Homann, F.

TEMPERATURE DISTRIBUTION IN BOILING WATER, Phys. Zeits. 37, 873-8 (1936).

Water is contained in a Cu cylinder, having a highly reflecting Cr-plated bottom heated by an electric heater. The cylinder is closed at the top except for a pipe leading to a condenser where the steam generated is condensed and weighted. It is surrounded by a steam jacket, and long tubes of German silver, of different diameters can be fixed centrally within it, so that they extend from just above the heating surface, to well above the water surface. The temperature can be measured, by means of calibrated thermocouples, within and outside this shielding cylinder, in the steam jacket, and at a number of other points of the apparatus. One of these thermocouples can be moved up and down the axis of the cylinders, so that the temperature can be measured at all heights in the water column, and in the steam above it. The results are expressed in terms of the deviation from 100°C., and are said to be measured to 0.01°C. The temperature distribution was determined for different loadings of the heating surface, with a constant water column; for different heights of column, with constant heater loading; and for different diameters of the inside shielding cylinder. The results are given graphically, and are compared with the saturation curves corresponding to the hydrostatic pressure at the different levels. The measured temperature distribution differs considerably from that calculated from the pressure increase. The only agreement is between the mean temperature over the whole height of the column and the temperature corresponding to the hydrostatic pressure for half the height of the water column, for different values of the column height.

428. Gaertner, R. F.

DISTRIBUTION OF ACTIVE SITES IN THE NUCLEATE BOILING OF LIQUIDS, A.I.Ch.E. Preprint 5, New York (1962) 30 p.

A statistical treatment is given of the only existing data for the spatial distributions of boiling nucleation sites on a copper surface. The local density of nucleation sites for boiling water containing dissolved nickel salts, at heat fluxes of 200,000, 294,000, and 317,000 Btu per hr. sq. ft., were found to fit a Poisson distribution quite well. The fraction of the surface having a local active site population N in local areas a is given by the equation, $P_u(Na) = [e^{-\overline{Na}}(\overline{Na})^{Na}/(Na)!]$ and the distribution of nearest-neighbor distances having a value between S and S + dS by the equation, $P(S) = 2\pi\overline{N}S\, e^{-\overline{N}\pi S^2} dS$. This result shows that the average distance between nearest-neighbor sites is $\overline{S} = 1/2\ \overline{N}^{1/2}$. It was concluded that "patchwise boiling," often observed on isotropically polished surfaces uniformly heated at low Δt, is not real but is a visual manifestation of a completely random spatial distribution of active sites. From a cursory examination of published data for five liquids boiling from three different surfaces it was also found that the population of active sites depends on surface temperature according to the equation, $\overline{N} = N_0 e^{-K/T^3 w}$, as expected from classical nucleation theory.

429. Gaertner, R. F., et al.

NOVEL METHOD FOR DETERMINING NUCLEATE BOILING SITES, Chem. Eng. Prog. 55, 58-61 (Oct. 1959).

To measure the number of active bubble-producing sites in a boiling liquid a method of simultaneous electroplating during boiling was developed which successfully permitted counts of active sites as dense as 1130/sq. in. at 317,000 Btu/hr. per sq. ft. A random geometrical distribution of active sites was revealed by a photographic study of a nickel-plated heated surface.

430. Gaertner, R. F., and Westwater, J. W.

POPULATION OF ACTIVE SITES IN NUCLEATE BOILING HEAT TRANSFER, Chem. Eng. Prog. Symp. Series, No. 30 56, 39 (1960).

Counts of active bubble-producing sites were determined throughout most of the nucleate region for a boiling liquid. An aqueous solution of nickel salts containing 20% solids was boiled at atmospheric pressure on a horizontal, flat, copper surface 2 in. in diameter in a 7 1/2 in. vessel with no forced convection. The technique for determining active sites consisted of plating a thin layer of nickel on the copper surface during the boiling runs and subsequently counting the number of pin holes in the plate.

The heat flux was varied from 7680 to 535,000 Btu/(hr) (sq ft) and the Δt from 17.3° to 218.8°. Counts of active sites were obtained from zero to a maximum of 1,130/sq in. at 317,000 Btu/(hr)(sq ft). A random geometrical distribution of active sites was revealed by a photographic study of the nickel-plated heated surface. For this system a linear relationship between the number of active sites and the heat flux, as suggested by Jakob, is nonexistent. The heat flux was proportional approximately to the square root of the number of sites. Widely known theoretical analyses for nucleate-boiling heat transfer do not include the functionality in the latter manner.

431. Gibbons, J. H., and G. Houghton,

EFFECTS OF SONIC VIBRATIONS ON BOILING, Chem. Eng. Sci. 15, 146-8 (1961).

Boiling of H_2O from an immersed, heated Pt wire was measured with the wire in a field of sonic vibrations at 20-2000 cycles/sec. The film coeff. is increased substantially in certain frequency ranges for nucleate boiling and nonboiling heat transfer and increased only moderately in film boiling.

432. Gilmour, C. H.

NUCLEATE BOILING - A CORRELATION, Chem. Eng. Prog., 54, 77-79, No. 10 (1958).

The purpose of this paper is to present an expression for nucleate boiling which resembles those

expressions for sensible heat transfer and condensing and which is based on a new and satisfactory correlation of existing data. No new experimental data are included in this correlation.

433. Grady, J.

POOL BOILING, MS Thesis, Columbia Univ. (1950).

434. Griffith, P.

THE DYNAMICS OF BUBBLES ON NUCLEATE BOILING, Sc. D. Thesis, Mech. Engrg. MIT (1956).

435. Griffith, P., and Wallis, J. D.

THE ROLE OF SURFACE CONDITIONS IN NUCLEATE BOILING, Presented at 3rd Nat. Ht. Trans. Conf. ASME-AIChE, Aug. 1959, Chem. Eng. Prog. Symp. Series 30, 56, 49-63 (1960).

A study of nucleation from a single cavity indicates that cavity geometry is important in two ways. The mouth diameter determines the superheat needed to initiate boiling, and its shape determines its stability once boiling has begun. Contact angle is shown to be important in bubble nucleation primarily through its effect on cavity stability. Contact-angle measurements made on clean and paraffin-coated stainless steel surfaces with water show that the contact angle varies between 20 and 110 deg. for temperatures from 20° to 170°C. On the basis of single-cavity nucleation theory, it is proposed to characterize the gross nucleation properties of a given surface for all fluids under all conditions with a single group having the dimensions of length. Finally this characterization is shown experimentally to be adequate by boiling water, methanol, and ethanol on different copper surfaces finished with 3/0 emery and showing that the number of active centers per unit area is a function of this variable alone.

436. Gunther, F. C., and Kreith, F.

PHOTOGRAPHIC STUDY OF BUBBLE FORMATION IN HEAT TRANSFER TO SUBCOOLED WATER, JPL-Prog. Rept-4-120 (1950), 29 p.

A close-up photographic study of surface boiling in a subcooled pool of distilled water was undertaken. The use of a stagnant pool of coolant isolated the bubble activity from the influence of forced convection. An account is given of a study of multiple-flash photographic sequences of bubble growth-and-collapse cycles taken at heat fluxes ranging from 1 to 4 Btu/(in.^{2})(sec). Results of temperature measurements on and near the heating surface are presented. Data on the increase of burnout heat-transfer rate resulting from increased subcooling show that a heat flux as high as 5 Btu/(in.^{2})(sec) can be transferred to a pool of distilled water subcooled 145°F below saturation temperature. In a pool of water subcooled more than 100°F to permit high heat-transfer rates, photographs clearly indicate a surface boiling activity consisting in a random distribution of very small vapor bubbles which never detach from the heating surface, but grow and collapse hemispherically at frequencies higher than 1000 cps. The growth-and-collapse cycling of bubbles excites microconvection in the sublayer; this microconvection appears to be the dominant transport mechanism for high heat fluxes observed with surface boiling. 12 references.

437. Han, Chi-Yeh, and Griffith, P.

THE MECHANISM OF HEAT TRANSFER IN NUCLEATE POOL BOILING, Technical Report No. 19, NP-11491 (1962), 81 p.

A criterion is developed for bubble initiation from a gas-filled cavity on a surface in contact with a superheated layer of liquid. It is found that the temperature of bubble initiation on a given surface is a function of the temperature conditions in the liquid surrounding the cavity as well as the surface properties themselves. It is also found that the delay time between bubbles is a function of the bulk liquid temperature and the wall superheat and is not constant for a given surface. By consideration of the transient conduction into a layer of liquid on the surface, a thermal layer thickness is obtained. With this thickness and a critical wall superheat relation for the cavity, a bubble growth rate is obtained. Bubble departure is considered and it is found that the Jakob and Fritz relation works as long as the true (non-equilibrium) bubble contact angle is used. The effect on the departure size of the virtual mass in the surrounding liquid is found to be negligible at one gravity. That is, at one gravity the primary effect of bubble growth velocity on bubble departure size is found to be due to contact angle changes. The initiation, growth, and departure criterions are each experimentally and individually checked. They are then used to compute the heat transfer near the knee of the boiling curve using only an experimental determination of the number of bubbles as a function of wall superheat and other known quantities. Finally the q vs. $T_w - T_{sat}$ relation is computed and measured and compared. The comparison is satisfactory.

438. Haslam, F.

A STUDY OF THE MECHANISM OF BOILING, Ph.D. Thesis, London (1956).

439. Hayashi, S., et al.

EXPERIMENTAL STUDY OF THE TEMPERATURE OVERSHOOT AND THE DELAY TIME OF THE TRANSIENT BOILING, J. Atomic Energy Soc. Japan, 2, 736-41 (1960)(In Japanese).

In order to study the transient nucleate boiling on the fuel plate surface of a light water cooled and moderated reactor when a sudden large reactivity is given to it, a fundamental experiment was made by means of stepped electrical heating of metal foil located in stagnant water under atmospheric pressure. From these studies, it is understood that the temperature overshoot of the metal surface from the saturation temperature of water and the delay time between passage of saturation temperature and the beginning of boiling, may, regardless of the degree of subcooling, be predicted in terms of the temperature rising velocity of the metal surface. With these

results, it is possible to make a precise analysis of the light water cooled and moderated reactor kinetics in case of the power excursion.

440. Hirano, F., and Nishikawa, K.

THEORETICAL INVESTIGATION OF HEAT TRANSFER BY NUCLEATE BOILING, Trans. Soc. Mech. Engrs. Japan 18, No. 72, 23-26 (Aug. 1952)(In Japanese).

Authors assume that the main driving force of convection at the stage of nucleate boiling is the change of apparent density due to rising bubbles, and introduce an equivalent Grashof number due to this effect, in place of the usual Grashof number, into the heat-transfer formula for free convection. They then show that Nusselt number is proportional to $n^{1/3}$, where n is the number of nuclei of steam bubbles generated on the horizontal heating surface. This fact was previously found experimentally by the same authors as one of the factors which determine n, the effect of contamination of the surface is discussed.

441. Hirano, F., and Nishikawa, K.

TIME VARIATION OF NUCLEATE BOILING HEAT TRANSFER OF WATER, Bull. JSME 2, 370-75 (Aug. 1959).

Experiments are described in which water is boiled at atmospheric pressure from regularly grooved surfaces. A parameter ζ is defined by

$$\zeta = \alpha R/\Delta\theta^2$$

where α is the coefficient of heat transfer, R the radius of the heating surface and $\Delta\theta$ the temperature difference between heating surface and boiling liquid. This is taken to be a measure for the "bubble formation ability" and the change of its value with time is found to be of the nature of an exponential decay. Small amounts of fatty acids given by $C_nH_{2n}O_2$ where the integer n varies between 6 and 18 are rubbed into the surface and it is found that the initial value of ζ varies in a regular fashion with n closely paralleling the dependence of the contact potential with n, while the exponent of time decay remains unchanged, and is also independent of heat flux, surface quality and presence of solute, unless scale deposits are produced. Authors conclude that the time variation of ζ is caused by desorption of adsorbed gas from the freshly polished heating surface into the liquid.

442. Hogan, J. M., and Boyd, L. R.

JOINT BETTIS-KAPL NUCLEATE BOILING DETECTION EQUIPMENT, WAPD-168 (1957), 32 p.

Three methods for detection of nucleate boiling were proposed and tested. These were (1) a hydrophone mounted inside the water space downstream of the boiling area for passive listening to identify any sound characteristic of boiling, (2) an external accelerometer rigidly connected to the heater (through a low-impedance seal) to study heater vibrations characteristic of boiling, and (3) a receiver hydrophone downstream of the boiling area to measure the attenuation of sound from an upstream input hydrophone as the sound passes through the boiling area. The conclusions reached as a result of these tests are that (1) passive listening with a single internal hydrophone or accelerometer is not feasible, although some small-scale accelerometer indications obtained at 800 psi, 350°F, and 5 fps velocity might be improved, and (2) the attenuation method does show promise for a system of boiling detection but may have major difficulties as far as use in a reactor system is concerned. However, only one valid attenuation test was run before a hydrophone failed; additional testing would be necessary to fully evaluate the transmission method. In addition, it is concluded that the present experimental hydrophone design is inadequate under these simulated reactor conditions and that boiling detection by sonic methods in a reactor would involve an extensive transducer development and application program.

443. Holt, V. E.

AN EXPERIMENTAL INVESTIGATION OF HIGH-FLUX FREE CONVECTION HEAT TRANSFER TO WATER UP TO NEAR-CRITICAL CONDITIONS, ANL-6400 (1961), 113 p.

The primary purpose of this investigation was to increase the basic knowledge of nucleate and film boiling heat transfer to fluids up to their critical pressures.

An extensive literature survey of the subject indicated a scarcity of consistent data and an absence of proven methods for analysis. This situation led to the design and construction of experimental apparatus suitable for measuring rates of free convection heat transfer and associated temperature differences for fluid conditions up to 4000 psi and 800 F, with provision for visual observation.

The apparatus incorporated a stainless steel system for containing the fluid. Ten-mil-diameter cylindrical and $\frac{1}{8}$ in.-high vertical-plate platinum test sections were placed in the fluid inside a pressure vessel, 5 in. in inside diameter and 21 in. high. The pressure and temperature of the fluid environment were controlled by constant-volume heating of the fluid in the pressure vessel with aid of seven zones of radiant guard heaters located between the external wall of the pressure vessel and the insulation. Each of these zones was controlled by a differential-thermocouple-sensed circuit that automatically kept the pressure vessel at a prescribed uniform temperature.

Fluid pressure was measured with a dead-weight tester and a 0-4000-psi Heise gauge. Fluid temperature was measured with a calibrated resistance thermometer and Mueller bridge, purchased specifically for that purpose. The heat flux in the test section was obtained from electrical measurements of the direct current power supplied for Joule heating. The temperature of the test section was measured by means of a resistance thermometer.

The system was outgassed and filled under a vacuum with water that was deionized, degassed, and deionized again. The quality of the water was maintained

during an experiment with the aid of a thermal-siphon deionizing loop which was connected to the system.

The results were tabulated and plotted in terms of heat flux and temperature difference between the heated surface and the bulk fluid (water). Nucleate boiling results are included for pressures of 14.7, 1300, 2400, 2800, 2900, 3000, 3100, 3150, and 3180 psia. Results also included for free convection to water at pressures of 3200, 3250, 3300, 3400, 3625, and 3925 psia. The nucleate and film boiling results were correlated and compared with other data. At a particular nucleate boiling heat flux, the heat transfer coefficient was observed to increase with pressure up to about 2800 psia. The characteristics associated with transition film boiling vanished above the critical pressure according to the plotted results and the experimental behavior. In fact, for pressures above the critical, a trend toward the characteristics associated with single-phase free convection to a constant-property fluid was observed. A large convective flow of the fluid and large density gradients accompanied by considerable optical distortion were observed within ±400 psi of the critical pressure. Near the critical pressure, sheets of fluid appeared to be passing the field of observation.

444. Howells, Earl

CS-2 NUCLEATE BOILING TEST, BW-5433 (1957), 27 p.

When corrosion products from a carbon steel system deposit on Zircaloy-2 heat transfer surfaces subjected to nonboiling and nucleate boiling water, no significant decrease in the over-all heat transfer coefficient occurs in 2800 hr under the test conditions used in this program. Pressurized water heated to about 600°F will react with Zircaloy-2 to form zirconium hydride. More hydride is formed when a nucleate boiling condition exists. These tests indicate that carbon steel can be used in place of stainless steels to fabricate some components of a pressurized water reactor system without fear of blocking flow passages or causing overheating of fuel elements due to decrease in the over-all heat transfer coefficient providing the coolant water has a pH of 10. Materials will preferentially deposit on heat transfer surfaces where nucleate boiling occurs.

445. Howells, E. and Ferguson, K. M.

CS-2 NUCLEATE BOILING TEST, BW-5429 (1957), 52 p.

The objective of this work was to determine if corrosion products from a carbon steel system would deposit on Zircaloy-2 heat transfer surfaces in sufficient quantity to cause measurable changes in heat transfer resistance. The effect of non-boiling and nucleate boiling water was investigated with respect to both the deposition of corrosion products and secondarily, the corrosion of Zircaloy 2 itself.

446. Hsu, S. T., and Schmidt, F. W.

MEASURED VARIATIONS IN LOCAL SURFACE TEMPERATURES IN POOL BOILING OF WATER, J. Heat Transfer 83, Series C, 254-260 (1961).

An investigation of the surface temp. variation during nucleate pool boiling at atmospheric pressure was conducted. The effect of surface temperature, heat flux, and heating surface material was investigated. The temp. variation of the surface was found by a specially fabricated thermocouple placed in contact with it. The average maximum temp. variation may be found from the following equation:

$$\Delta T_{avg\ max} = c\,[q(f/\alpha)^{1/2}]^{-a}\,\frac{q\,\Delta T_{sur\text{-}sat}}{k}$$

The exponent a is a function of surface roughness. The rate of heat flow was denoted by q in Btu/sq ft hr, α the thermal diffusivity in sq ft/hr, f the frequency of variations in cphr, k the thermal conductivity in Btu/ft-hr-deg F, and $\Delta T_{sur\text{-}sat}$ the temp. difference between the heating surface and the saturation temp. of the water. The coefficient c and exponent a were determined experimentally for various heating-surface materials and surface finishes.

447. Hughmark, G. A.

A STATISTICAL ANALYSIS OF NUCLEATE-POOL-BOILING DATA, Int. J. Heat Mass Transfer, 5, p 667-672 (1962).

Nucleate pool boiling experimental data have been analyzed with a statistical technique to obtain an eight variable equation for the heat flux. The dimensional derived equation considers only the thermodynamic properties of the liquid and vapour and neglects the effects of the surface condition, the geometry and orientation. The equation has no theoretical justification but it does indicate the best agreement with the experimental data that can be obtained when only the thermodynamic properties are considered as products of powers. An average absolute deviation of 40 per cent is obtained between experimental and predicted heat flux for a range of materials from boiling hydrogen to boiling mercury.

448. Ishigai, S., et al.

BOILING HEAT TRANSFER FROM A FLAT SURFACE FACING DOWNWARD, International Developments in Heat Transfer, Part II, A.S.M.E., N. Y. p 224-9 (1961).

Pool boiling from a downward facing surface was experimentally studied by heating the top of a copper rod whose bottom end was immersed in water and served as the heating surface. The curve obtained by plotting the heat flux against the temperature difference was in many ways similar to the curve for the boiling from electrically heated wires. The behavior of the fluid on the heating surface was

observed and photographed. Up to the burnout limit, the heating surface did not entirely dry out in spite of the presence of steam blanket because at least a part of the surface was intermittently swept by water when the steam blanket left the heating surface to escape into the atmosphere. After the burnout limit was reached, the heating surface was completely dried in spite of the violent motion of the bubbles emerging from the persisting steam blanket.

449. Jakob, M., and Linke, W.

HEAT TRANSFER FROM A HORIZONTAL PLATE TO BOILING WATER, Forsch. Gebiete Ingenieurw, 4, 75-81 (Mar-Apr 1933).

Qualitative and quantitative investigation of heat transfer from horizontal plate to boiling water.

450. Jicha, J. J., and Lemanski, E. J.

NUCLEATE BOILING (LITERATURE SEARCH), MND-1062-1 (Rev.) (1958), 56 p.

The mechanism of boiling heat transfer is described including the effects of various liquid conditions. Forced convection and nucleate boiling heat transfer are considered in addition to partial film boiling. Equations are presented for various pressure ranges, flow rates, and heating element geometries from which boiling locations can be predicted. Also included is a listing of equations which define conditions under which burnout would occur. Some of the more important variables and their effect on nucleate boiling and burnout are discussed, and a glossary of boiling heat transfer terms is included. 210 references.

451. Jicha, J. J., and Frank, S.

AN EXPERIMENTAL LOCAL BOILING HEAT-TRANSFER AND PRESSURE-DROP STUDY OF A ROUND TUBE, American Society of Mechanical Engineers, Preprint Paper No. 62-HT-48 (1962), 20 p.

Local boiling heat-transfer and pressure-drop data were obtained for a tubular test section. The stainless-steel test section was 30 in. long and had a 0.416-in. ID. Fifteen wall thermocouples and five pressure-drop increments were employed to secure the data over the following range of parameters: system pressure at 800, 1100, 1300 and 1500 psia; flow rate at 1.2×9.0 gpm; and heat flux at 0.1×10^6 to 1.3×10^6 Btu/hr ft^2. The pressure-drop data were correlated using an equation of the form $f/f_{iso} = a + bj + c$ (Re). The pressure-dependent constants a, b, and c were established by a least-square fit of the data at each pressure. The linearity of the equation was verified by the computation of multiple correlation coefficients which ranged from 0.82 to 0.93. Calculated standard deviations ranged from 0.152 to 0.201. The equation developed was applied with fair success to the data of other investigations obtained at Prandtl numbers, pressures, and heat fluxes different from those of this study.

452. Johnson, H. A.

TEMPERATURE VARIATION, HEAT TRANSFER, AND VOID VOLUME DEVELOPMENT IN THE TRANSIENT ATMOSPHERIC BOILING WATER, SAN-1001 (1961), 227 p.

Experimental determinations of surface temperature, and the volume of vapor produced are given for the atmospheric pool boiling of water on metallic ribbons in which energy is uniformly generated at an exponentially increasing rate in time. The subcooling of the pool was varied between 2 and 112°F and the period of the transient pulse ranges between 5 and 80 milliseconds. These conditions are typical of those in a nuclear reactor experiencing a prompt-critical excursion. The effects of thermal capacity of the ribbon and orientation of the heating surface were also studied. These results exhibited decided trends although, since the system was extremely sensitive to minor random variations, they were reproducible only within limits that were necessarily broad. No general correlations were formed, but a method for predicting the rate of vapor volume development was devised and applied with some success in the case of saturated transient boiling. The effects of pressure and velocity are presently being studied.

453. Johnson, H. A., et al.

TRANSIENT POOL BOILING OF WATER AT ATMOSPHERIC PRESSURE, p. 244-54 of "International Developments in Heat Transfer, Part II." New York, The American Society of Mechanical Engineers, 1961.

Experimental values of surface temperature and the volume of vapor produced are given for the atmospheric pool boiling of water on metal ribbons in which energy is uniformly generated at an exponentially increasing rate. The subcooling of the pool was varied between 2 and 112°F and the period of the transient pulse ranged between 5 and 80 milliseconds. These conditions are typical of those in a nuclear reactor experiencing a prompt-critical excursion. The results exhibited decided trends. They were reproducible only within broad limits, however, since the system is extremely sensitive to minor random variations. No general correlations were formed, but a method for predicting the rate of vapor volume development was devised and applied with some success in the case of saturated transient boiling.

454. Jontz, P. D., and Myers, J. E.

THE EFFECT OF DYNAMIC SURFACE TENSION ON NUCLEATE BOILING COEFFICIENTS, A.I.Ch.E. Journal, 6, 34-38 (1960).

Air-bubble and boiling investigations were performed with aqueous solutions of detergents known as Tergitol and Aerosol; boiling coefficients of Tergitol-Water solution were found to vary inversely with

dynamic surface tension; for Aerosol-Water solutions, coefficients varied in manner which could not be related to surface-tension effects.

455. Katz, K., Esper, R. T., and Hopkins, W. E., Jr.

NUCLEATE BOILING DETECTION TECHNIQUES, WAPD-T-588 (1957), 25 p.

Several non-visual methods used for the detection of steady-state local boiling are discussed in detail. In addition, an audio detection technique which appears technically feasible but has not been fully developed, is described briefly.

456. Kreith, F., and Foust, A. S.

REMARKS ON MECHANISM AND STABILITY OF SURFACE-BOILING HEAT TRANSFER, Am. Soc. Mech. Engrs - Paper n 54 - A-146 for meeting Nov 28-Dec 3, 1954, 10 p.

Recent theories of nucleate boiling are critically analyzed with regard to their range of applicability; new criteria for stability limits of boiling heat transfer are suggested.

457. Kutateladze, S. S.

HYDRODYNAMIC THEORY OF THE CHANGE OF STATE ON BOILING A LIQUID UNDER CONDITIONS OF FREE CONVECTION, Translated from: Izvest. Akad. Nauk SSR, Otdel. Tekh. Nauk 529 (1951) AEC Trans. 1441, (1951), 14 p.

458. Kutateladze, S. S., and Moskvichevia, V. N.

HYDRODYNAMICS OF A TWO COMPONENT LAYER AS RELATED TO THE THEORY OF CRISES IN THE PROCESS OF BOILING, Soviet Physics, Technical Physics, 4, 1037-40 (1959).

The paper gives some data on the bubbling of a liquid through another liquid. It is found that the change in the hydrodynamic structure of a two-component layer is determined by the same dimensionless parameters as in the transition from bubbling to pellicular boiling.

The presence of complex changes in the structure of a two-component layer is definitely established.

459. Kutateladze, S. S.

BOILING HEAT TRANSFER, Intern. J. Heat Mass Transfer, 4, 31-45 (1961).

The problems of heat transfer with nucleate boiling are discussed to generalize the exptl. results. The intensity of heat transfer with nucleate boiling is conditioned by the interaction of convection, connected with the directed motion of the whole flow of a liquid, and local convection, caused by the origin, growth, and rise of vapor bubbles. The latter process is of decisive importance at sufficiently high flux ds. The probability of the creation of a vapor phase in a superheated liquid is proportional to exp $(1/-(\Delta t)^2)$. Consequently, the vapor bubbles should rise just near the heating surface where the superheating of the liquid is greatest in comparison with the satn. temp. above the surface. The growth of a vapor bubble is connected with the d. of the heat flow on a bubble surface. The transition from nucleate to film boiling is considered to be a specific process, the basis of which involves the loss of the stability of structure of a 2-phase boundary layer. The rise of temp. caused by the decrease of the heat transfer coeff. leads to a further development and distribution of film boiling over the heating surface. The influence of the directed convection characterized by the "d. displacement" velocity and vapor content of the flow on the intensity of heat transfer with nucleate boiling depends both on the d. of the heat flux and the phys. properties of the boiling liquid. With nucleate boiling the flow rate has little influence on the heat transfer coeff. at high pressure and high heat flux. At low pressures and moderate heat flux this influence may be important. A system of differential equations for a nucleate boiling process was formulated and rational system of criteria characterizing it was developed, proceeding from the hypothesis on the hydrodynamic nature of crises in the boiling mechanism. (CA-62-16354i)

460. Lance, R. P., and Myers, J. E.

LOCAL BOILING COEFFICIENTS ON A HORIZONTAL TUBE, AIChE Journal, 4, 75-80 (1958).

Local boiling heat-transfer coeffs. were dtd. by expt. for nucleate boiling around the outer circumference of horizontal Cu tubing. The tubes used were of 16 B.W.G. hard-temper Cu with outside diams of $1\frac{1}{4}$ and 2 in.; the liquids boiled were MeOH and hexane. The max. peripheral variation occurred with the $1\frac{1}{4}$ in. tube in MeOH where an overall T of 30.2°F gave local outside coeffs. varying between 249 and 548 Btu/(hr)(sq ft)(°F) The min. variation occurred in the same system, in which an overall T of 72.3°F gave coeffs. varying between 856 and 910 Btu/(hr)(sq ft)(°F). The results, plotted in polar coordinates, showed a cardioid configuration for MeOH, with the max. coeffs. occurring at the bottom of the tube. The hexane results had the general shape of horizontal ellipses, with max. coeffs. occurring at the sides of the tube.

461. Larson, R. F.

FACTORS AFFECTING BOILING IN A LIQUID, Ind. Eng. Chem 37, 1004-09 (1945).

The phenomena of liquid superheat and of nucleate and film boiling in connection with heat transfer are reviewed. On the basis of wettability or interfacial free adhesion energy, a theory for the solid ebullator is evolved. An apparatus to test the theory is described, and various solids are tested for the ebullition property.

462. Larson, R. F.

FACTORS THAT INFLUENCE HEAT TRANSFER IN BOILING, CF-52-8-178 (1952), 56 p.

The attack upon the problem of how heat is transferred from a heated surface upon which a liquid is boiling has followed conventional and traditional lines set up by fluid film and convective flow theory. The use of the usual parameters has been only partially successful in correlation and prediction of boiling coefficients. A better understanding and a recognition of the mechanism involved is needed.

This article drawn from numerous sources and observations is an attempt to describe the mechanism and to indicate the direction in which effort should be expended.

463. Layman, D. C.

HEAT TRANSFER TEST PROGRAM EVALUATION FLOW STABILITY IN NUCLEATE SURFACE BOILING, KAPL-M-SAR-RES 2 (1955), 7 p.

The need for data permitting an evaluation of coolant flow disturbances in the Submarine advanced reactor core due to nucleate surface boiling is discussed.

464. Levy, S.

GENERALIZED CORRELATION OF BOILING OF HEAT TRANSFER, ASME Trans. J. of Heat Transfer, 81, 37-42 (1959).

A generalized equation to describe surface boiling of liquids is derived. The expression which correlated all fluid independently of pressure and heating surface-fluid combination is

$$\frac{Q}{A} = \frac{k_L C_L \rho_L^2}{\sigma T_s(\rho_L - \rho_V)} \frac{1}{B_L} (\Delta T)^3$$

The form of the relation was obtained from a simplified model of heat transfer to the bubbles close to the heated surface. The coefficient B_L, determined empirically was found to be a function only of the product $\rho_V h_{fg}$ and is shown in Fig. 4.

Good agreement between test results and the derived equation was obtained for pool boiling and nucleate boiling heat transfer of subcooled and vapor-containing liquids.

465. Lieberman, E., and Hopkins, W. E.

PROGRAM FOR THE INVESTIGATION OF CORROSION AND CRUD DEPOSITION UNDER NUCLEATE BOILING, WAPD-A1W(PCh)-69.

466. McAdams, W. H., et al.

HEAT TRANSFER FROM SINGLE HORIZONTAL WIRES TO BOILING WATER, Chem. Eng. Prog., 44, 639-646 (1948).

Heat-transfer data were obtained for water boiling at 1 atm. on electrically heated horizontal Pt wires ranging in diam. from 0.004 to 0.024 in. The Pt served both as the heat-transfer surface and as a resistance thermometer. By use of Pt potential taps of small diam. the central portion of the heat-transfer wire was isolated as a test section; this minimizes end effects. Contamination due to electrolysis was avoided by using a special neg. electrode for deposition of metallic ions. A special technique was developed for obtaining uniform film boiling and avoiding burnout of the wire. For Δt from 4 to 10°F, the results were roughly equal to those predicted for natural convection. For Δt from 17 to 42°F, the d. of heat flux rose rapidly with increase in Δt, reaching a peak value of 380,000 Btu/(hr.)(sq.ft.) independent of wire diam., except for the smallest wire which gave 210,000. For Δt from 1350 to 2550°F, the convection coeffs. of heat transfer through the vapor film ranged from 110 to 310. The largest flux d. was obtained with the smallest wire (580,000 at Δt of 2340°F), and was 2.8 times the peak d. for this 0.004-in. wire. In the range of nucleate boiling, exploratory runs with a dirty 0.0117-in. Pt wire showed that peak flux d. increased from 400,000 Btu/(hr.)(sq.ft.) at 1 atm. to 2,100,000 at 83 atms.

467. McEwen, L. H., Batch, J. M., and Toyoda, K. G.

TECHNICAL NOTE ON GENERALIZATION OF BOILING CURVES, HW-42469C (1956).

468. McFadden, P. W., and Grassmann, P.

THE RELATION BETWEEN BUBBLE FREQUENCY AND DIAMETER DURING NUCLEATE POOL BOILING, Intern. J. Heat and Mass Transfer, 5, 169-73 (1962).

Data concerning the frequency and diameter with which bubbles leave a given bubble site in nucleate pool boiling are presented. The data were obtained from a boiling study of liquid nitrogen. It is shown that the existing correlation relating the frequency and diameter does not predict the data. From a dimensional analysis coupled with available experimental data a new relationship was developed, viz. f. $D^{1/2}$ = const. A simple force balance on the departing bubble is shown to indicate the same result.

469. McLean, E. A., Scherrer, V. E., and Faneuff, C. E.

NUCLEATE AND FILM BOILING DUE TO REPETITIVE PULSE HEATING OF SMALL WIRES IMMERSED IN WATER, TID-7529(pt.1) (p. 227-247), 1956. In Reactor Heat Transfer Conference (1956), J. E. Viscardi, comp.

As part of a program to study heat transfer problems related to nuclear reactors, basic studies of transient boiling phenomena were made using high speed photography coupled with model type experiments. All the data reported here are obtained by passing repetitive, short-duration (1 μ-sec) electrical pulses through small wires immersed in a pool of water at atmospheric pressure and observing the resulting transient boiling processes. A special "ordered sampling" photographic technique enables effective camera framing rates up to 500,000 fps to be obtained, such that previously unresolved initial stages of boiling are observed. Although the temperature distribution for such fast effects has not been determined, the energy per pulse has been measured in most cases. Data are reported on the effect of pulse energy and ambient water temperature on bubble frequency, bubble velocity away from the heating surface, bubble lifetime, vapor volume, bubble growth curves and the transition to film boiling.
9 references.

470. McNelly, M. J.

A CORRELATION OF THE RATES OF HEAT TRANSFER TO NUCLEATE BOILING LIQUIDS, Journal of the Imperial College Chemical Engineering Society, 7, 18-34 (1953).

The mechanism of nucleate boiling (I) is examd. and a dimensional analysis of available data with corrections for condition of the heating surface results in the following dimensionless relation for the entire range of I: $Nu = 0.225\ (Pr)^{0.69}(Re)^{0.69}\cdot(Pd/\sigma)^{0.31}\ ((\rho L/\rho v) - 1)^{0.33}$ where Nu is the Nusselt no., Re is a Reynolds no. based on the mass flow to the heating surface for vaporization, P is the abs. pressure in lb./sq. ft., d is a shape factor for the bubbles in ft., σ is the interfacial tension in lb. force/ft. and ρL and ρv are the liquid and vapor ds., resp., in lb./cu. ft. (CA(54) 13286b)

471. Magladry, R.

TRANSIENT NONCONDUCTIVE HEAT TRANSFER AND STEAM FORMATION, MND-E-2155 (1959), 45 p.

The rates of nonconductive heat transfer and steam formation associated with transient local boiling in pool reactors are examined by use of macroscopic temperature and pressure measurements. The results can be used to provide conservative bases for operation or design limitations on the transient behavior of reactors having pumped flow. Measurements were made at the SPERT I facility using SM-1 type fuel elements. Results are tabulated.

472. Merte, H., Jr., and Clark, J. A.

POOL BOILING IN AN ACCELERATING SYSTEM, Trans., ASME, Series C, J. Heat Transfer, 83, 233-42 (1961).

A study is reported of the influence of system acceleration (1 to 21 g) on pool boiling heat transfer using distilled water at approximately atmospheric pressure. The acceleration of the system is such that the resulting force field is normal to the heating surface, thereby increasing the buoyant forces acting on the vapor bubbles. Heat-flux rate is varied from approximately 5000 Btu/hr-ft^2 (non-boiling) to 100,000 Btu/hr-ft^2. Data are presented for the influence of subcooling with the boiling system under acceleration at the lower values of heat flux. A preliminary analysis is presented for a theoretical description of the process of boiling under the influence of high acceleration, including the simultaneous effect of natural convection.

473. Mesler, R. B.

THE EFFECTS OF SUPERATMOSPHERIC PRESSURES ON NUCLEATE BOILING, Thesis, Univ. of Mich. (1955).

474. Michenko, N.

ON THE PROBLEM OF HEAT TRANSFER IN NUCLEATE BOILING, Energomashinostroenie, No. 6, 17 (1960).

475. Mixon, F. O., Jr., Chon, W. Y., and Beatty, K. O., Jr.

THE EFFECT OF ELECTROLYTIC GAS EVOLUTION ON HEAT TRANSFER, Chem. Eng. Prog., 55, 49-53 (1959).

As part of a long-range study of the mechanism of heat transfer in boiling, the effect of electrolytic bubble generation on the heat transfer coefficients between a horizontal copper surface and a pool of stagnant water was measured. The metal surface was pure copper about 2. in. by 2 in. and faced upward 10 in. below the liquid surface.

Temperature of the block was varied by the use of electrical resistance heaters. Electrolysis was carried out by application of a direct current between the copper heating surface and a large anode located some distance from this surface. Small amounts of sodium hydroxide were added to the water to facilitate the electrolysis. The temperature of the heating surface was varied from room temperature up to 310°F., and the bath temperature was held approximately constant at 80° to 100°F.

Electrolysis current was varied from 0 to 545 amp./sq. ft. Material enhancement of heat transfer coefficients was noted with the electrolytically generated bubbles when the surface temperature was both below and above the boiling point of water in the bath.

Interpretation of the data is made with special reference to its contribution to heat transfer in the cooling of nuclear reactors where liquids may be subjected to surface temperatures in excess of their boiling points.

476. Miyauchi, Terukatsu and Yagi, Sakae

NUCLEATE BOILING HEAT TRANSFER ON A HORIZONTAL FLAT SURFACE, Kagaku Kogaku 25, 18-30 (1961).

The film-coeff. was detd. of boiling heat-transfer on a horizontal, flat surface which was specially machined to make artificial ebullition points (A.E.P.) for bubble formation. The A.E.P. played the role of active sites for bubble-formation and the no. of A.E.P. per unit surface area was observed to affect the values of the coeff. noticeably. The expts. were carried out over the range of A.E.P. from zero to 64/sq. cm. The data obtained on the surface with A.E.P. of 32 per sq. cm. were correlated by the relation: $(h/k) = \alpha\ (q\rho_l/\gamma\mu\rho_v)^{.074}\ (\rho_v/\rho_{v_0})^{.069}\ (c\mu/k)^{.063}$, where h is the boiling heat-transfer coeff., k is the liquid thermal cond., q is heat flux, ρ_l is d. of liquid, ρ_v is d. of satd. vapor, ρ_{v_0} is value of ρ_v at atm. pressure, γ is latent heat of vaporization, μ is abs. viscosity of liquid, and c is sp. heat of liquid. α has a value of 1.33 ±0.09 in m.$^{-0.26}$. In general, the value of the factor α depends on the properties of the liquid and the condition of the surface, and may be considered a measure of ebullition ability of heating surfaces. The data on ordinary surfaces at atm. pressure were well correlated by the above relation with different values of α. The authors classified the boiling liquids used statistically into three groups, i.e., water, aq. soln., mainly alcs., and others.

477. Moissis, R., and Berenson, P. J.

ON THE HYDRODYNAMIC TRANSITIONS IN NUCLEATE BOILING, American Society of Mechanical Engineers, New York, Preprint Paper No. 62-HT-8 (1962), 6 p.

The two hydrodynamic transitions which take place in nucleate boiling off a horizontal surface are described. The first, which is governed by continuity considerations, results in a change in the vapor removal process from an intermittent to a continuous one. The second, which is a result of a Taylor-Helmholtz instability, determines the maximum ("burnout") heat flux. Equations are presented which predict with good accuracy the two transition heat fluxes.

478. Moore, F. D., and Mesler, R. B.

THE MEASUREMENT OF RAPID SURFACE TEMPERATURE FLUCTUATIONS DURING NUCLEATE BOILING OF WATER, A.I.Ch.E. Journal 7, 620-24 (1961).

The surface temperature during nucleate boiling was measured with a special thermocouple so designed as to measure the temperature of a small area and to have an extremely rapid response time. The surface temperature was found to drop occasionally 20 to 30°F in about 2 msec during the boiling of water. This indicates a rapid extraction of heat during a short time interval. The significance of this observation is that it provides an important new clue to an understanding of nucleate boiling. A hypothesis is advanced to explain these observations.

479. Nesis, Ye. I.

THE EFFECT OF ULTRASONIC WAVES ON THE BOILING UP OF LIQUIDS, Referativnyy zhurnal, Fizika, no. 5, 1962, 46, abstract 5G422 (V sb. "Primeneniye ul'traakust. k issled. veshchestva," no. 13, Moscow, 1961, 115-122)

The start of the process of boiling in a liquid - the boiling up, is characterized by the formation of a great number of nuclei in the liquid, i.e. of steam or gas bubbles which grow and rise to the surface of the liquid. Sound waves propagating in this liquid accelerate the boiling up process. An analysis of the equilibrium conditions of the bubbles in presence of a sound wave demonstrates that the periodical changes of pressure in the sound wave lead to the decrease of the critical radius of the nuclei, i.e., to the increase in the number of nuclei, which have a tendency to unlimited growth. The radius of the critical nucleus enters in the exponent, which characterizes the boiling rate. Hence a sharp increase of the boiling rate can be caused by a small decrease of the critical nucleus.

480. Nevstrueva, E. I., and Gonsales, Kh.

DETERMINATION OF STEAM CONTENT DISTRIBUTION DURING SURFACE BOILING OF WATER BY MEANS OF β RADIATION, Teploenergetika 7, 34-9 (Sept. 1960).

Technique and results of experimental study on distribution of steam and liquid phases near surface of liquid not heated up to saturation temperature.

481. Nishikawa, K.

HEAT TRANSFER IN NUCLEATE BOILING, Mem. Fac. Eng. Kyushu Univ. 16, 1-28 (1956).

The effect of liquid level on the heat transfer in nucleate boiling is examined over ranges of 5-450 mm., the coefficient of heat transfer, α, and the temperature distribution of boiling liquid being determined at various levels of: distilled water, 30% sugar solution, EtOH, and CCl_4. It is found that α remains essentially constant when the liquid level is above a certain limit. The distance from the heating surface to this limiting liquid level is termed the "effective stirring length of bubbles" and is proportional to $Rv(\gamma/\sigma)^{3/4}$, where R is the radius of the heating surface, v the kinematic viscosity, γ the sp. wt., and σ the surface tension of the liquid. The concept is used to develop equations which correlate α values for nucleate boiling under various conditions of heating surface and of pressure. (CA 51:6237).

482. Nishikawa, K.

NUCLEATE BOILING HEAT TRANSFER OF WATER ON THE HORIZONTAL ROUGHENED SURFACE, Mem. Fac. Eng. Kyushu Univ. 17, 85-103 (1958).

The effect of surface roughness on the transfer of heat from brass plates to surrounding water has been studied. Full exptl. details are given.

483. Nishikawa, K., and Urakawa, K.

NUCLEATE BOILING UNDER REDUCED PRESSURE, Mem. Fac. Eng., Kyushu Univ. 19, 63-71 (1960).

The mechanism of nucleate boiling was detd. from expts. with distd. H_2O at 0.4, 0.423, 0.7, 0.9, and 1.033 kg./sq. cm. abs., and heat fluxes of 9000-30,000 kcal./sq. m. hr. in an app. similar to Jakob's (J. and Fritz, CA 26, 1679), with minor modifications of the heating surface. Bubble agitation of the liquid is the dominant factor affecting heat transfer in nucleate boiling, and the coeff. of heat transfer increases in proportion to the 0.4th power of the pressure of boiling H_2O. The mechanism of bubble formation is quant. explained with data from oscilloscope photographs.

484. Nishikawa, K., and Yamagata, K.

ON THE CORRELATION OF NUCLEATE BOILING HEAT TRANSFER, Internat. J. Heat Mass Transfer (GB), vol. 1, No. 2-3, 219-35 (Aug. 1960).

A generalized equation to describe nucleate boiling is derived. The expression which correlates all fluid independently of pressure and heating surface-fluid combination is as follows:

$$Y = 8.0(f_\zeta^{1/2} f_p X)^{2/3}$$

where

$$X = \left(\frac{1}{M^2 P \lambda \sigma r \gamma''} \frac{c_p \gamma'^2}{} \right)^{1/2} R^{3/2} q$$

$$Y = \frac{\alpha R}{\lambda}$$

and c_p = specific heat of liquid; γ' and γ'' = specific weight of liquid and vapour; λ = thermal conductivity of liquid; σ = surface tension of liquid; R = the representative length of heating surface; q = heat flux; α = coefficient of heat transfer; M = 900 m^{-1}, P = 1.699 kcal/hr. f ζ = foamability, and f_p = pressure factor. Furthermore, it is indicated that this correlating equation is applicable to forced-convection saturated or surface boiling. The proposed correlating equation is theoretically sought by analysing the elementary processes of phenomena, but it is not based on dimensional analysis. In order to reach the final solution of the problem, it is necessary to analyse the elementary processes of boiling phenomena and elucidate the relations underlying the problem. (SA 61 18676).

485. Otterman, B.

PHOTOGRAPHIC STUDY OF BUBBLE DIMENSIONS AND BOILING ACTION ON Hg AND STANDARD ENGINEERING SURFACES, Proc. Heat Transfer Fluid Mech. Inst., 185-96 (1962).

A series of expts. was conducted, in which H_2O and iso-PrOH were heated on clean and dirty Hg surfaces. At superheats attained, nucleation characterized by the repetitive formation and release of bubbles from a specific spot on the heater surface did not occur on clean Hg surfaces. Total heat transfer occurred by natural convection. Liquids heated on a dirty Hg surface exhibited nucleate boiling at superheat typical of com. surfaces. Surface irregularities are probably responsible for initiating and sustaining nucleate boiling. Nucleate boiling of H_2O and iso-PrOH at low and intermediate heat fluxes from com. available metal surfaces was investigated. Bubble diams. and contact angles at breakoff were measured. The Fritz equation (Physik. Z. 36, 379(1935)) can be used only to correlate bubble diam. at low values of the heat flux. At intermediate values of the heat flux most individual bubbles coalesced while still attached to their resp. nucleating centers, or immediately after detaching from the heater surface. A correlation for noncoalesced bubble diam. must include the effects of bubble drag at departure. (CA 62 13573b).

486. Paschkis, V., and Stolz, G., Jr.

RESEARCH AND DEVELOPMENT WITH RESPECT TO HEAT TRANSFER IN QUENCHING, Final Report, Dec. 16, 1955 to Dec. 15, 1961, Columbia U. Heat and Mass Flow Analyzer Lab., New York (1962), 52 p., AROD-1540:6.

This final report contains a summary of the results obtained in a program aimed at the determination of heat transfer coefficients from experiments under controlled conditions and at the correlation and generalization of the experimental results. In terms of heat transfer theory, most of the experiments fall in the category of transient subcooled pool boiling. The three major types of boiling (nucleate, unstable and stable film) are discussed. A unique method for investigating boiling phenomena (the only method of obtaining data on unstable film boiling of subcooled water in a pool) is described. The experimental and computational methods used in this study are presented.

487. Pendergast, M. S., Jr.

REACTOR SHUTDOWN BY NUCLEATE BOILING, PART I. SURFACE AREA IN NUCLEATE BOILING, KAPL-M-MSP-1 (1956), 58 p.

The problem to be solved is that of determining the conditions under which a reactor such as S3G/S4G, which accidentally has reached a fast period, may be controlled by the use of nucleate boiling, without either rod burnout, bulk boiling, or metallurgic phase change of the fuel. This report deals primarily with determining the surface area of a rod which is in nucleate boiling, and is therefore only a first step in the over-all problem.

488. Pike, F. P., Miller, P. D., and Beatty, K. O.

EFFECT OF GAS EVOLUTION ON SURFACE BOILING AT WIRE COILS, Chem. Eng. Progr. Symposium Ser. 51, No. 17, 13-19 (1955).

The effect of gas evolution on surface boiling was investigated experimentally by use of water and glycerol with dissolved air and CO_2. The presence of a dissolved gas was found to initiate surface boiling at lower surface-to-liquid temp. differences than did degassed liquids. The satn. temp. of the gas-liquid soln. was found to be controlling. The results support the hypothesis that the marked effectiveness of surface boiling is the result of mech. action rather than latent heat effects. (CA-50-623g).

489. Pinchera, G. C.

CRITICAL HEAT FLUX IN POOL BOILING-EFFECT OF GEOMETRY AND HEATER CHARACTERISTICS, NAA-SR-Memo-6928 (1961), 37 p.

A comparative study was initiated to check the consistency and reliability of the suggested mechanisms and correlations for pool boiling on the basis of available experimental data. As the data present a high degree of scattering, the contribution to this scatter by such parameters as geometry and heater characteristics was investigated. Geometrical parameters such as orientation of the heating surface, heater size, liquid level, boiler shape and size, and heater characteristics such as material, roughness, aging and cleanliness of the surface, and thermal characteristics were considered. The critical heat flux in pool boiling depends essentially on the coolant properties. Another parameter that has some influence is the heater geometry. The size of the heater and, for very thin walls, the thickness have a definite effect on the critical heat flux. Horizontal and sufficiently long vertical tubes seem to give essentially the same values. Some increase in the critical heat flux appears to occur along with the fouling of the heating surface. The critical heat flux is essentially independent of the material for most cases, but inexplicably high values were observed for some materials.

490. Preckshot, G. W.

THE EFFECT OF CHEMICAL NATURE OF HEATING SURFACES ON THE HEAT TRANSFER COEFFICIENTS OF POOL BOILING LIQUIDS, AECU-3183, Final Report for February 1952-June 1955 (61 p.).

An investigation was made of the effect of the chemical nature of the heat transfer surfaces on the boiling heat transfer coefficients when the boiling takes place from a pool. Apparatus and procedures were developed for an understanding of the boiling process. Metallic surfaces of Au and Ag were uniformly placed on Cu wires by vapor methods. An apparatus for the determination of surface energies using gravimetric vapor absorption isotherm measurements was assembled. Finely divided metallic powders of two surfaces (Cu, Ag) to be used for the boiling studies were prepared for the surface energy measurements.

491. Rallis, C. J., Greenland, R. V., and Kok, A.

STAGNANT POOL NUCLEATE BOILING FROM HORIZONTAL WIRES UNDER SATURATED AND SUBCOOLED CONDITIONS, S. African Mech.Engr. 10, 171-86 (1961).

Experiments indicate heat flux variable in nuclear boiling heat transfer, is accounted for by natural convection from undisturbed surface plus transport of latent heat from surface by bubbles; general equation for saturated and subcooled boiling was found; frequency of bubble emission is proportional to cube of liquid superheat.

492. Rockow, R. A.

SURVEY OF THE LITERATURE PERTAINING TO THE PHENOMENA OF NUCLEATE BOILING, NAA-SR-MEMO-4160 (1957), 27 p.

A literature survey is presented to consolidate and summarize the information presently available in the area of nucleate boiling heat transfer. Effort was employed to present as much information about organic boiling heat transfer characteristics as presently available.

493. Rohsenow, W. M., Somna, E. H., and Osborn, P. V.

CONSTRUCTION AND OPERATION OF APPARATUS FOR STUDY OF HEAT TRANSFER WITH SURFACE BOILING, Mass. Inst. of Tech., NP-3543 (1950), 63 p.

A detailed description is given of test apparatus designed and constructed to study the effects of surface boiling on heat transfer to water flowing in a tube under the following conditions; water pressures up to 2000 psia, water velocities up to 40 ft/sec, and water bulk temperatures up to 550°F. The apparatus is a closed system consisting of a vertical test section of pure Ni, a Hayward-Tyler centrifugal pump, a calibrated orifice, a heat exchanger, and a pressure vessel. A discussion is given of operating techniques, data measurements, and calculating procedure, with derivations of formulas, calibration of instruments, and other experimental determinations. A series of photographs which record the dismantling of the Hayward-Tyler centrifugal pump for cleaning is presented. They indicate very clearly the source of the contamination which has led to a continual deposition of scale on the inside of the test section, apparently due to an electroplating of ferric ions. Cleaning of this scale has proved to be exceedingly time consuming, and an ion exchange to trap the objectionable ions is to be added to the circuit. (NSA-1443).

494. Rohsenow, W. M.

A METHOD OF CORRELATING HEAT TRANSFER DATA FOR SURFACE BOILING OF LIQUIDS, TECHNICAL REPORT NO. 5, NP-3443 (1951), 27 p.

A method is presented whereby heat-transfer data for pool boiling in the nucleate region of a liquid on a clean surface can be correlated. A Reynolds no. and a Nusselt no. both based on the bubbles receding from the heating surface were defined and incorporated along with the Prandtl no. into a mathematical relation. The proposed relation was applied to experimental data from the literature. 16 references.

495. Rohsenow, W. M.

A METHOD OF CORRELATING HEAT-TRANSFER DATA FOR SURFACE BOILING OF LIQUIDS, Trans. ASME 74, 969-76 (1952).

A method (and a math. equation) based on a logical explanation of the mechanism of heat transfer assocd. with the boiling process is presented for correlating heat-transfer data for nucleate boiling of liquids for the case of pool boiling. (CA-46-8426e).

496. Rohsenow, W. M.

HEAT TRANSFER ASSOCIATED WITH NUCLEATE BOILING, Heat Transfer and Fluid Mechanics Institute, Stanford Univ. Press, Stanford, Calif., p. 123 (1953).

497. Rohsenow, W. M., and Griffith, P.

CORRELATION OF MAXIMUM HEAT TRANSFER DATA FOR BOILING OF SATURATED LIQUIDS, Chem. Engrg. Progress Symposium Series 52, No. 18, 47 (1956).

Since it was observed that bubbles "shoot" away perpendicularly from vertical surfaces, it appears that gravity should perhaps not have a significant effect on the peak heat-flux values. The correlation method proposed here is based on reasoning similar to that used in the development of the boiling heat transfer correlation employing the concept of a bubble Reynolds number.

498. Ruckenstein, E.

HEAT TRANSFER IN THE CASE OF BOILING, Acad.Rep Populare Romine Inst.Energet., Studii Cercetari Energet, 8, 15-20 (1958).

The transmission of heat between the liquid and moving bubbles in the case of boiling is analyzed under conditions of free convection. The heat exchange

between the bubbles and the small part of the liquid which remains in contact with the bubble during an interval of time τ is considered. An expression for the coefficient of heat transfer is obtained which gives values in agreement with experimental data.

499. Ruckenstein, E.

HEAT TRANSFER BETWEEN VAPOR BUBBLES IN MOTION AND THE BOILING LIQUID FROM WHICH THEY ARE GENERATED, Chem. Eng. Sci. 10, 22-30 (1959).

The mechanism of heat transfer between a boiling liquid and vapor bubbles in motion is discussed. Heat-transfer coeffs. of approx. 3000 Btu/hr/sq ft/ degree F. which have been exptl. observed in boiling water are explained.

500. Ruckenstein, E.

MECHANISM OF BOILING HEAT TRANSFER, Acad. Rep. Populare Romine, Studii Cercetari Chim. 7, 117-23 (1959).

A new model is proposed which takes into account the heat transfer from a heating surface to liquid layers in its vicinity by means of turbulent cond., in addn. to mol. thermal cond. The former mode of transfer is due to the mixing of the liquid layers by vapor bubbles which are formed and grow on active centers on the heating surface. The replacement of elements of the liquid near the surface, caused by bubbles which sep. from the active centers, is also considered.

501. Ruckenstein, E.

A PHYSICAL MODEL FOR NUCLEATE BOILING HEAT TRANSFER FROM A HORIZONTAL SURFACE, Bul. inst. politeh. Bucuresti 23, 79-85 (Jul-Sept. 61)(In English).

An equation for the heat transfer coefficient from a horizontal surface is established on the basis of a physical model for the nucleation and hydrodynamical process.

502. Sabersky, R. H., and Gates, C. W.

ON THE START OF NUCLEATION IN BOILING HEAT TRANSFER, Jet. Prop. 25, 67-70 (1955).

Experiments designed to show whether pressurization treatment would affect boiling of liquid in presence of metallic heating surface; with properly cleaned vessel and heating surface, nucleation point may be significantly delayed by subjecting water and vessel to pressurization treatment.

503. Scorah, R. L.

HEAT TRANSFER FROM HOT METAL TO BOILING WATER, Heat Transfer Lectures, Vol. I, Fairchild Engine and Airplane Corp., NEPA Division, NEPA 804 (p. 121-133) (1948), 279 p.

Some experiments with Ni, W, chromel A, and chromel C wires are described. Boiling curves were determined over a wide range of metal surface temperatures, and heat-transfer coefficients were calculated for various temperature differences. Data were taken at atmospheric and at elevated pressures.

504. Semeria, R.

METHOD FOR DETERMINATION OF POPULATION OF CENTERS GENERATING BUBBLES ON HEATED SURFACE IN BOILING WATER, Acad des Sciences - CR 252 no. 5, 675-7 (1961).

In study of ebullition it is very important to know evaluation of population of centers generating bubbling as function of temperature of superheating, pressure, nature of surface and liquid; using thin electrical conductors it was possible to count more than 10 centers/sq mm.

505. Shcherbakov, V. K.

SPECIAL PROPERTIES OF HEAT TRANSFER THROUGH A WALL WITH LONGITUDINAL RIBS, WITH SURFACE BOILING OF THE COOLING LIQUID, Soveshchaniye po teplo- i massoobmenu. Minsk, 1961. Tezisy dokladov i soobshcheniy (Dopolneniye), 43 (Also available in NP-tr-827 (p. 59) English Translation).

Theoretical and experimental investigations of the properties of heat transfer through a wall with longitudinal ribs, with surface boiling of the cooling liquid, the heat flow exceeding 10^6 kcal/$m^2 \cdot h$, are important for the correct design of heat exchange devices. The general condition of utility of ribs is $1/\alpha_g F_g > (1/\alpha_r F_r) + \Phi_r$, Φ_r being the thermal resistance of the body of the rib. An approximate equation has been obtained for temperature distribution on the smooth surface at the base of a rib: $\theta_g = (\theta_0 - q_g/\alpha_g) \exp(-x\sqrt{(\alpha_g/\delta_g \lambda)}) + q_g/\alpha_g$ [Abstracter's note: Indices g and r are transliterated as no quantity except the one above is defined] Verification of the equation obtained and experimental determination of the magnitude of θ_0 was carried out by the method of electro-thermal analogy. The results of the experiment are plotted, a comparison of theoretical and experimental data is given. In the presence of strengthening ribs in heat exchange devices operating under large heat loads, it is necessary to take into account the possibility of increase of the density of heat flow at the base of ribs which should be less critical for an equally smooth surface under given conditions of cooling. [Abstracter's note: Complete translation].

506. Styushin, N. G.

NEW RESULTS IN THE INVESTIGATION OF HEAT TRANSFER IN THE CASE OF SURFACE BOILING, Translated from: Tezisy Dokladov i Soobshchenii na Soveshchanii po Teplo-i Massoobmenu, Minsk, NP-tr-827, June 5-9, 1961 (p. 71-2).

The heat transfer intensity in surface boiling depends on the number of existing steam-formation centers and hence on the saturation temperature. The point at which steam formation begins to affect the heat transfer (intensive boiling) is established at a certain flow temperature which bounds the region of intensive boiling from below. In the region of

intensive surface boiling, flow temperature has no effect on the number of existing steam-formation centers. The heat transfer coefficient is the same as that calculated with the Sterman formula for developed boiling.

507. Tien, C. L.

A HYDRODYNAMIC MODEL FOR NUCLEATE POOL BOILING, Internat. J. Heat Mass Transfer (GB), vol. 5, 533-40 (June 1962).

A hydrodynamic model of stagnation flow is proposed for saturated nucleate boiling over a flat surface. Through the established analytical results in axisymmetrical stagnation flow, a relation between the heat-transfer coefficient and the thermal boundary-layer thickness induced by rising bubbles is obtained, and a good agreement with measured results in the low heat-flux region is indicated. The predicted heat-transfer is given as

$$q = cPr^{0.33}kn^{0.5}\Delta T$$

where c is a numerical constant equal to 61.3 as determined from the boiling data of water. The predicted relation is found to be in agreement with boiling data of most liquids. (SA 62 15815).

508. Tochidlovskii, B. I.

FREQUENCY OF BUBBLE RELEASE INTO A BOILING LIQUID, Odessa Technological Institute of the Food and Refrigeration Industry, 5, No. 1 (1952).

509. Tolubinskii, V. I.

THE THEORY OF BOILING HEAT TRANSFER, Izvest. Vysshikh Ucheb. Zavedenii Energet. 2, No. 1, 15-22 (1958).

Heat transfer by convection through bubbles during boiling can be represented by a formula K_0 = const. $K_1^{m_1} K_2^{m_2}$, where K_0 is the Nusselt no. (Nu), K_2 the Prandtl no. (Pr), and K_1 is a specific dimensionless group varying with the type of convection. $K_0 = \alpha\delta/\lambda$, where $\delta = \sqrt{(\sigma/\gamma - \gamma')}$, α is the thermal diffusivity, λ is the thermal cond. of the liquid, σ is the surface tension in kg./m., γ and γ'' are the sp. wts. of the liquid and the vapor, resp., in kg./cu. m. Introducing thermodynamic considerations, the ratios of the vapor velocity to the rate of formation of bubbles and the no. of bubbles formed per hr. are calcd. With this approach, $K_1 = q/r\delta''d_0U$, where q is the heat flux in kcal./sq. m. hr., r is the latent heat of vaporization, d_0 is the diam. of the bubbles, and U is the frequency of bubble formation. From this the following equations are derived: $(\alpha/\lambda)\sqrt{\sigma/(\gamma-\gamma'')}$ = const. $(q/r\,\gamma''d_0U)^{m_1}(\nu/\alpha)^{m_2}$ (ν is the kinematic viscosity coeff.) = Nu = 54 $K^{0.6}Pr^{-0.3}$. This formula has had exptl. confirmation on a series of liquids and solns., on various metal surfaces, at various pressures and heat fluxes, and at various values of the groups K and Pr. Results obtained with Freon 12 are compared to results obtained with H_2O.

510. Usiskin, C. M., et al.

AN EXPERIMENTAL STUDY OF BOILING IN REDUCED AND ZERO GRAVITY FIELDS, J. Heat Transfer 83, 243-53 (1961).

A pool boiling app. was mounted on a counterweighted platform, which could be dropped a distance of 9 ft. By varying the size of the counterweight, the effective gravity field on the equipment was adjusted between 0 and 1. A study of boiling burnout in H_2O indicated that a variation in the crit. heat flux according to the 0.25 power of gravity was reasonable. Consideration of the transient burnout process was necessary to properly interpret the data. A photographic study of nucleate boiling showed how the velocity of freely rising vapor bubbles decreased as gravity was reduced. The bubble diams. at the time of breakoff from the heated surface varied inversely as gravity to the 0.286 power.

511. Van Camp, W. M., and St. Clair, C. R.

BOILING FROM SMALL WIRES WITH EMPHASIS ON TRANSITION PHENOMENA, ASME Paper 54-F-33, June 1954. For meeting Sept. 8-10, 1954.

Investigation of typical "boiling curve;" free convection heat transfer coefficients determined for small horizontal wires submerged in ethyl alcohol at 1 atm; results establish existence of previously observed discontinuity in boiling curve in transition region between free convection and nucleate boiling; curves differed when heat flux values were increased or decreased.

512. van Wijk, W. R., and van Stralen, S. J.

GROWTH RATE OF VAPOUR BUBBLES IN WATER AND IN A BINARY MIXTURE BOILING AT ATMOSPHERIC PRESSURE, Physica, vol. 28, No. 2, 150-71 (Feb. 1962).

The growth rate of vapour bubbles generated on an electrically heated wire in water and in a mixture of methylethylketone and water (4.1% wt of MEK) was studied using a high-speed cine camera. A sharp increase in maximum nucleate boiling heat flux from the heating wire to the boiling liquid was previously observed in this mixture. A smaller growth rate in the mixture than in pure water was expected at the same superheat, as the most volatile component (MEK) is rapidly exhausted in the liquid near the bubble. Further growth is then limited by the relatively slow process of diffusion of MEK towards the bubble boundary. A smaller growth rate was actually observed for free bubbles. Forster and Zuber (Abstr. 5540 of 1954), and independently Plesset and Zwick (Abstr. 5541 of 1954), derived the asymptotic law $r = C_1\delta\sqrt{t}$, in which r (cm) is the radius of a free, spherically expanding vapour bubble in an infinite volume of a superheated pure liquid, C_1 is a constant, δ(°C) the initial superheat of the liquid and t (sec) the time elapsed since first formation of the bubble. The theory predicts C_1 = 0.23 for

water at atmospheric pressure. In the present investigation C_1 = 0.29 was found for ascending free vapour bubbles in water and C_1 = 0.06 in the mixture. However, the initial growth rate of bubbles, attached to the heating surface, was much higher and corresponded to the relatively large wire superheat. Several bubbles were found to vibrate. (SA 62 5217).

513. Viscardi, J. E., ed.

REACTOR HEAT TRANSFER PROGRESS, (Issue) No. 9, NDA-26 (1956), 40 p.

Transient pool boiling due to sudden large heat generation was investigated to study the effect of sudden large power surges on surface boiling and metallic ribbon fuel element burnout. Heat transfer to water from platinum surfaces was studied in finding the time required for initiation of boiling when the surface temperature exceeded boiling. In an investigation of the effect of vertically downward flow on burnout flux, no difference was found in the burnout flux due to the direction of flow. Molten metal-water reaction tests were continued. The temperature distribution in boiling water was determined with liquid heads up to 1 meter and the effect of convection on the temperature distribution was studied.

514. Viskanta,R., and Lottes, P. A.

NUCLEATION AND BOILING FROM A LIQUID-LIQUID INTERFACE, Proceedings of the 1962 Heat Transfer and Fluid Mechanics Institute, held at Univ. of Washington, Seattle, June 1962, Stanford Univ. Press., June 1962.

An experimental investigation of nucleate boiling of saturated water and n-hexane from a mercury surface at atmospheric pressure was made. High-speed motion pictures were also taken. Visual observations revealed that there existed favored locations for bubble formation on the mercury surface, and it was also noted that a nucleation site sometimes became displaced because of agitation and flow currents, even without an intermission in the activity of a site. The superheats required to initiate boiling from a liquid surface were higher than those for boiling from a solid surface. However, boiling usually started at lower superheats than those reported in the literature for static-type measurements because the presence of contaminants and gases absorbed and adsorbed on the mercury surface. The results also showed that the position and slope of the nucleate boiling curve varied with the immediate history of boiling from the liquid-liquid interface.

515. Wallis, G. B.

GAS-LIQUID ANALOGUE OF NUCLEATE BOILING, Nuclear Power 5, 99-101 (Aug. 1960).

Presents a case for the separate considerations of the hydrodynamic and thermal aspects of nucleate boiling.

516. Wallis, G. B.

THE ANALOGY BETWEEN THE BUBBLING OF AIR INTO WATER AND NUCLEATE BOILING AT SATURATION TEMPERATURE, AEEW-R-28 (1960), 21 p.

A basis for separate consideration of the hydrodynamic and thermal aspects of nucleate boiling is discussed. It is shown how boiling phenomena may be simulated in detail by the use of porous media to introduce air bubbles into water. Points of similarity and equivalence are described and analyzed.

517. Wallis, G. B.

TWO-PHASE FLOW ASPECTS OF POOL BOILING FROM A HORIZONTAL SURFACE, Paper No. 3, Symposium (Preprint of Proceedings) on Two-Phase Fluid Flow, Inst. Mech. Engrs., London, England, February 7, 1962.

The flow regimes which occur during one-dimensional vertical two-phase flow are described and analyzed. Criteria for the transition between flow regimes are derived and are used to show that the maximum and minimum heat fluxes in pool boiling from a horizontal surface can be regarded as hydrodynamic phenomena. Experiments are reported in which the dependence of maximum heat flux on fluid properties was accurately reproduced in a two-component system using various gas-liquid combinations.

518. Wallis, J. D.

NUCLEATION FROM A SINGLE CAVITY IN BOILING, MS Thesis ME Dept. MIT (1957).

519. Westwater, J. W.

THE BOILING OF LIQUIDS, Sci. American 190, 64-8 (June 1954).

Recent studies show three types of boiling: nuclear, marked by large rates of heat transfer and rapid formation of bubbles from fixed points; transition, exhibiting poorer heat transfer and random bursts of vapor; and film, showing the poorest heat transfer and complete blanketing of the hot solid with a film of vapor. The best heat transfer is obtained at the dividing line between nuclear and transition boiling. (CA-49-675h).

520. Westwater, J. W., Lowery, A. J., and Framuk, F. S.

SOUND OF BOILING, Science 122, 332-3 (1955).

The sound of boiling is a function of the heat-transfer rate during boiling. It does not increase continuously with the heat flux, but is a function of the temp. difference between the hot solid and the boiling liquid. In this work a horizontal Cu bayonet heater was used to boil MeOH. During nucleate boiling (temp. differences up to 85°F), any increase in the temp. difference increases the heat flux and also increases the sound intensity. (Nucleate boiling is characterized by repeated, systematic bubble formation at

specific locations on the hot solid.) During transition boiling (temp. differences of 85-130°), bubbles form violently and explosively at random locations on the hot tube. The sound increases steadily as the transition region is traversed. Although the sound increases, the heat flux decreases. Above a temp. difference of 130°, film boiling occurs and the sound level is rather uniform. Because the hot solid is blanketed with a film of vapor, no solid-liquid contact occurs and heat-transfer is poor. Hysteresis in boiling curves (heat transfer vs. temp. difference) is supported by sound measurements. (CA-49-15324a)

521. Westwater, J. W.

BOILING OF LIQUIDS, Advances in Chem. Eng., Academic Press Inc., New York, 1, 1-76 (1956).

522. Westwater, J. W., and Strenge, P. H.

ACTIVE SITES AND BUBBLE GROWTH DURING NUCLEATE BOILING, Motion Picture, Univ. of Ill., Urbana, Ill. (1958).

523. Westwater, J. W.

BOILING HEAT TRANSFER, Amer. Scientist 47, 427-46 (1959).

A review with 17 references.

524. Westwater, J. W., and Gaertner, R. F.

POPULATION OF ACTIVE SITES IN NUCLEATE BOILING HEAT TRANSFER, Paper presented at Third National Heat Transfer Conf., A.S.M.E.-A.I.Ch.E., August 1959, Preprint No. 105.

525. Westwater, J. W.

NUCLEATE POOL BOILING. II., Petro/Chem. Engr. 33, no. 10, 53-60 (1961).

Fourteen equations relating variables for nucleate-boiling heat transfer are reviewed and compared.

526. Whitehead, A. L.

AN EXAMINATION OF BUBBLE SIZE FOUND IN LOCAL BOILING HEAT TRANSFER EXPERIMENTS, S.M. Thesis, MIT (1955).

527. Yamagata, K., et al.

NUCLEATE BOILING OF WATER ON THE HORIZONTAL HEATING SURFACE, Reprint from Memoirs of the Faculty of Engineering, Kyushu Univ. 15, No. 1 (1955), also in Japan Sci. Rev. 2, 409-20 (1952).

Nucleate boiling of a pool of water on a horizontal heating surface was investigated by an optical method and thermocouples to det. the thickness of the boundary layer and the temp. difference between the heating surface and the boiling liquid. Photographs of bubble formation on the heating surface revealed that 4 different types of bubbles can be generated in boiling liquids. In the free-convection region (heat fluxes below 9800 kcal./sq.m.hr.), the bubbles formed were uniform in size and either spherical or bell-shaped. There was little turbulence, only a small no. of vapor columns, and very little stirring effect from the rising steam bubbles. In the forced-convection region (heat fluxes greater than 15,000 kcal./sq.m. hr.), the stirring effect of the bubbles formed was important, and great liquid turbulence was evident in the boundary layer. The 2 types of bubbles formed in the forced-convection region were large bubbles with a small one trailing after each large one and multiple or tandem bubbles formed by the coalescence of single bubbles. It was concluded that the most important factor controlling the coeff. of heat transfer for boiling liquids was the stirring effect of the vapor bubbles being formed and not the heat flux or the temp. difference between the heating surface and the boiling liquid. The data indicate that the Nusselt no. is proportional to the cube root of the no. of vapor columns formed in the boiling liquid. (CA-49-5b).

528. Zavoyskiy, V. K.

STEADY BOILING OF A VOLUME HEATED LIQUID, Atomnaya energiya, 10, no. 5, 521-523 (1961).

The present "Letter to the Editor" is connected with an earlier paper (Zavoyskiy, Atomnaya energiya, 10, n. 3, p. 272 (1961)). Some regularities hold for the boiling of a liquid in whose volume heat sources are regularly distributed. It was shown in the previous paper that during steady boiling the radius of a moving vapor bubble is given by $R = (kau)^{1/3}(c\gamma'\Delta Tt/r\gamma'')^{2/3}$, where k is a constant coefficient; γ', c, and a denote, respectively, the density, the specific heat, and thermal diffusivity of the liquid; r is the heat of bubble formation, γ'' the vapor density, u the relative velocity of the bubble in the liquid, ΔT the temperature difference of the liquid and the vapor, and t is the lifetime of the bubble, the time for which the bubble lasts in the boiling liquid. For the derivation of this formula it was assumed that u and ΔT are constant. This relation is now used to determine the distribution of the vapor bubbles according to size. The liquid is assumed to be strongly boiling and therefore in rapid motion so that a mean lifetime of the bubble (independent of the age of the bubble) can be introduced. τ is independent also of the size of the bubble. Further, the probability P(t) is introduced which gives the probability that the bubble does not leave the liquid volume during the time t:

$$P(t)dt = (1/\tau)e^{-t/\tau}dt; \int_0^\infty P(t)dt = 1.$$

If f(R) is the distribution function showing how the bubbles are distributed according to their radii, then on account of $f(R)dR = P(t)dt$:

$$f(R)dR = \frac{3}{2}\alpha R^{1/2}\exp(-\alpha R^{3/2})dR, \text{ where } \alpha = \frac{1}{\tau}\left(\frac{1}{kau}\right)^{1/2}\left(\frac{r\gamma''}{c\gamma'}\right)\frac{1}{\Delta T}.$$

Since α is constant one obtains for the most probable bubble radius: $R_{prob} = (1/3\alpha)^{2/3}$. If the new variable $x = R/R_{prob}$ is introduced there results:

$f(x)dx = \frac{1}{2}x^{1/2}\exp(-\frac{1}{3}x^{3/2})dx$ with $\int_0^\infty f(x)dx = 1$.

That is, if the most probable radius of the bubble is known the distribution function of the bubbles in size is also known. The ratio of the average to the most probable radius is given by: $\bar{R}/R_{prob} = \bar{x} = 3^{2/3}\Gamma(1+2/3) \simeq 1.87$. The ratio of the total surface of the bubbles to their total volume is given by

$S/V = \frac{4\pi\bar{R}^2 n}{\frac{4}{3}\pi\bar{R}^3 n}$, where n is the number of the bubbles.

Approximately, $S/V \simeq 0.86/R_{prob}$. The validity of this formula was checked by an instrument described in the previous paper mentioned above. There are 3 figures and 1 Soviet-bloc reference. English Translation in: Soviet Journal of Atomic Energy, 10, 513-515 (1962).

529. Zuber, Novak

REPORT ON BOILING HEAT TRANSFER (Russian Review), AECU-3569 (1957), 7 p., Heat Transfer Research Laboratory, Columbia Univ., N. Y.

A brief compilation is made of Russian papers on boiling heat transfer and two-phase flow.

530. Zuber, Novak

ON THE STABILITY OF BOILING HEAT TRANSFER, Trans. ASME 80, 711-20 (1958) (also paper No. 57-HT-4).

Boiling heat transfer in the nucleate region is reviewed. The transition film-boiling region is analyzed by considering the stability of a plane vortex sheet separating two inviscid fluids. Using the classical results of Helmholtz, Kelvin, and Rayleigh, expressions have been derived that predict the maximum and minimum heat-transfer rates in the nucleate and the film-boiling regimes, respectively. The model exhibits the essential features of the phenomenon and shows good agreement with experimental data.

531. Zuber, N., and Tribus, M.

FURTHER REMARKS ON THE STABILITY OF BOILING HEAT TRANSFER, AECU-3631 (1958), 71 p.

An analytical expression is presented which permits the prediction of the maximum nucleate heat flux in pool boiling of saturated or subcooled liquids. The numerical values of the empirical constants which appear in the Kutataladze and Borishanskii criteria for the "burnout" heat flux are derived from the theory. An analytical expression for the empirical function which appears in the correlation of Griffith is also derived. The hitherto unexplored features of transition boiling, i.e., the hydrodynamic instability, the well defined geometrical configuration and the frequency dependence are described, supported by experimental evidence, and used as the basis for the analytical work. The peak heat flux in transition boiling is shown to be limited by the combined effects of Taylor and Helmholtz instabilities; whereas the minimum transitional heat flux is limited by the effect of Taylor instability only.

532. Zuber, Novak

HYDRODYNAMIC ASPECTS OF BOILING HEAT TRANSFER, (Thesis), AECU-4439 (1959), 210 p.

A theoretical analysis is given for 5 aspects of boiling. The analytical model of Bošnjakovic for a bubble growing in a uniformly superheated liquid is extended to include a nonuniform field, and the growth is shown to be a function of the heat flux as well as the superheat. A theory for the diam. and emission frequency for bubbles at a cavity shows both factors to be functions of the cavity diam. A relation is derived showing the superheat and heat flux at which a cavity of stated diam. will nucleate. The max. heat flux is shown to be caused by the same hydrodynamic factors that cause flooding in perforated-plate absorber towers. The min. flux in film boiling is derived from considerations of Taylor instability. Soviet literature is reviewed extensively. 114 references.

533. Zuber, Novak

HYDRODYNAMIC ASPECTS OF NUCLEATE POOL BOILING, PART I. THE REGION OF ISOLATED BUBBLES, Ramo Wooldridge, Div. of Thompson-Ramo-Wooldridge, Inc., RW-RL-164 (1960), 60 p.

The theory of Bošnjakovic and Jakob (bubble growth is limited by the rate of heat transfer) is extended to predict the rate of vapor formation, in steady or transient boiling, with the assumption that the evaporation takes place at the base of the bubble. The predicted values are in satisfactory agreement with experimental results. An analytical expression, in terms of the bubble population, is derived for the velocity of the liquid adjacent to the heating surface. This velocity is used to estimate the heat transfer in nucleate boiling. Experimental data indicate that when bubbles can be considered as isolated, the heat transfer in nucleate boiling is intermittent and bears a similarity to the transfer of heat from a flat plate with boundary-layer formation. Experimental data indicate also that as the vapor void fraction (vapor hold-up) on the heating surface increases, a change occurs in the hydrodynamic conditions of the two-phase system. This change occurs at a heat-flux density well below the critical heat flux. The vapor removal is altered from an intermittent to a continuous process. The mechanism of heat transfer is affected but not the process. An equation is derived for analyzing the relation which exists between the heat-flux density, the liquid-superheat temperature, and the bubble population in nucleate pool boiling. The predicted values are in qualitative and quantitative agreement with available experimental results.

534. Zuber, N., Tribus, M., and Westwater, J. W.

THE HYDRODYNAMIC CRISIS IN POOL BOILING OF SATURATED AND SUBCOOLED LIQUIDS, International Developments in Heat Transfer, Part II. ASME, 1961, p. 230-6.

An analysis of the critical heat flux in pool boiling is presented. The similarity between nucleate boiling and the process of gas bubbling from a porous surface is discussed. The similarity indicates that the critical heat flux corresponds to the hydrodynamic

phenomenon known as "flooding." The problem is formulated by considering the combined effects of Taylor and Helmholtz instabilities on the flow of the two-phase mixture. An analytical expression is derived which permits the prediction of the critical heat flux from a horizontal surface (facing upward) in pool boiling of liquids at saturation temperature or subcooled. The theoretical results are in good agreement with available experimental data.

535. Zysina-Molozhen, L. M.

HEAT TRANSFER WHILE BOILING IN A LARGE VOLUME OF LIQUID, Collection "Za novoe sovetskie energooborudovanie (For a New Soviet Power Plant)" The Central Scientific Research Institute for Boilers and Turbines. (1939).

Pool (See Nucleate)

Surface (See Nucleate)

TRANSITION

536. Bankoff, S. G., and Mehra, V. S.

A QUENCHING THEORY FOR TRANSITION BOILING, Ind. Eng. Chem., Fundamentals, 1, 38-40 (Feb. 1962).

A quenching theory of transition boiling is proposed, which is consistent with Berenson's data. An interesting result is that the thermal boundary layer in the liquid contacting the surface is very much larger than the critical bubble radius for nucleation.

537. Berenson, P. J.

TRANSITION BOILING HEAT TRANSFER FROM A HORIZONTAL SURFACE, NP-8415 (1960), 117 p.

An experiment, utilizing a condensing fluid as the heat source, was performed to determine the heat flux vs. temperature difference curve for transition pool boiling from a horizontal surface. The boiling curve was determined as a function of surface roughness, material, and cleanliness for n-pentane at atmospheric pressure. The results of the experiment show that the liquid contacts the solid heating surface in transition boiling. The burnout heat flux and the film boiling curve are independent of surface properties. For commercial heating surfaces and probably provided that the combination of surface energies which exist do not result in spreading of the liquid on the solid heating surface, the location of the minimum point is independent of surface properties. It is concluded that transition boiling is a combination of unstable nucleate and unstable film boiling alternating at a given location on the heating surface. The heat transfer data in the transition region was found to be correlated by a straight line on log-log graph paper which connects the burnout point and the minimum point. The bubble spacing and growth rates in film pool boiling from a horizontal surface are shown to be determined by Taylor Hydrodynamic Instability for temperature differences near the minimum. An analytical expression for the heat transfer coefficient in film pool boiling from a horizontal surface is derived. Combining this equation with the equation for the minimum heat flux yields an analytical expression for the temperature difference at the minimum, which defines the location of the minimum point. The above equations agree with the experimental measurements made on n-pentane and carbon tetrachloride within ±10%.

538. Donald, M. B., and Haslam, F.

THE MECHANISM OF THE TRANSITION FROM NUCLEATE TO FILM BOILING, Chem. Eng. Sci. 8, 287-94 (1958).

The av. area of heat transfer surface covered by boiling water over a heat flux range from zero to that for onset of film boiling was measured by detg. the resistance between the surface and an electrode immersed in the boiling water. Theory suggests that one-half the heated surface should be covered at the onset of film boiling. A surface-active material added to the water increases film strength, resulting in coverage of a greater area of the surface with bubbles before film boiling starts.

539. Framuk, F. S., and Westwater, J. W.

EFFECT OF AGITATION ON THE CRITICAL TEMPERATURE DIFFERENCE FOR A BOILING LIQUID, Chem. Eng. Prog. Sym. Ser. 52, No. 18, 79 (1956).

Other workers have studied the two ends of the boiling curve and have shown that agitation can increase the heat transfer coefficient for nucleate and film boiling. This work was concerned with the critical temperature difference and the transition region of boiling. Methanol was boiled at atmospheric pressure while being agitated with a 3-in. three-bladed propeller at speeds up to nearly 1,000 rev./min. Heat was supplied by a 6-in. long by 3/8-in. O.D. steam-heated, horizontal, copper tube located within 1 in. of the agitator blades. The critical temperature difference for copper to methanol was about 51°F. and was independent of the degree of agitation. The heat transfer coefficient throughout the entire transition region and also at the critical temperature difference was increased as agitation increased. The maximum increase in heat transfer due to agitation was over 100%. It is now known that agitation can improve the heat transfer coefficient over the entire boiling curve.

540. Goldman, K.

IMPROVED HEAT TRANSFER BY APPLICATION OF CENTRIFUGAL FORCES, ASME-AIChE Heat Transfer Conference, Transient Boiling Session, NDA 2-79 (1958), 7 p.

A series of tests of the application of centrifugal forces to fluids to break up boundary layers, thereby increasing heat transfer coefficients, was conducted. The results indicate that these forces are effective in breaking up vapor films; however, increased velocities appear to be less effective in vapor film breakup. The test apparatus is described, and observations of the flow streams are included, as well as graphs of burnout fluxes vs. pumping power.

541. Hellman, S. K., et al.

COMPILATION OF CURRENT WORK IN TRANSIENT BOILING, WAPD-V(FBE)-25 (1958), 12 p.

A report on progress of work related to boiling bubble dynamics is presented. The information presented was obtained primarily from investigators working in the field of heat transfer and hydraulics. Tabular summaries of work are included along with a list of all papers noted by investigators.

542. Hellman, S. K., Kaminsky, S., and Kupp, R. W.

REPORT ON COMPLETED WORK ON TRANSIENT BOILING, Vitro Engineering Co., New York, NY, WAPD-V(FBE)-115 (1959), 100 p.

The results of an effort toward the ultimate formulation of a function which can be used to predict void volumes during runaway of a pressurized water reactor are presented. The emphasis is on bubble formation and dynamic aspects of the bubble void function relating the built-in parameters such as wall temperatures, flow, and bulk temperature to the void. A literature search was conducted, and the information gained was used to resolve some of the numerous phenomena associated with transient void formations in nucleate boiling. Mathematical analyses are included as well as numerous graphic presentations.

There are 44 entries in the bibliography.

543. Hellman, S. K., Kaminsky, S., and Kupp, R. W.

SECOND COMPILATION OF CURRENT WORK ON TRANSIENT BOILING, Vitro Engineering Co., New York, N.Y., WAPD-V(FBE)-159 (1959), 11 p.

A brief account of the current and projected transient boiling work going on at Atomics International, Ramo-Wooldridge, National Aeronautical and Space Administration, General Electric, University of Illinois, and Massachusetts Institute of Technology is presented. Abstracts of some Japanese papers are presented.

544. Hellman, S. K., Kaminsky, S., and Kupp, R. W.

THIRD COMPILATION OF CURRENT WORK ON TRANSIENT BOILING, Vitro Engineering Co., New York, N.Y., WAPD-V(FBE)-226 (1959), 17 p.

The third and final review on boiling heat transfer and related topics presently being investigated is presented. At North Carolina State College, several experiments were conducted and are planned for a program aimed at controlling variables that affect boiling heat transfer. Abstracts of papers obtained from program participants are included, and data on uniform rod burnout are presented along with data on bubble properties.

545. Lurie, H., and Johnson, H. A.

TRANSIENT POOL BOILING OF WATER ON A VERTICAL SURFACE WITH A STEP IN HEAT GENERATION, J. Heat Transfer 84, 217-24 (1962).

A study was made of the transient heat transfer from a vertically submerged metallic ribbon undergoing a step in Joule heating leading to boiling on its surface. The tests were made in deaerated distd. water at atm. pressure with pool temps. at satn. and 112°F. subcooled, and with heat generation rates per unit of ribbon surface area from nonboiling to 1.6×10^6 Btu/sq. ft. hr. Although the heat capacity of the ribbon is low, the surface temp. overshoot compared to the steady-state temp. is minor with values of less than 10°F. The time required to reach this overshoot, or the time required to reach steady state, is very short and decreases with increasing heat flux. These values are short compared to Goldstein and Eckert (Intern. J. Heat Mass Transfer 1, 208-18(1960) and Siegel, Trans. Am. Soc. Mech. Eng. 80, 347-59(1958)) estimates of the time required to develop the hydrodynamic and thermal boundary layers in natural convection, and indicate that nucleate boiling heat transfer is probably a weak function of the fluid circulation. Some further support for this is evidenced by calcd. transient temps. based on steady nucleate boiling heat transfer which are in reasonable agreement with the measured performance. (CA 62 16355e)

546. Morozov, V. G.

EXPERIMENTAL INVESTIGATION OF THE TRANSITION FROM FILM BOILING TO NUCLEATE BOILING OF A LIQUID ON A SUBMERGED HEATING SURFACE, Inzh.-Fiz. Zh., Akad. Nauk Belorussk, SSR 5, No. 4, 15-19 (1962).

When the heat flux is q_1, only film boiling occurs. If q_1 is decreased to q_2, only nucleate boiling occurs. q_2 is detd. for MeOH (1-21.1 atm.), PhOH (1-24.15 atm.), 95% EtOH (1-31.8 atm.), and CCl_4 (1 atm.) boiling on plates made of strips of Nichrome. The heating surfaces were heated by low-voltage d.c.; $0.190 < q_1/q_2 < 0.320$. The results can be correlated to ±30% by Sterman's method (CA 62 12279d)

547. Rosenthal, M. W., and Miller, R. L.

AN EXPERIMENTAL STUDY OF TRANSIENT BOILING, ORNL-2294, May 1957, 40 p. Also in: Nuclear Sci. and Eng. 2, 640-56 (1957).

An experimental investigation of heat transfer to subcooled water under transient conditions has been conducted. Heat was generated electrically in platinum and aluminum ribbons in such a manner as to produce exponentially increasing heat generation rates which simulated reactor excursions. Surface temperature was measured and the events were photographed with a high-speed camera. The temperature attained by the surface before boiling commenced was determined and the time delay between passage of the boiling point and the beginning of boiling was measured. Heat flux at the beginning of film boiling was obtained. The effects of water temperature, exponential period, and gas concentration were studied. Periods ranged from 5 to 75 milliseconds. The bulk water temperature was varied from 90°F to near the boiling point; in all experiments the water was initially stagnant and at atmospheric pressure.

548. Scherrer, V. E., and McLean, E. A.

WORKING CONFERENCE NO. V: TRANSIENT BOILING HEAT TRANSFER AND FLUID FLOW CHARACTERISTICS, Reactor Heat Transfer Conference, New York, TID-7529 (Part 1) (p 612-621), Nov 1 and 2, 1956.

549. Steinle, H. F.

AN EXPERIMENTAL STUDY OF THE TRANSITION FROM NUCLEATE TO FILM BOILING UNDER ZERO GRAVITY CONDITIONS, p. 208-19 of "Proceedings of the 1960 Heat Transfer and Fluid Mechanics Institute, Stanford University, Calif. June 15-17, 1960." Stanford, Calif., Stanford Univ. Press, 1960.

Drop tests of an electrically heated platinum wire horizontally submerged in a pool of Freon-114 were performed to study the transition from nucleate to film boiling under zero-gravity conditions at atmospheric pressure. The change of the wire temperature as a function of time was recorded by use of an oscillograph and an oscillograph-record camera. The drop distance was nine feet, giving an approximate zero-gravity condition for about 0.75 seconds. Data relating heat flux to temperature difference between heater and liquid were collected and plotted, and were compared with the one-g condition. With the heating rates used in this study, boiling under zero-g started sooner and at a lower heating rate than under one-g, with no or only a very small period of natural convection. Nucleate boiling appeared to be time dependent and was present only for a few milliseconds. Film boiling occurred with repeatability in zero-g, at heat fluxes which would permit only nucleate boiling under one-g.

550. Stock, B. J.

OBSERVATIONS ON TRANSITION BOILING HEAT TRANSFER PHENOMENA, ANL-6175 (1960), 78 p.

A study was made of boiling heat transfer from a horizontal tube to a saturated liquid at atmospheric pressure in the nucleate, transition, and film boiling regions. Particular consideration was given to the beginning and end of the transition boiling region. Two liquids were used, Freon 11 and demineralized water. An attempt was made to determine what changes in the boiling curve can be produced by wide variations in the surface. Both metallic and nonmetallic surfaces were studied. The results indicated: (1) that $(Q/A)_{max}$ for these conditions is almost a constant and is unaffected by a shift of $(\Delta T)_{max}$ of as much as 40°; (2) $(\Delta T)_{max}$ is strongly dependent on surface conditions; (3) that data in the transition region are highly unstable, depending on surface conditions and on wetting properties of the liquid; and (4) that the inception of transition boiling is marked by violent motions of a two phase mixture which alternately approaches and is driven from the heated surface. Thus a vapor film is gradually produced as the surface temperature rises, and stable film boiling is established only when the surface temperature becomes relatively constant, such that: (1) the liquid does touch the surface during transition boiling; (2) there is no unique minimum point; (3) the minimum point does not necessarily mark the dividing line between transition and film boiling; and (4) the criterion for stable film boiling should be the absence of fluctuations in the surface temperature. Heat transfer data for water and Freon 11 in all the boiling regimes are presented.

551. Akselrod, L. S., and Dilman, V. V.

PERFORMANCE OF MESH BUBBLES AT LOW GAS VELOCITIES, Kislorod (Oxygen) Nr 5 (1952).

552. Balandina, O. B., and I. P. Levsh.

INFLUENCE OF SURFACE TENSION ON THE HYDRAULIC RESISTANCE OF A LIQUID LAYER TO BUBBLING, uzbek. khim. zhur. No. 4, 17-24 (1960).

By bubbling air at various rates through water, EtOH, and gasoline, it is shown that the surface tension of the liquid has no influence on the hydraulic resistance of the liquid column, which is the same for all 3 liquids in heights of 50 cm. or more, and within 25% for lower heights. A slight foam layer is formed. With 0.5M aq. EtOH and BuOH solns., there is extensive and continuous foaming, and the hydraulic resistance varies; although these solns. have the same sp. gr. and viscosity as pure water, the change in the hydraulic resistance does not follow the change in the surface tension; the change in the height of the stable foam layer does. With 8 and 25% $Na_2S_2O_2$ solns., foaming is slightly greater than with water, but the foam layer does not continuously increase in height.

553. Barus, C.

GLUE BUBBLES AND PRESSURE THEREIN, Science, 57, 151-54 (Feb 2, 1923).

The interferometer U-gauge previously described has been applied to determine the excess pressure in the interior of bubbles of sugar solutions, molasses, and glue, the bubble in each case passing, by evaporation, from the liquid to the solid state. The surface tension of the film is deduced from the measured excess pressure, and its variation with time plotted. In the case of glue bubbles, the surface tension initially increases, at first slowly and then rapidly, until a maximum value is attained. The surface tension remains constant at this value for an interval of some minutes until the bubble is practically solid. Thereafter, gas leaks through the bubble and the value of the surface tension apparently decreases. The surface tension of a solution of glue is low and constant (about 25 c.g.s. units) until a dilution of the order 0.005 is reached. On further diluting the solution, the surface tension increases very rapidly, the value for a concentration 0.001 being approximately 60 c.g.s. units. (CA-17-1569-2)

554. Binder, R. C.

DETERMINING FALL OR RISE VELOCITY OF SPHERES IN FLUIDS, Chem. and Met. Eng. 51, No. 8, 104-5 (1944).

One relation for computing the settling rates of fine particles in a liquid or gas is called Stoke's law, which can be written: $V = D^2(w_1 - w)/18\mu$, where V is the relative velocity between the sphere and the fluid, D is the diam. of the sphere, w_1 is the sp. weight of the sphere, w is the sp. weight of the fluid, and μ is the dynamic viscosity of the fluid. This equation is limited to laminar flow. Exptl. data on the resistance of spheres for steady flow were organized by expressing a resistance coeff. as a function of the Reynolds no. The following form is customary: $R = C\rho(V^2/2)A$, where R is the resistance to relative motion (as lb.), C is a dimensionless resistance coeff., ρ is the mass d. of the fluid ($\rho = w/g$ where g is the gravitational acceleration), and A is the projected area of the sphere (as square feet). The resistance coeff. C is a function of the Reynolds no. $N = \rho VD/\mu$. Since both C and N are dimensionless ratio, any set of consistent units can be employed. For a steady vertical motion the resistance to relative motion, R, equals the difference between the buoyant force and the weight of the sphere. Considering downward motion of the sphere through stationary fluid as an example of this type we obtain: $B = [2R\rho D^2/\mu^2 A]^{1/2} = NC^{1/2}$ where the left side will be designated as a B no. B is a dimensionless ratio and can be written as: $B = [4D^3w(w_2 - w)/3g\mu^2]^{1/2}$. In a particular problem B is known, but N and C are not known. N and C, however, are coördinates of the established plot of N vs. C. Employing logarithmic scales, then a const. B line is a straight line and requires only two points for plotting because $\log B = \log N + \frac{1}{2} \log C$. A plot of data is given for resistance coeff. C against the Reynolds no. to which const. B lines have been added. In making a velocity calcn., the procedure is to calc. B, follow along a B line to the curve, det. the Reynolds no. and then compute the velocity. The procedure can be used for a wide variety of problems involving different fluids and different velocities. B lines can be easily constructed on other plots of resistance coeffs. vs. the Reynolds no., for example, on plots giving data for bodies of shapes other than spherical, or bubbles, in a fluid. (CA-38-5704-7)

555. Blanchard, D. C.

ELECTRICALLY CHARGED DROPS FROM BUBBLES IN SEA WATER AND THEIR METEOROLOGICAL SIGNIFICANCE, J. Meteorol., Vol. 15, 383-96 (August, 1958).

A modification of Millikan's oil-drop experiment was used to determine the electric charge and radius of drops that were ejected from a bursting bubble at an air-sea water interface. Charge measurements were made of both the natural and the induced charge. Drops of 2 to 20 μ in radius carry natural charges of at least 2×10^2 to 5×10^3 e.s.u., respectively. The induced charges are considerably higher, reaching 10^6 elementary units on drops of 50 μ radius. The sign of the natural charge is positive on drops $\sim<4\mu$. For larger drops both the sign and magnitude of the charge appear to be a function of the depth of water through which the bubble rises. The meteorological significance stems from the fact that rain and snow, as well as whitecaps, can produce great numbers of small bubbles in the surface waters of the oceans. Both laboratory and field work suggest that the majority of these bubbles produce positively charged drops that contribute to the atmospheric space-charge. Of special significance is the fact that, for positive induction fields less than about 25 V/cm, a positive charge is found on the small drops. For fields greater than 25 V/cm the induced negative-charge exceeds the natural positive-charge and so the drops carry a net negative-charge. Consequently, small bubbles breaking at the surface of the sea in the presence of the earth's fair-weather positive

field of about 1 V/cm will produce drops that carry a positive charge. Calculations based on measurements of the bubble spectrum produced by whitecaps indicate that the charge on the drops may, under some conditions, provide a counter-current of the same order of magnitude as the fair-weather conduction current. Thus the sea may be a source as well as a sink for the charge that maintains the earth's positive electric-field.

556. Bond, W. N.

BUBBLES AND DROPS AND STOKES' LAW, Phil. Mag., (7) 4, 889-98 (1927).

Stokes' calcns. for the slow rectilinear motion of a solid sphere through a viscous fluid are extended to fluid spheres. Expts. on the rate of rise of air bubbles in water-glass and in golden sirup, and on the velocity of the fluid in the neighborhood of the bubbles in the former liquid, are in substantial agreement with the prediction that the bubble should rise one and a half times as fast as it would if it were solid. A smaller number of expts. on air bubbles and drops of syrup in castor oil also show reasonable agreement with theory. But those on water bubbles in castor oil indicate an effect due to surface contamination.

557. Bond, W. N., and Newton, D. A.

BUBBLES, DROPS AND STOKES' LAW, Phil. Mag., 5, 794-800 (1928).

The present paper shows experimentally and theoretically that surface tension of the drop or bubble decreases the terminal velocity. For radii less than a critical value the drop behaves as a rigid sphere. After a fairly rapid transition through the critical point the effect of surface tension becomes small. (CA-22-2501-7).

558. Boothe, W. A.

TECHNICAL STUDY OF GAS ENTRAPMENT IN ORIFICES AND IN VERTICAL PASSAGES, KAPL-M-WAB-1 (1953), 43 p.

Mathematical analyses are made of gas bubble entrapment in flow systems for the cases where the bubbles are in a downward flowing section of the loops, pass through flat plate orifices, or pass through slots in flat plates. Included in appendices are conversion of drag coefficient curves, data on the check on bubble drag, force balances on bubbles of various shapes, and minimum pressures for bubbles.

559. Borodkin, V. C.

LABORATORY INVESTIGATIONS OF THE KINEMATIC RAISING OF DEEP WATERS BY MEANS OF AIR BUBBLES, Trudy Leningradskogo Instituta Iizhenerov Vodnogo Transporta, no. 22, pp. 152-165 (1955) (Referativnyi Zhurnal Mekhanicka, no. 1, 1957, Rev. 720).

A description is given of experiments carried out to investigate the range of velocities created in still and running water as a result of the lifting of air bubbles from the bottom of a water basin to its surface. The experiments were carried out in the tanks of the hydrotechnical laboratory LIIVT and imitated the appliances used for the raising of water from the deep layers of a water basin by means of compressed air, delivered through perforated tubes laid on the bottom of the water basin. The experiments were carried out with several combinations of water depth, air expenditure, and flow velocity in the tank. The range of velocities was studied with the help of photography and measurements of the components of the velocity; a study was specially made of the surface velocity, for which, in the absence of flow in the tank, an empirical formula is alloted; a formula by I. M. Konovalov (1951), for the assumption of air and for the velocity of the ascending flow was checked and experimental corrections were made in the coefficients of the formulas named.

560. Brown, A. S., et al.

CRITICAL MICELLE CONCENTRATIONS BY A BUBBLE PRESSURE METHOD, J. Phys. Chem., 56, 701-5 (1952).

In a kinetic adaptation of the bubble method of detg. surface tension, air pressure, vs. concn. of dodecylpyridinium chloride, Santomerse No. 3 and Tergitol TMN-650 gave curves which showed 4, 4, and 1 discontinuities, resp. These discontinuities, observed at several bubble rates, were confirmed as crit. concns. by cond. measurements on the same systems. Use of the bubble-pressure method of studying surfactants is suggested where other methods are inoperative.

561. Bryan, J. C.

BUBBLE DYNAMICS, Ph.D. Thesis, U. of Tenn. 105 pp. (June 1954).

562. Burdiett, P. H.

FUNDAMENTAL PROPERTIES OF TEXTILE-PROCESSING WASTES. VII. ELECTRIC CHARGE ON ESCAPING BUBBLES, Textile Research 8, 353-6 (1938).

Contrary to previous general conclusions, no electric charge was found on a gas (air) after being bubbled through pure H_2O or aq. solns. of NaCl and glycerol. (CA-33-6606-1).

563. Calderwood, G. F., Mardles, E. W.

HYDRAULIC FLUIDS, ETC. THE DECREASE IN RATE OF FLOW ALONG TUBES OF A COLUMN OF LIQUID WHEN BROKEN BY AIR GAPS, AD 52402 (1954).

564. Chapman, S.

INTERPRETATION OF CARRIER-MOBILITY SPECTRA OF LIQUIDS ELECTRIFIED BY BUBBLING AND SPRAYING, Phys. Rev., 54, 528-33 (1938).

The homogeneous group of negative carriers of mobility 1.8 cm/sec per volt/cm, produced by bubbling distilled water, consists of a normal negative ion in moist air. The positive and negative groups at mobilities +1.0 and -0.95 appear to be due to carriers containing an extra H^+ and OH^- ion, respectively. It is likely that the other distilled water groups

are formed partly by the breaking of the thin bubble film in uniform fashion, and partly by the evaporation of larger carriers. The presence of electrolytic ions in the bubble film seems to cause irregular rupture, and thus a wide distribution of mobilities. With increasing concentration in solutions more concentrated than 10^{-3} mole per liter, the reduced vapor pressure of the carriers containing solute causes the main maximum to shift gradually to lower mobilities (i.e., larger drop sizes). Presence of sucrose in the bubble film appears to provide "nuclei" so that a greater number of droplets are formed than is the case with distilled water. Thus more total charge and more types of carriers are produced. When distilled water is bubbled more violently than usual, the bubble films are more extensively torn into thick fragments by the air blast, so that the positive charges (which on Lenard's theory are in the under layer of the electrical double layer) are more frequently torn off. Hence the proportion of positive charge produced relative to the negative is greater. The less turbulent breaking of the bubble film in the case of gentle bubbling seldom exposes positive charges, so that no positive carriers are produced. The use of supersaturated air in the bubbling blasts inhibits evaporation so that only a wide distribution of carriers of all sizes is observed. (CA-32-8911-7)

565. Cohen, P., and Vogen, K.

THE EFFECT OF DISSOLVED GASES ON THE BUBBLE POINT OF WATER, WAPD-RM-7 (1950), 8 p.

Within the limitations of currently available data, the effect of dissolved hydrogen on the bubble point of water has been expressed as a function of concentration and of total system pressure in the form of a bubble point chart. Improved charts for hydrogen and oxygen mixtures will be required for the control of bubble point by the analysis of the reactor fluid. Because of the complexity of the analytical instrumentation required and the complicated relationship between gas solubility pressure and bubble point, direct measurement of bubbles point may be preferable for control purposes. The lines along which a suitable instrument might be developed have been indicated.

566. Deshpande, P. K., Bhat, G. N.

BUBBLE-PICK-UP STUDIES WITH ALUMINA, J. Indian Inst. Sci., 37A, 141-6 (1955).

Data are presented for bubble-pick-up studies on Al_2O_3 with oleic acid and Na silicate (Na_2SiO_3). The much more surface-active acid is adsorbed from slightly acidic or neutral solns. to a greater degree, whereas the long-chain paraffin ions are adsorbed from strongly basic solns. The data indicate the possibility of the formation of a partial or complete 2nd layer of adsorbed collector mols. on Al_2O_3 oriented the wrong way for attraction between the collector film and an air bubble.

567. Evett, A. A.

PRESSURE REDUCTIONS IN WATER PRODUCED BY BUBBLE LAYERS, AD 62559 (1954).

568. Evett, A. A.

PRESSURE REDUCTIONS IN WATER PRODUCED BY BUBBLE LAYERS, AD 62137, Appendix to AD 62559 (1954).

569. Garner, F. H. and Hammerton, D.

CIRCULATION INSIDE GAS BUBBLES, Chem. Eng. Sci., 3, 1-11 (Feb. 1954).

Air, ethylene, or CO_2 gas bubbles of diam. smaller than 0.03 cm. rise in water as rigid spheres. Above this diam. a circulation within the bubble sets in, resulting in a greater velocity of rise. The difference between the velocity of rise for the bubble as a rigid sphere and its actual velocity is a measure of the existence of circulation. The transition with bubble size from rigid to circulating conditions has been observed for air bubbles in glycerol, white hydrocarbon oil, and water. The effect of time interval between bubbles, surface contamination, temp. and wall effect upon bubble velocity was studied. (CA-48-7955g)

570. Gardescu, I. I.

BEHAVIOR OF GAS BUBBLES WITHIN CAPILLARY SPACES, Oil Gas J. 28, 42, 115-6 (Feb. 20, 1930).

Discussion of earlier literature; includes study of static condition of equilibrium of gas and liquid bubbles confined to capillary spaces; Jamin action; distortion of gas bubbles when forced to small opening is discussed as separate phenomena; distortion of gas bubbles in motion is not included. (CA-24-4925-9)

571. Hahn, B., and Knudsen, A. W.

STABILIZATION AND CONTROL OF BUBBLE CHAMBER SENSITIVITY, International Conference on High-Energy Accelerators and Instrumentation-CERN 1959. Geneva, European Organization for Nuclear Research (1959), p. 506-7.

The bubble density of a bubble track is known to depend strongly on the liquid temperature and on the pressure drop. Pressure stabilization by providing pressure communication of the chamber liquid with a reference pressure through flexible membranes is discussed.

572. Harrison, D., and Leung, L. S.

RATE OF RISE OF BUBBLES IN FLUIDIZED BEDS, Trans. Inst. Chem. Engrs., 40, 146-51 (1962).

The rate of rise of an air bubble in an air-fluidized bed of sand 3 m. high and of 3700 sq cm section was detd. for beds maintained just above incipient fluidization. The bubble size varied from 25 ml. to 10 l. The equation for the rate of rise confirms that this rate is the same as that in an inviscid liquid of zero surface tension. The results for a large air slug (vol. 60 l) of diam. equal to that of the column were also presented for various heights of packed columns. (CA62-13575b)

573. Kushner, L. M., and Hubbard, W. D.

THE DETERMINATION OF CRITICAL MICELLE CONCENTRATION BY A BUBBLE-PRESSURE METHOD, J. Phys. Chem. 57, 898-9 (1953).

Bubble pressure-concn. curves were reported for com. and purified Na dodecyl sulfate over a range of 10^{-3} to 10^{-1}M and at bubbling rates of 10 bubbles/10 sec and 10 bubbles/4 sec. The curves obtained with the com. material had a considerable structure that depended on the bubbling rate. The pure material gave a curve that dropped off with increasing concn. up to 10^{-2}M, above which point the pressure remained essentially const. The interpretation of bubble pressure and conductance data for solns. of impure surface-active materials is discussed. (CA-48-2446d)

574. Laird, A. D. K., and Chisholm, D.

PRESSURE AND FORCES ALONG CYLINDRICAL BUBBLES IN A VERTICAL TUBE, Ind. and Eng. Chem. 48, 1361-4 (1956).

The pressure distribution and forces acting on a bubble rising in still water at room temp. in a smooth vertical tube of 2-in. bore were measured as bubbles passed fixed points in the water at the tube walls. The results obtained indicate that the pressure within each bubble is const. and approx. equal to the head of water above it. The shear force at the wall acts upward on the water column. Kinetic-energy head is partially converted into pressure head for a short distance below the bubble tail in bubbles less than 30 inches long. The assumption of free fall of liquid along the bubble wall agrees well with observations.

575. Lange, E., and Nagel, K.

GRAPHIC REPRESENTATION OF WETTING ANGLES FOR THE METHOD OF MAXIMUM BUBBLE PRESSURE, Kolloid-Z., 73, 268-9 (1935).

In the present publication, a simple graphical process is described for the determination of wetting-angle relationships based on the surface energies given by the maximum bubble pressure method. (CA-30-1631-8)

576. McTaggart, H. A.

A PROPERTY OF VERY SMALL BUBBLES OF GAS IN WATER, Roy. Soc. Can. Trans., 18, 129-32 (1924).

The paper describes a method for the observation of small air bubbles in gas-free water and suggests a possible mode of attack for problems regarding the origin of the electric charge on the surface of small bubbles of air in water and on liquid surfaces in general. The experiments now described show that if small oil bubbles are introduced on to the surface of the air bubbles, they exhibit a mutual repulsion for each other and push each other off the air bubble in a way that cannot be attributed to the Brownian movements. The microscope arrangement is detailed and a record of experimental procedure given. (CA-19-1215-1)

577. McTaggart, H. A.

STUDY OF FILMS OF OIL INSIDE A SMALL BUBBLE OF GAS IN WATER, Roy. Soc. Can. Trans., 21, 249-54 (May, 1927).

Liquids which do not mix with water fall into two groups with reference to their tendency to spread on water, the spreading coefficient $\sigma_2 - (\sigma_1 + \sigma_{12})$, being positive or negative; σ_1 is the oil-air, σ_2 the water-air, and σ_{12} the water-oil surface tension. Oils with positive spreading coefficients, such as benzene chloroform and oleic acid, form on the inner surface of an air-bubble in water small globules with Brownian movement, even while in the surface, the identity and movement of these globules being retained when the bubble is absorbed and the globules dispersed. Sufficiently frequent repetition of this operation results in an emulsion of oil in water, and it seems probable that this phenomenon is the principal factor in the formation of an emulsion by shaking. In water containing a trace of thorium nitrate, films of oil which spread no small globules in Brownian movement, and no dispersion of the oil into globules-occurs; moreover, the electrolyte alters the electric charge in the surface layer of the bubble, presumably reducing the concentration of free negative ions in the surface. Carbon disulphide, acetylene tetrabromide and methylene iodide, which show negative spreading coefficients, do not spread over the surface of the bubble but tend to form a pool at the bottom with a large number of globules, having Brownian movement, round the edge. These globules are electrically charged and with the heavier liquids, retain their motion even in the thorium nitrate solution. (CA-22-1072)

578. Mikumo, J.

STUDIES ON SOAP SOLUTIONS. I. COMPOSITION OF BUBBLES OF MIXED SOAP SOLUTIONS, J. Soc. Chem. Ind. Japan, 37, 1317-20 (Oct. 1934).

Composition of bubbles of mixed soap solutions. (CA-29-1274-6)

579. Mumford, A. R.

A THEORY OF CARRYOVER, Combustion 18, 39-41 (1947).

Based on the idea that chemicals in water from which steam is made are concd. in a film surrounding the steam bubble, a theory is proposed relating operating pressure and chem. concn. to steam contamination. If each steam bubble is surrounded by such a highly concd. film of high surface tension and strength it is necessary to agitate these bubbles violently with boiler water to reduce the film concn. and weaken the film to a degree that will allow it to burst and release the steam. As the boiler water concn. increases, the bubble film concn. and strength increase and the sepg. and purifying equipment may become overloaded and unable to destroy the strong bubble films. (CA-41-4257e)

580. Novick, M.

EFFECTS OF RADIOLYTIC GAS BUBBLES ON REACTORS, 2nd U.N. International Conf. on Peaceful Uses of Atomic Energy Paper No. A/Conf. 15/p./946, 7, 436 (1958).

581. Omae, T. and Furukawa, J.

SURFACE TENSION OF FLUIDIZED PARTICLES, J. Chem. Soc. Japan, Ind. Chem. Sect. 57, 785-7 (1954).

Air bubbles were moved upwards through a fluidized column composed of sand and water, and the surface tension of fluidized particle system (more accurately the surface tension of fluidized system to air), σ, was obtained by the following relation: $\sigma = 2.9$ Vp, where V is the vol. of air bubble and p the apparent d. of fluidized system. The values obtained for sand-H_2O systems of p 1.34-1.36 g/cc and the mean particle diam. of sand of 0.54, 0.38, and 0.32mm were 180, 205, and 235 dyne/cm, resp.

582. Orlob, G. T. and Radhakrishna, G. N.

THE EFFECTS OF ENTRAPPED GASES ON THE HYDRAULIC CHARACTERISTICS OF POROUS MEDIA, Transactions of the American Geophysical Union, 39, pp. 648-659 (August 1958).

Investigation of the hydraulic characteristics of prepared porous media indicate that a 10% increase in air content of media voids is capable of producing a 15% reduction in "effective porosity," a 35% decrease in permeability, and about 50% reduction in hydraulic dispersion. The location of bubbles in large or small pores affects the uniformity of pore sizes and determines the amount of water-saturated void volume which is isolated by air bubbles. The shape of the chloride tracer "breakthrough" curve is greatly modified by changes in uniformity of pore size. An appreciation of the effects of gas accumulation is essential to a proper interpretation of the hydraulic behavior of natural formations.

583. Owens, J. S.

EXPERIMENTS ON AIR-LIFT PUMPING, Engineering, 112, 458-61 (September 1921).

The author reports on experimental investigations for the determination of the following:

1. Relation of diameter of air bubble to velocity of rise through water.
2. Effect of surface tension.
3. Effect of diameter of orifice delivery of air, and rate of flow of air on the size of the bubbles.
4. Rate of oscillation of the bubbles.

The diameters of the bubbles were measured by means of a perforated plate and a wire loop. The observed results are:

1. The curve of velocity versus diameter bends rapidly downward towards a maximum as the bubble increases in diameter; it is stated that this is due to the flattening of the bubble.
2. The effect of nozzle diameter is very slight. The factor governing the size of bubble is the rate of air flow.
3. Surface tension, in the form of a film over the orifice, causes pulsation of air flow.
4. All bubbles oscillate rapidly as a result of the shedding of eddies.

584. Pannetier, P.

THE IONIZATION PHENOMENA THAT ACCOMPANY THE BREAKAGE OF LIQUID SURFACES, Compt. rend., 234, 1881-3 (1952).

The bottom of a bottle contg. a liquid consists of a ceramic plate of low porosity. Air of regulated pressure is pressed through this porous plate and produces small bubbles in the liquid which simultaneously is the one electrode of an ionization chamber. The other electrode is a plate with a guard ring connected to a quadrant electrometer. For a given potential of this electrode pos. or neg. particles produced by the bubbles can be measured. With twice-dist. H_2O already at a potential zero a neg. current flows. With 0.001 N HCl, however, the voltage/current curve goes through the zero point and is perfectly symmetric. (CA-46-7842h)

585. Piontelli, R.

EFFECT OF GAS BUBBLES ON THE ELECTRODEPOSITION OF METALS, Rend. ist. lombardo sci., 72, 10-35 (1939).

The formation of pits in deposited plates of Bi, Cu, Fe and Ni due to gas bubbles adsorbed on the surface of the cathode was studied. A theory is given and equil. conditions are formulated. Particular attention must be paid to the phys. structure of the surface of the basis metal. Also, the presence of addn. agents, other metals, etc., will affect the results. Expts. confirm the theory advanced. Numerous photographs are given. (CA-34-4996-5)

586. Rodewald, H. J.

MERCURY BUBBLES, Naturwissenschaften 37, 284 (1950).

A technique is described for producing air-and water-filled Hg bubbles that float on water. The bubbles have a max. diam. of 3.3 cm., the larger ones have by far the shorter life, their wall thickness is 10 to 40μ, they are often ellipsoidal. Presence of strong electrolytes prevents formation of the bubbles.

587. Schiff, L. I.

AIR BUBBLE BREAKWATER, AD 80217 (1953).

588. Seeliger, R.

GAS BUBBLES IN LIQUIDS, Naturwissenschaften, 36, 187-8 (1949).

A review on the mechanism of formation of bubbles, gas exchange between bubble and liquid, movement of bubbles in liquid, etc. (CA-44-3759f)

589. Seitz, F.

ON THE THEORY OF THE BUBBLE CHAMBER PHYSICS OF FLUIDS, vol. 1, pp. 2-13 (January-February 1958).

The "bubble chamber" (see, eg., Glaser, The Physical Review, vol. 87, p. 665, 1952, vol. 97, p. 474, 1955; II Nuovo Cimento, vol. 11, p. 361, 1954) was suggested & promises to accomplish in the study of high-energy particles what the cloud chamber did in classical nuclear physics. In this instrument,

bubbles are formed in a superheated liquid along the path of incident particles. However, the mechanism which accounts for the bubble nucleation is still somewhat in doubt. It was first thought that nucleation is associated with the forces resulting from charges induced by ionizing radiation. A later, more likely, suggestion is that nucleation results from local thermal fluctuations caused by passage of energetic particles.

Author examines such a mechanism in some detail; his own summary is reproduced here:

"An attempt is made to analyze the factors which determine the operation of the bubble chamber. It is concluded that the majority of bubbles in conventional chambers are nucleated by moderately energetic free electrons produced by the incident particles in Coulomb encounters. Nuclei are displaced too infrequently by Coulomb encounters to account for the observed densities of bubbles. The electrons deposit their kinetic energy in highly localized regions which then are the source of explosions which produce bubbles of greater than critical size in a time of the order of 10^{-10} or 10^{-11} sec. The bubbles grow subsequently by evaporation of the fluid. The temperature of the fluid should be sufficiently close to the critical temperature that the energy required to produce the bubble of critical size can be provided by an electron with a range comparable to or less than the diameter of the bubble of critical size. Otherwise the electron will be unable to localize its energy in a sufficiently small volume in any but highly improbable cases. It is also concluded that the viscosity of the liquid plays a very important role in determining the threshold energy for forming a bubble of critical size when it has a value near 1 centipoise or larger."

NOTE: The importance of the bubble chamber is, in reviewer's opinion, twofold: (1) its use in the research for which it was originally conceived, of course, i.e., as a "bubble chamber;" and (2) the possible use of subatomic radiation in the study of the properties of liquids and very viscous materials, once the triggering mechanism is understood, with applications to the problems of tensile strength and cavitation, radiation damage, etc.

590. Slonczewski, J. C., and Heller, R.

DETERMINATION OF THE COEFFICIENT OF SURFACE TENSION BY THE BUBBLE LENGTH METHOD, Am. J. Phys. 21, 313-14 (April 1953).

The method of Everard and Hurley (1944) is confirmed with twelve liquids. The overall length l of an air bubble of given volume V is measured in a horizontal tube of known internal diameter 2r. The equation $pg/2y = Al + B$ holds; A and B are obtained by calibrating with known liquids (p = density; y = surface tension). (Sci. A-56-3915)

591. Spells, K. E.

SENSITIVE BUBBLE JETS, Proc. Phys. Soc. (London) B, 66, 258-9 (March 1953).

It has been shown that the bubbling process associated with the rapid flow of air through vertical rectangular slots submerged in water, is affected by sound at frequencies corresponding to first-order resonance in the air column of the slotted tube, and at a higher frequency independent of the tube length and probably associated with some other part of the apparatus used (See Smith, Phi. Mag., 19, 1147 (1935)). (Sci. A-56-3908)

592. Spitzer, L.

ACOUSTICAL PROPERTIES OF GAS BUBBLES IN A LIQUID, OSRD-1705 (July, 1943).

593. Steber, L.

HOW TO METER ACCURATELY WHEN LIQUIDS CONTAIN BUBBLES, Chem. Ind. 60, 210 (1953).

594. Weyl, W. A., and Marboe, E. C.

SOME MECHANO-CHEMICAL PROPERTIES OF WATER, Research (London) 2, 19-28 (1949).

"Mechano-chemistry" treats those phenomena that involve a cooperation between mech. forces and chem. forces. It is not possible to draw water by a vacuum higher than 30 ft., but a column of water in a tube fitted with a plunger can be brought under a hydrostatic tension of more than 50 atm. If water has been subjected to high pressure to eliminate all gas nuclei and is placed in a thoroughly clean vessel, it can be heated above 200° without boiling. Such behavior cannot be explained by the pictures usually presented for liquids, i.e., individual mols. packed closely, swarm structure, etc. Subdivision of properties into mech., chem., elec., etc., so convenient for textbooks, must not confuse the researcher. The paper treats phenomena involving the mech. properties of water in much the same manner as that used successfully for glasses. If the ocean is a single mol. (as Langmuir once described it) a whirling ship's propellor breaks chem. bonds, i.e., dissocn. occurs. The propellor is then moving in a soln. of H^+ and OH^-, and the oxide on its surface forms chem. bonds with the water. During cavitation the bond between the metal oxide and the metal, the weakest link concerned, is broken. Thus each rupture exposes fresh metal surface and the corrosion continues. The analog in glass is that a clean glass surface is scratched by metals; even if the metal is soft a visible or invisible mark is formed. In all cases the broken glass surface extends chem. bonds to the metal. The physics of explosives requires mechano-chem. explanation for improved understanding. Most modern explosives must be initiated by a shock wave and the reason for the lack of understanding of the phenomenon is due to a purely mech. approach. The processes going on in front of a detonation wave are mechano-chem. in nature. App. and expts. to measure the release of CO_2 from a supersatd. aq. soln. are described. When a captive air bubble is inserted into a soln. and the pressure is lowered, the CO_2 diffuses from the soln. into the gas phase, the captive bubble serving as a seed and sending forth a steady stream of CO_2 bubbles. Glass powder free from contamination and thoroughly degassed does not start gas nucleation. If the powder is exposed to air for a short time it will cause nucleation. Rough surfaces or sharp edges cannot in themselves cause gas evolution despite the popular lab. belief. Substances of the

extreme ionic type, e.g., NaCl, do not enhance cavitation by themselves; however, their soly. increases the sp. supersatn. and thus gas release is favored. Insol. ionic substances were ineffective. Diamond and SiC were found to facilitate gas nucleation strongly. Glass powder treated with aq. solns. of Pb salts releases gas supersatn. (CA-43-3682c)

595. Whelan, P. F.

EFFECT OF pH OF XANTHATE SOLUTIONS ON THE CONTACT ANGLE BETWEEN A BUBBLE OF AIR AND AN IRON DISULFIDE SURFACE NOT OF MINIMUM RUGOSITY, J. Phys. Chem. 58, 375-9 (1954).

The contact angles between air bubbles and pyrite, marcasite, and four specimens of massive iron disulfide from coal seams have been measured in solutions of xanthates at a concentration of 50 mg/liter. The results with all six forms of iron disulfide were similar. The existence of a critical pH, 10-11.5, above which bubbles do not adhere has been confirmed. With surfaces ground to only a comparatively poor polish, the contact angles are lower than those characteristic of the xanthates, and are related to the pH of the solution, being small at pH over 10, and rising as pH falls, until by pH 3 or thereabouts they approach the value of the characteristic angle. It is suggested that measurements of contact angles developed on surfaces not of minimum rugosity are of value, as the curves obtained as pH is varied appear to reflect the performance realized in practical mineral separations.

596. White, E. T., and Beardmore, R. H.

VELOCITY OF RISE OF SIMPLE CYLINDRICAL AIR BUBBLES THROUGH LIQUIDS CONTAINED IN VERTICAL TUBES., Chem. Eng. Sci. 17, 351-61 (1962).

The rise of air bubbles, constrained by the contg. tube walls to a cylindrical shape was measured in a variety of liquids. Results are presented in a general correlation involving the Eotvos and Froude nos. In a clean tube, bubbles will not rise unless Eo > 4. Velocity is unaffected by viscosity of $p^2gd^3/\mu^2 > 3 \times 10^5$; by surface tension if Eo > 70; by inertial effects if $(Fr)^{1/2} > 0.05$. The bubble velocity is unaffected by the length of the bubble or the head of liquid over the bubble. Inclination of the tube markedly changes the bubble velocity. (CA-62-14907b)

597. Yosioka, K., and Kawasima, Y.

ACOUSTIC RADIATION PRESSURE ON A COMPRESSIBLE SPHERE, Acustica 5, 167-73 (1955).

Calculations are given of the acoustic radiation pressure on compressible spheres suspended freely in a plane progressive or plane stationary sound wave field in a non-viscous fluid. With plane progressive waves the radiation pressure on bubbles shows a prominent peak corresponding to resonance in the pulsation mode. With plane stationary waves, on the contrary, the radiation pressure on the resonant bubble vanishes and the directions of the pressure are such that the bubbles smaller than the resonant are forced towards the nodes and the larger ones towards the loops. On small spheres, of which the densities are of the same order as that of the surrounding medium, such phenomena in the radiation pressure disappear and the formulae contain the density-compressibility factors instead of King's density factors. (Sci. Abst. 58-9509)

598. Yosioka, K., et al.

ACOUSTIC RADIATION PRESSURE ON BUBBLES AND THEIR LOGARITHMIC DECREMENT, Acustica 5, 173-8 (1955).

Radiation pressure on bubbles in a plane progressive sound wave field is calculated taking the effect of heat conduction into account. At 70 and 120 kc/s in water, measurements were made on H_2 and O_2 bubbles. The result of the experiment is in good agreement with theory, showing a prominent peak corresponding to the pulsation resonance. Logarithmic decrements of the resonant bubbles deduced from the data on radiation pressure are also in good agreement with the theory of Pfriem and Saneyoshi. In the case of plane stationary waves, bubbles smaller than the resonant are found to accumulate at the nodes and larger ones at the loops, as expected from the authors' calculations, while the radiation pressure on the resonant bubble vanishes.

ADSORPTION PHENOMENA

599. Astre, G.

DEPOSITS OF $NaHCO_3$ ON GAS BUBBLES IN THE WATER OF BOULOU, Bull. sci. pharmacol. 49, 93-7 (1942).

Distribution of unusual sediment formation on the contact surface between CO_2 bubbles and mineral water at Boulou in the Pyrenees. (CA-38-5622-9)

600. Bogdanov, O. S., and Filanovskii, M. Sh.

ADHESION OF MINERAL PARTICLES TO AIR BUBBLES, J. Phys. Chem. (USSR) 14 244-7, (1940).

Motion pictures are made of air bubbles and PbS particles meeting each other and moving together in H_2O contg. Bu xanthate and pine oil. The speed of small particles sliding along the interface bubble/H_2O is calcd. (CA-36-3721-3)

601. Engeles, M. A.

KINETICS OF MINERALIZATION OF AIR BUBBLES IN FLOTATION SUSPENSIONS, Tsvetnye Metal, No. 2, 39-45 (1940).

The kinetics of adhesion of particles of barite, fluorite and calcite to air bubbles was investigated in relation to particle size and the action of collectors. An app., representing an improvement of a previously existing app., was designed for measuring the duration of contact of air bubbles with mineral particles, necessary for the adhesion of the latter. It was ascertained that in pure water, particles of fluorite and barite, as ground, or ground and cleaned, can adhere to the air bubbles if sufficient time of contact is given. Particles treated with collectors require much shorter time for adhesion. Theoretical considerations are given of the relation between the kinetics of adhesion and flotability and of the effect of collectors on the kinetics of adhesion. (CA-35-17-4)

602. Evans, L. F.

BUBBLE MINERAL ATTACHMENT IN FLOTATION, Ind. Eng. Chem. 46, 2420-4 (Nov. 1954).

A theoretical approach to the flotation process is presented in a study of the adhesion process by pressing a captive air bubble against a hydrophobic surface submerged in water. In the induction period, the elapsed time between the moments of apparent and true contact, it is shown that the bubble is not stationary and that the water film which separates the bubble from the solid surface drains continuously through a restricted outlet. The problem is dealt with in three parts: first, the concept of "rupture thickness" is introduced, and a method for its determination described; the collision between a particle and a bubble is then examined, and an expression for the time available for contact is derived; finally, the shape of the bubble pressed against a hydrophobic surface is studied, and the possibility of calculating the induction period is discussed.

603. Frumkin, A.

PHENOMENA OF WETTING AND THE ADHESION OF BUBBLES. PART I. Acta Physicochim. (USSR), 9, 313-27 (1938).

In general, the curve relating surface tension and area per mole for a layer of liquid on a solid shows both a maximum and a minimum. A theory of the stability of thin layers is developed on this basis and the significance of the theory in connection with the adhesion of bubbles is explained.

604. Glembotskii, V. A.

RATE OF ADHESION OF AIR-BUBBLES TO MINERAL PARTICLES DURING FLOTATION, AND METHODS OF ITS MEASUREMENT, Izvest. Akad. Nauk. S.S.S.R. Otdel, Tekh. Nauk. 1524-31 (1953).

A high-sensitivity electronic app. is described for measuring the rate of air-bubble adsorption to flotable mineral particles, which is used as a measure of the hydrophilic or hydrophobic properties of the surfaces. (CA-49-6667d)

605. Philippoff, W.

SOME DYNAMIC PHENOMENA IN FLOTATION, Trans. Am. Inst. Mining Met. Engrs., Tech. Pub. No. 3265-B In Mining Eng. 4, 386-90 (1952).

A possible mechanism for the attachment of a conditioned mineral particle to a rising bubble has been developed. The time during which the phenomenon occurs is detd. by the time of impact, which can be calcd. and was proved by expts. During this time the film of liquid between the particle and the bubble must recede, creating the particle-air interface. This velocity of film-recedence has been both calcd. and measured and found to be dependent on the dynamic receding contact angle, which is much smaller than the equil. contact angle, measured in the bubble machine. This mechanism, as distinct from the static equil., accounts for the more difficult flotation of fines and slimes. Expts. were made by using particles within the range of sizes used in flotation, but large enough to give easily measurable contact times. Regular cylinders were filed from short lengths of steel wire, and were allowed to fall on a captive bubble blown in a cavity bored in a paraffin block. The cylinders were made hydrophilic to insure that they did not stick to the bubble but bounced off. This was done by treating them with chromic acid right before the expt. They were suspended by an electromagnet directly over the captive bubble. When the current was switched off, the general area of the top of the bubble was photographed at about 1000 frames per sec. The film velocity was timed by using a spark discharge of 120 sparks per sec photographed on the bubble image. Knowing the diam. of the particle, the magnification could be detd. exactly. The evaluation of the film in terms of time-displacement curves was done with a Gaertner spectrum-comparator. Positions of the perforations varied by only a few μ and could be chosen as reference points for the displacement. (CA-46-4443d)

606. Plaksin, I. N., and Bessonov, S. V.

THE ADHERENCE OF SULFIDE MINERALS TO AIR BUBBLES IN THE ABSENCE OF REAGENTS, Doklady. Akad. Nauk. S.S.S.R., 97, 495-8 (1954).

In expts. with galena, chalcopyrite, pyrites, sphalerite, pyrrhotite, and arsenopyrite, bubble adhesion of the particles was found to depend on the age of the exposed surfaces. Fresh mineral surfaces adhere rapidly to the bubbles. Within as little as 10 min, however, the oxidation of the surface proceeds sufficiently to permit partial wetting and caused bubble adherence to decline rapidly. This decline is prevented when the expts. are conducted in O-free conditions. (CA-49-12083c)

607. Spedden, H. R., and Hannan, W. S., Jr.

ATTACHMENT OF MINERAL PARTICLES TO AIR BUBBLES IN FLOTATION, Eng. & Min. J., 149, 95-7 (July 1948).

Reactions in a glass flotation cell mounted on a 16X microscope were photographed by a high-speed camera operating at 3000 frames per sec. Air bubbles 2 mm in diam. were regulated so that a rising column would meet a falling stream of xanthate-conditioned galena particles within the field of view. The bubbles rose under conditions of turbulent flow. It was found that collector-coated mineral particles attach to free air bubbles as a result of simple contact between the two. Fine particles were influenced by flow of fluid around the bubble surface to a greater degree than coarser sizes.

608. Sun, S. C., and Troxell, R. C.

QUANTITATIVE BUBBLE PICK-UP METHODS, Min. Eng., Trans., 5, 715 (July 1953).

Adoption of magnifying mirror and microscopic method as pre-flotation investigation tool; procedure and results of tests.

609. Suterland, K. L.

PHYSICAL CHEMISTRY OF FLOTATION XI: KINETICS OF THE FLOTATION PROCESS, J. Phys. and Colloid Chem. 52, 394-425, 1948.

A math. analysis is given of the direct-encounter hypothesis on the adhesion of mineral to bubble. The "collision area" of a bubble of radius R is proportional to Rr, where r is the radius of the mineral particle; more fully expressed, the area over which fruitful collision is possible is given by $3rR\ \mathrm{sech}^2(3V\lambda/4R)$. The induction period λ, i.e., the time required for mineral-to-bubble adhesion to occur, largely dets. the sech term, because the ratio of bubble velocity V to its radius does not vary appreciably. Calcd. induction periods are probably about as accurate as the exptl. values. When there is a distribution of mineral particle sizes, the rate of flotation is the sum of a no. of exponential functions of time.

610. Volkova, Z. V.

THE ADHERENCE OF MINERAL PARTICLES TO THE SURFACE OF AIR BUBBLES DURING FLOTATION, J. Phys. Chem. U.S.S.R. 14, 789-800 (1940).

Such adherence was studied for both accelerated and uniform motion of the air bubbles. Because of the acceleration at the start of the rise of the air bubbles conditions are not favorable for adherence. Nevertheless, the formation of bubbles with adhering mineral particles can take place at low values of the critical angle. At the transition from accelerated to uniform motion there is a decrease in the angle formed by the capillary surface and the horizontal to $\theta=\theta-\alpha$, where α is the angle of inclination of the micro boundary surface of the limiting lines of attachment with the horizontal. The size of the bubbles carrying mineral particles increases with increase in the particle size when θ remains the same; i.e., there is a greater probability of small particles adhering to small bubbles. As the crit. angle of wetting is increased in limiting surface adherence, the adherence of small particles takes place first of all. For a given particle size, the circumference of the bubble increases sharply with increase in the crit. angle of wetting, i.e., the probability of adherence to large bubbles becomes greater. With increase of the particle size and that of the crit. angle the conditions become unfavorable for the formation of mineralized particles. (CA-37-2977-6)

611. Wark, I. W.

THE PHYSICAL CHEMISTRY OF FLOTATION. I, J. Phys. Chem. 37, 623-644 (1933).

The basis of the flotation process is adhesion between a bubble of air and a solid surface. An air bubble in water will not adhere to the clean surface of any sulfide or metal. When, however, a film of xanthate is adsorbed by the mineral, the air spreads over the surface, partly replacing the aq. phase. Spreading ceases when a definite angle between the air-water and the water-mineral interface is attained. The significance of changing contact angle on flotability is mathematically developed. The surface characteristics of stationary air bubbles are considered. Equations are derived which connect Vol. of bubble, angle of contact and area of air-solid contact. The angle of contact is also used for the derivation of tenacity of adhesion. Further discussion deals with the true and apparent area of contact, the difficulties in the expt., detn. of angle of contact (hysteresis), the stability of air-mineral attachments, froths and air mineral aggregates and max. size of particle which will float.

BREAKUP, COLLAPSE AND STABILITY

612. Aspden, R. L.

A NEW HIGH SPEED PHOTOGRAPHIC TECHNIQUE APPLIED TO THE INVESTIGATION OF BUBBLES BURSTING AT AN AIR-WATER INTERFACE, AD 40888 (1954).

613. Birkhoff, G.

STABILITY OF SPHERICAL BUBBLES, Quart App Math 13, 451-453 (1956).

The perturbation equation for a spherical vapor-filled bubble can be written in the form (1) $\chi'' + p(t)\chi' + q(t)x = 0$ where $x(t)$ is a perturbation amplitude and p and q are known functions. This note contains the following general criterion for the stability of solutions of (1): If $q>0$ or if $q<0$ and $2pq + q'<0$, then (1) is unstable; if $q>0$ and $2pq + q'<0$, the (1) is stable. More specifically, if $q<0$ it is shown that $x(t)$ grows forever in magnitude as $t\to\infty$, while if $q>0$ the solution oscillates with increasing or decreasing amplitude depending on whether $2pq + q'$ is less or greater than zero. This result is applied to obtain in a different way the author's earlier conclusion that collapsing vapor-filled bubbles are unstable. App. Mech. Rev.-9-1853

614. Blanchard, D. C.

A SIMPLE METHOD FOR THE PRODUCTION OF HOMOGENEOUS WATER DROPS DOWN TO 1 MICRON RADIUS, J. Colloid Sci. 9, 321-8 (1954).

The collapse of a bubble at a clean air-water interface produces an upward moving jet of water that disintegrates into several small drops of different sizes. If bubbles of the same size are formed repeatedly and a slow drift of air exists over the surface of the water, drops of the same size will fall over the same path as long as the bubble production continues. The drop size is a direct function of bubble size.

615. Blanchard, D. C., and Newitt, D. M.

BURSTING OF BUBBLES AT AN AIR-WATER INTERFACE, Nature 173, 1048-9 (1954).

The suggestions of Knelman et al. [Abstr. 5335 (1954)] on the mechanisms involved in the bursting of bubbles are questioned, the author considering that they apply only to large bubbles. Newitt confirms that the bubbles were large but thinks his theory will hold for smaller bubbles. [See also Abstr. 2954 (1954).] (Sci. Abst. 57-8085)

616. Chao, B. T., and Petrick, M.

COLLAPSE OF A VAPOR BUBBLE IN A UNIFORMLY SUB-COOLED, QUIESCENT LIQUID (Internal ANL Report) (December 7, 1960).

Two simple models for the collapse of vapor bubbles in a quiescent, subcooled liquid are analyzed. The first concerns with a stationary bubble and the second is for a bubble in motion. Good agreement is obtained between theoretical prediction and the limited amount of published experimental data for the collapse of moving bubbles.

617. Constable, F. H., and Baykut, S.

THE LIFE OF SINGLE BUBBLES ON WATER, Rev. fac. sci. univ. Istanbul A17, 309-21 (1952).

The bubble lives are subject to large variations even when the bubble volume is fixed. The standard deviation (σ) was little less than the mean life. But the value of $\sigma = \sqrt{\frac{\Sigma(t - t_m)^2}{(n - 1)(n)}}$ for the mean of 100 observations was only a small fraction of the mean life, so that it was possible to work with mean observations. The relation between mean t and volume of bubble was $t = \nu^{1/3}/(A + B\nu^{2/3})$, where A = 0.0285, B = 0.4592, and σ could be calculated. To avoid the increase in t due to single large bubbles of long life the work was repeated using the most frequent life of a grown bubble. The same general formula seemed to be applicable with different constants. (Sci. Abst. 57-5334)

618. Constable, F. H., and Reizi, S.

MAXIMUM LIFE OF BUBBLES IN OIL, Rev. fac. Sci. Univ. Istanbul 10A, 43-53 (1946).

Life of a bubble is detd. by its radius (r), viscosity (η), and its final thickness. Thickness is calcd. from the rate of flow away from the top of a bubble on the assumption that this rate is that which is calcd. between concentric hemispheres. The life (t) reduces to $3r/g\rho\alpha^2$, where α is thickness and ρ density. Effect of bubble size on rate of fall of oil foams was studied by expts. in which measured vols. of air were run through capillary tubes into a paraffin oil below a glass column in which the bubbles collected. Size of bubbles was controlled by size of capillary and by rate of flow of air. For bubbles of 0.1 to 1 cm diam. max. life depends on diam. (d). Above 1 cm max. life decreases rapidly with increasing size. Fall of the top layer of foam is usually stepwise or periodic, but the av. velocity (V) equals $Kd^{1.3}$ at 18°. (CA-40-4933-2)

619. Constable, F. H., and Amirhanyan, V.

STABILITY OF AN EMULSION OF FINE AIR BUBBLES IN WATER, Rev. Fac. Sci. Univ. Istanbul Ser. C 22, 378-82 (1957).

The life of suspensions of fine air bubbles was investigated in pure water and in saponin soln. The suspensions were contained in 3 tubes: 50 cm high, 6 cm diam.; 9 cm high, 7.5 cm diam.; and 14.0 cm high, 5.0 cm diam. The bottom level of the bubbles was observed with a cathetometer, and height-time measurements were made, first in pure water, then after the addn. of 8×10^{-5} g/cc of saponin. Results are tabulated. The bubble life was short, but in long columns it is prolonged by the saponin which retards the union of the fine bubble originally present. The max. increase in suspension life found was 4-fold. Microscopic measurements of the finest bubbles in the foam formed on the surface with the addn. of saponin gave a diam. of about 3×10^{-2} cm, from which the velocity of upward ascent of the bubbles was calcd. to be 0.05 cm/sec.

620. Culick, F. E.

COMMENTS ON A RUPTURED SOAP FILM, J. Appl. Phys. 31, 1128 (1960).

The work done in accelerating parts of the film is taken into account in an attempt to reconcile Ranz's experimental results (Abstr. 931 of 1960), on the speed of opening of a hole in a horizontal soap film, with Rayleigh's theory.

621. Ellis, A. T.

OBSERVATIONS ON CAVITATION BUBBLE COLLAPSE, Hydrodynamics Lab., Calif. Inst. of Tech., Rpt. No. 21-12, Dec. 1952 (25 references) (See also California Institute of Technology, Thesis (1953)).

622. Epstein, P. S., and Plesset, M. S.

ON THE STABILITY OF GAS BUBBLES IN LIQUID-GAS SOLUTIONS, J. Chem. Phys. 18, 1505-9 (1950).

With the neglect of the translational motion of the bubble, approximate solutions may be found for the rate of solution by diffusion of a gas bubble in an undersaturated liquid-gas solution; approximate solutions are also presented for the rate of growth of a bubble in an oversaturated liquid-gas solution. The effect of surface tension on the diffusion process is also considered. (Sci. Abst. 54-2428)

623. Epstein, P. S., and Plesset, M. S.

ERRATUM: THE STABILITY OF GAS BUBBLES IN LIQUID-GAS SOLUTIONS, J. Chem. Phys., 19, 256 (1951).

The cuts of Figs. 3 and 4 are interchanged.

624. Facy, L.

BURSTING OF THIN FILMS AND CONDENSATION NUCLEI, J. Sci. Meteorol. 3, 86-98 (July-Sept. 1951).

Electron microscope analysis of sea spray obtained when bubbles burst, reveals the composition of condensation nuclei in different size ranges, as well as the relative and absolute nuclei size distribution. Mechanics of formation and bursting of bubbles or films, of collecting and photographing and, finally, of analysis are described and illustrated. Theory of drop shattering is treated in detail and natural description compared with description of artificially produced films in the Laboratory. Many excellent photomicrographs are reproduced. The conclusion is that bursting produces numerous liquid drops between 10^{-2} and 10^{-3} cm composed of $MgCl_2$, with relatively few NaCl nuclei in the lower range. Between 10^{-4} and 10^{-3} the nuclei are nearly always

surrounded by $MgCl_2$, with sometimes NaCl and more rarely with sulphates or carbonates of Na or Mg as nuclei. It is estimates that the rate of sea salt nuclei production on the earth is $10^5/cm^2/sec$. (Sci. A-56-7255).

625. Friedman, A.

FREE BOUNDARY PROBLEMS FOR PARABOLIC EQUATIONS: Part 3, DISSOLUTION OF A GAS BUBBLE IN LIQUID, J. Math. Mech. 9, 327-345 (1960).

626. Gerjuoy, E.

THE STABILITY OF GAS BUBBLES IN WATER, Phys. Rev. 73, 538 (1948).

Measurement of tensile strengths of liquids by centrifuge method. (CA-43-4066e)

627. Gleim, V. G.

STUDY OF THE FORMATION OF DROPS WITH THE AID OF MOTION PICTURES, Trudy Novocherkassk. Politekh. Inst., 25, 173-7 (1955).

The mechanism of bubble bursting and the penetration of the moisture from the bubbles into the vapor-filled space over a boiling liquid are studied with the aid of motion pictures. Pictures of liquid drops forming at the moment the bubbles burst in the cold (bubbling of air through the liquid) and after prolonged boiling are given. The results of the motion-picture study confirm the idea of drop generation at the place the bubbles burst and the possibility of introducing foam protection on the evapg. surface to lessen the carrying away of the drops.

628. Hartunian, R. A., and Sears, W. R.

ON INSTABILITY OF SMALL GAS BUBBLES MOVING UNIFORMLY IN VARIOUS LIQUIDS, J. Fluid Mechanics, 3, 27-47 (Oct. 1957).

Instability is investigated experimentally and theoretically; experiments consisted of measurement of size and terminal velocity of bubbles at threshold of instability in various liquids; results of experiments indicate existence of universal stability curve.

629. Kientzler, C. F., et al.

PHOTOGRAPHIC INVESTIGATION OF THE PROJECTION OF DROPLETS BY BUBBLES BURSTING AT A WATER SURFACE, Tellus 6, 1-7 (Feb. 1954) (also AD-20215).

Bubbles of air reaching the air-water interface burst and eject liquid droplets into the air to heights large compared to their diameter. Photographic evidence is introduced to prove the existence of a jet of liquid which upon breaking up produces these droplets. The jet is shown to be produced by the collapse of the bubble cavity. The droplets are found to be of the order of one-tenth of the bubble size, for the range investigated (0-2 to 1-8 mm dia.), each bubble producing about 5 droplets. The droplet-producing mechanism is essentially the same for fresh and sea water or sea water with oleic acid surface film. The time required for the bubble to burst and the jet formation to take place is found to be proportioned to the bubble size. The sea-water droplets produced by this mechanism leave, upon evaporation of the water, salt nuclei having the size range observed by Woodcock (1952). It is suggested that such bursting of bubbles plays an important role in the natural production of air-borne sea-salt nuclei at the sea surface. (Sci. Abst. 57-8954)

630. Knelman, F., Dombrowski, N. and Newitt, D. M.

MECHANISM OF THE BURSTING OF BUBBLES, Nature 173, 261 (1954).

High-speed photographic records show that when a gas or vapour bubble bursts at the surface of water the thin upper surface disintegrates into a cloud of very fine droplets which are then blown away by the egress of gas through the gap in the envelope. The inrush of water into the crater thus formed produces an unstable jet which breaks up into one or more large drops of about 1 mm diameter. (Abst. Sci. A-57-5335)

631. Kornfeld, M.

HOW DOES A SOAP BUBBLE BURST?, Zh. Tekh. Fiz., 24, 1520 (Aug. 1954).

A sequence of 6 high speed photographs shows the skin of the bubble contracting to a small disk, with filaments of droplets extending from the edge. (Abst. App. Mech. Rev.-8-3448)

632. Levenspiel, Octave.

COLLAPSE OF STEAM BUBBLES IN WATER, Ind. Eng. Chem. 51, 787-90 (1959)

The rate of collapse of steam bubbles in water was studied photographically and the heat transfer coeffs. detd. Theoretical predictions are not substantiated by exptl. findings. The rate of heat transfer for steam collapse in water is in the order of 10^4 Btu/(hr)(sq ft) (°F) for bubbles 1 cm in diam.

633. Lord, R.

PRESSURE DEVELOPED IN A LIQUID DURING THE COLLAPSE OF A SPHERICAL CAVITY, Phil. Mag. 34, 94 (1917).

634. Mason, B. J.

BURSTING OF AIR BUBBLES AT THE SURFACE OF SEA WATER, Nature 174, 470-1 (1954).

Bubbles between 0-3 and 4-3 mm diameter at the surface of sea water have been studied. As well as large droplets projected vertically on bursting all diameter bubbles appear to produce a number of very small bubbles projected horizontally. Cloud chamber experiments on fresh water and sea water show that bubbles bursting at the surface of the latter produce a cloud of small droplets, thought to be due to production of very small salt particles which act as condensation nuclei. (Sci. Abst. 58-105)

635. Mellen, R. H.

AN EXPERIMENTAL STUDY OF THE COLLAPSE OF A SPHERICAL CAVITY IN WATER, J. Acoust. Soc. Amer. 28, 447 (1956).

The pressure wave produced by the collapse of an electrically generated spherical cavity (~1 cm in radius) in water was measured by means of a small

electroacoustic hydrophone ($\frac{1}{16}$ in. in diameter) at a distance of 50 cm. The pressure was found to increase as the bubble collapsed according to the $t^{-4/5}$ (time) law in the interval corresponding to subsonic flow. The pressure then suddenly jumped to a higher value and rapidly decayed to zero. This rapid increase in pressure is assumed to be a shock wave. Using Gilmore's theory for the collapse of the cavity and finite amplitude-wave theory for the pressure wave, we find that the value of the pressure-amplitude characteristic at the shock front corresponds to a cavity-wall velocity approximately equal to the velocity of sound. Since the shock wave has been attenuated, the peak wall velocity must be greater than this value. (Sci. A-59-4860)

636. Nakagawa, T., and Sameshima, J.

STABILITY OF LIQUID FILMS. II. EXPERIMENTS ON THE LIFE OF SINGLE BUBBLES, J. Chem. Soc. (Japan) 64, 360-4 (1943).

It is known that a bubble formed on the surface of pure liquid is very unstable. However, it can be stabilized by blowing dry air against it. This is due to the contraction of the film forming the bubble owing to the increase of surface tension caused by the depression of temp. accompanying evapn. This phenomenon is observed for the bubble on the surface of water, EtOH, PrOH, benzene, ether, acetone, MeOH, BuOH, but not for nitrobenzene, which has a small vapor pressure.

637. Pennington, R. H.

SURFACE INSTABILITIES ON PULSATING GAS BUBBLES, AD 32031 (1954).

638. Plesset, M. S., and Epstein, P. S.

ON THE STABILITY OF GAS BUBBLES IN LIQUID-GAS SOLUTIONS, J. Chem. Phys. 18, 1505 (1950).

With the neglect of the translational motion of the bubble, approximate solutions may be found for the rate of solution by diffusion of a gas bubble in an undersaturated liquid-gas solution; approximate solutions are also presented for the rate of growth of a bubble in an oversaturated liquid-gas solution. The effect of surface tension on the diffusion process is also described.

639. Plesset, M. S., and Mitchell, T. P.

ON THE STABILITY OF THE SPHERICAL SHAPE OF A VAPOR CAVITY IN A LIQUID, Quart. Appl. Math. 13, 419 (Jan. 1956).

Authors study the problem of the stability of small amplitude disturbances of a spherically shaped vapor cavity during its growth or collapse in a liquid. Critical assumptions involve the neglect of the vapor density (compared with that of the liquid) and the assumption of constant internal pressure in the cavity. This latter assumption, particularly, is not valid during the final stages of collapse of a bubble, as is pointed out by the authors.

An analytical solution is found for the cavity expanding under the action of a finite pressure difference (not stable). The problem of the cavity collapsing under the action of surface tension alone is also treated. The initially spherical shape is shown to be unstable in this case, too.

Authors point out that the linearized perturbation theory breaks down in the range of radii which corresponds to that for which the proposed constant pressure vapor cavity model is also invalid, i.e., during the latter stages of collapse.

The instability behavior agrees with that found previously by Birkhoff (Quart. appl. Math XII, 3, the amplitude of the surface distortions being proportional to the $(\text{radius})^{-1/4}$ as radius $\to 0$. This behavior is essentially unaffected by surface tension. (AMR-9-1852).

640. Poritsky, H.

THE COLLAPSE OR GROWTH OF A SPHERICAL BUBBLE ON CAVITY IN A VISCOUS FLUID, Proc. First U. S. Nat. Congr. Appl. Mech., June 1951, 813-821 (1952).

In the equations of motion in incompressible flow, for the growth or collapse of a spherical cavity it appears that the terms containing the viscosity disappear. But the proper evaluation of the pressure inside the cavity shows up in prescribing boundary condition. Through this boundary condition, the effect of viscosity on the growth or collapse of a spherical bubble is investigated. An example is worked out, giving the details of solving the differential equation.

The effect of surface tension is also considered. It is shown that without surface tension the complete collapse of bubble is never reached. Also the effect of surface tension is to slow down the rate of expansion of the bubble at first, but not in the later stages of expansion. (Appl. Mech. Rev. 7-3623)

641. Rayleigh, Lord

PRESSURE DUE TO COLLAPSE OF BUBBLES. Phil. Mag., 34, 94-98 (Aug. 1917).

The problem of the pressure developed by the collapse of spherical cavities in a liquid has been investigated by Besant; and S. Cook, starting from his result, has determined the pressure developed when the collapse is suddenly arrested by a rigid concentric obstacle, a problem of interest in connection with the cavitation behind screw-propellers. In the present note a simpler derivation of Besant's results is given, and the calculation is extended to find the pressure in the interior of the fluid during collapse. It appears that before the cavity is closed these pressures may arise to very high values in the fluid near the inner boundary.

642. Shishido, Shunsuke

STABILITY OF THIN LIQUID FILM, J. Chem. Soc. Japan, Pure Chem. Sect., 69, 27-33 (1948).

The stability of a liquid film is discussed in relation to bubble formation, absorption, and surface layer in the liquid.

643. Trilling, L.

THE COLLAPSE AND REBOUND OF A GAS BUBBLE, J. Appl. Phys. 23 14-7 (1952).

The velocity and pressure field in a slightly compressible liquid resulting from the collapse of a spherical bubble is computed as a function of the pressure at the bubble wall, using the acoustic approximation. The results are accurate as long as the liquid velocities are small compared to the sonic velocity in the liquid; they agree with the results previously obtained by C. Herring. The following bubble model is then investigated. The bubble is supposed filled with inviscid perfect non-conducting gas; special emphasis is given to the gas motion which involves a series of shock waves. A fraction of the energy of compression is thus degraded so that the radius of the bubble after the first rebound is somewhat less than the original radius. The pressure variation at the bubble wall is virtually the same as if the gas were compressed uniformly and isentropically. (Sci. A. 55-2466)

644. Turner, W. R.

MICROBUBBLE PERSISTENCE IN FRESH WATER, J. Acoust. Soc. Amer., 33, 1223 (1961).

Preliminary research confirms that microbubbles become stabilized in a body of water and persist for long periods of time in contradiction of classical theory. The evidence was obtained by generating bubbles at the bottom of a water tank and then measuring the decay of ultrasonic attenuation as bubbles of various sizes rose to the surface. Comparison of experimental and classical decay curves disclosed persistence that appeared to be a function of the solid particle content of the water and indicated that bubbles may stabilize at sizes as large as 30μ radius in water of high particulate content. In waters of low particulate content the decay of attenuation lasted over 100 hr. Substantial persistent abnormal attenuation was detected in all fresh tap water measured, amounting to a minimum 44% over that of distilled water (at 5.125 Mc/s) and is believed to be caused by stabilized bubble nuclei somewhat less than 0.8μ in size. An interesting discovery was that attenuation rose in an uncovered test basin but fell in a covered basin, indicating that microbubbles may enter water on dust particles. A hypothesis presented to explain the persistence effect suggests that solid particles collect on the bubble surface, forming a compressed wall capable of supporting the excess pressure necessary to halt gas diffusion. Other hypotheses explore the mechanism by which dust particles may carry air globules below the water surface and the dynamics of microbubble populations.

645. Volynskiy, M. S.

INVESTIGATION OF BUBBLE BREAK-UP IN A GAS FLOW, Akademiia Nauk SSSR, Comptes Rendus Doklady, 68, 237 (1949).

646. Woodcock, A. H. et al.

GIANT CONDENSATION NUCLEI FROM BURSTING BUBBLES, Nature 172, 1144-5 (1953)

High-speed motion pictures of small bubbles bursting at air/salt-water interfaces were taken. It is seen that each bubble, on bursting, ejects about five droplets, evaporation of the water from which leaves a salt residue similar in weight to salt nuclei found in the atmosphere and believed to be nuclei for rain formation. (Sci. A-57-2954)

647. Woodcock, A. H.

BURSTING BUBBLES AND AIR POLLUTION AD-88692b (1955)

CAVITATION

648. Ackeret, J.

EXPERIMENTAL AND THEORETICAL INVESTIGATIONS OF CAVITATION IN WATER, NACA-TM-1078 (1930), 61 p.

The cavitation in nozzles on airfoils of various shape and on a sphere are experimentally investigated. The limits of cavitation and the extension of the zone of the bubbles in different stages of cavitation are photographically established. The pressure in the bubble area is constant and very low, jumping to high values at the end of the area. The analogy with the gas compression shock is adduced and discussed. The collapse of the bubbles under compression shock produces very high pressures internally, which, according to more recent conceptions, are contributory factors to corrosion. The pressure required for purely mechanical corrosion is also discussed.

649. Acosta, A. J.

CAVITATION IN AXIAL FLOW PUMPS, AD 99273 (1956).

650. Binnie, A. M.

THE STABILITY OF THE SURFACE OF A CAVITATION BUBBLE, Proc. Cambridge Phil. Soc. 49, 151-5 (1953).

A theoretical examination is made of the stability of a spherical interface between two inviscid liquids accelerated radially from rest. If surface tension be neglected, it is found that the interface is unstable or stable according as the acceleration is directed towards or away from the liquid of greater density. Surface tension has a marked stabilizing effect, and numerical results are given for the minimum outward acceleration required to destroy the equilibrium of the surface of a cavity formed in water. These results are suggested as a possible explanation of the behavior of cavitation bubbles seen to form near a freed object under test in a water tunnel. (Sci. A. 56-3909)

651. Chesterman, W. D.

THE DYNAMICS OF SMALL TRANSIENT CAVITIES, Proc. Phys. Soc. (London) 65B, 846-57 (1952).

Experimental methods have been developed for creating and observing single spherical cavities in water and certain organic liquids. Rapid photography permits motion analysis to be made. The cavities show several cycles of expansion and collapse during their lifetime of a few milliseconds. At each volume minimum a sharp pressure maximum occurs in the liquid. It appears that these cavities form initially

on minute gas nuclei in the liquids, and the existence of these nuclei is essential for the type of cavitation studied. The relation of cavity life to maximum diameter is discussed. (Abst. App. Mech. Rev. 6-1986)

652. Crewdson, E.

CAVITATION, Engineer 195, 122-3 (Jan. 23, 1953).

Author suggests that damage done by cavitation is no consequence of collapse of bubbles; such collapse cannot take place, but high pressure and high temperature of gas within bubble can account for observed damage.

653. Daily, J. W., and Johnson, V. E., Jr.

TURBULENCE AND BOUNDARY-LAYER EFFECTS ON CAVITATION INCEPTION FROM GAS NUCLEI, Am. Soc. Mech. Engrs., Trans., 78, 1703-6 (Nov. 1956).

Discussion of the role of gas bubbles as nuclei for cavitation and the interrelation of the stability of small gas bubbles, their size and space distribution, and the velocity and pressure variations in the turbulent boundary layer, as observed in an experimental investigation.

654. Eisenberg, P.

DISCUSSIONS AND AUTHOR'S CLOSURE FOR A BRIEF SURVEY OF PROGRESS ON THE MECHANICS OF CAVITATION, DTMB-842 A (1953).

655. Eisenberg, P.

A CRITICAL REVIEW OF RECENT PROGRESS IN CAVITATION RESEARCH, Symposium on Cavitation in Hydrodynamics, Nat. Phys. Lab., London; Her Majesty's Stationery Office, Paper No. 1, 16 pp. (1956).

This review is a continuation of former publications of the author (David W. Taylor Mod. Basin Reps. 712 (1950) and 842 (1953) with the aim to formulate the basic problems in the field of cavitation, to summarize the results of research from a critical point of view, and to disclose, from this critical review, the presently urgent questions. This aim has been well achieved. Discussing first the theory of entrained gas nuclei and their stability, and stressing the need for a method of measuring nuclei content, author proceeds to shear flow phenomena and the effect of turbulence on the cavitation process. A great part of the paper deals with problems on scale effects, particularly with that of scaling cavitation onset. A chapter on the dynamics of transient cavities and collapse pressures, including compressibility effects, follows. Further, steady-state cavities are discussed distinguishing between cavitation in a wake flow and truly free-streamline flow. Considerations on the mechanics and theories of cavitation damage conclude the paper, to which a list of publications on the subject during 1951-54 is attached.

656. Elder, S. A.

CAVITATION MICROSTREAMING, Journal of the Acoustical Society of America, 31, pp. 54-64, January 1959.

An attempt was made to discover by experiment what physical assumptions and approximations are appropriate in the theory of cavitation microstreaming, especially for cavitation bubbles located near solid boundaries. A systematic investigation of the phenomenon was made and its dependence on certain parameters (e.g., amplitude of sound) was determined. The investigation has disclosed that as the sound amplitude is varied, other conditions remaining the same, the streaming changes discontinuously through several stable regimes. It appears that in order to account for the generation of vorticity one needs to assume different conditions at the boundaries for each regime. For at least one regime, a theoretical model due to Nyborg seems to be applicable; comparison is made with experimentally determined streaming velocities.

657. Ellis, A. T.

TECHNIQUES FOR PRESSURE PULSE MEASUREMENT AND HIGH-SPEED PHOTOGRAPHY IN ULTRASONIC CAVITATION, AD-75061 (1955).

658. Eskigian, N. M.

A MODEL STUDY OF THE FLUID FLOW AT THE RUDDER STOCK OF A SURFACE SHIP, AD-111735 (1956).

659. Fox, F. E., and Herzfeld, K. F.

GAS BUBBLES WITH ORGANIC SKIN AS CAVITATION NUCLEI, J. Acoust. Soc. Am. 26, 984-9 (November 1954).

Due to surface tension, small bubbles would dissolve in a very short time. If the bubbles are larger than 5×10^{-3} cm, or if the liquid is supersaturated, they may last longer or even be stable, but then no cavitation threshold exists. The hypothesis is expressed that the nuclei are very small bubbles, stabilized by an organic skin, which mechanically prevents loss of gas by diffusion. The cavitation occurs when the skin breaks and the threshold is determined by the breaking strength of the film and the size of the bubble. (Sci. A. 58-1577)

660. Frenkel, Ya.

ELECTRICAL PHENOMENA ASSOCIATED WITH CAVITATION DUE TO ULTRASONIC VIBRATIONS IN LIQUIDS, Acta Physicochim. (U.S.S.R.) 12, 317-22 (1940).

Theoretical. Ultrasonic vibrations produce rupture cavitation leading to lens-shaped bubbles in which strong elec. forces come into play. These elec. forces produce the observed chem. reactions. The

contribution of the orientation effect to the elec. field in the cavity is negligible except at very low ion concns. (CA-34-7682-6)

661. Fryar, R. M.

SUMMARY OF PRESENT STATUS AND FUTURE PROGRAM OF CAVITATION PROBLEM, HW 25837

662. Galloway, W. J.

AN EXPERIMENTAL STUDY OF ACOUSTICALLY INDUCED CAVITATION, AD 24646 (1953).

663. Gilbarg, D., and Anderson, R. A.

INFLUENCE OF ATMOSPHERIC PRESSURE ON PHENOMENA ACCOMPANYING ENTRY OF SPHERES INTO WATER, J. Appl. Physics 19, 127-139 (Feb. 1948).

Results of motion picture studies made of dependence of air water entry cavities on relevant physical parameters; experiments on vertical entry of spherical projectiles $\frac{1}{4}$ in. to 1 in. in diam., with entrance velocities between 15 fps and 100 fps, and air pressures between $\frac{1}{60}$ atm and 3 atm, show that surface sealing of cavity is major factor in controlling cavity formation.

664. Guth, W.

FORMATION OF SHOCK WAVES IN CAVITATION, Acustica, v. 6, pp. 526-531, 1956 (in German).

Paper is an exposition of results on approximate pressures and shock-wave formation associated with collapsing cavitation bubbles and the diffusion of air into oscillating cavities inferred from the theoretical results of Rayleigh (The Philosophical Magazine, v. 34, p. 94, 1917), Noltingk and Neppiras (Proceeding of the Physical Society, London, Section B, p. 674, 1958; Applied Mechanics Reviews, v. 5, Rev. 1760), and Blake's hypothesis of rectified diffusion (Harvard University Acoustical Research Laboratory T. M. 9, 1948). It is a supplement to author's previous description of schlieren photography of the shock waves propagated by collapsing cavities.

665. Harrison, M.

AN EXPERIMENTAL STUDY OF SINGLE BUBBLE CAVITATION NOISE, J. Acoust. Soc. Am. 24, 776-82 (Nov. 1952).

An experimental study of the noise produced by a single cavitation bubble has been made. The noise consists principally of a transient pressure pulse associated with the collapse of the bubble. The motion of the bubble has been photographed simultaneously with the measurement of the pressure pulse. (Sci. A. 56-715)

666. Harvey, E. N., McElroy, W. D., and Whiteley, A. H.

CAVITY FORMATION IN WATER, J. Applied Phys. 18, 162-72 (1947).

This study was made in connection with an investigation of possible causes of decompression sickness ("bends"). Glass and Al rods were driven rapidly through water and corn sirup at speeds up to 36.7 m/sec, and high-speed motion pictures were made of the cavitation in their wake at 3000 frames/sec. The rods were 5 mm and the tubes contg. the liquids 16 mm in diam. Special precautions were taken to retain dissolved air at 1 atm., but to remove all hydrophobic patches and small gas masses (gas nuclei). If the rod surface contained gas nuclei or was hydrophobic and free of gas nuclei, cavitation occurred at the rear end at speeds less than 3 m/sec, but if completely hydrophillic and gas-free, the speed could be 37 m/sec without cavitation. Addn. of diacetyl sodium succinate as a detergent to the water did not prevent cavitation at low speed with the hydrophobic rod free of gas nuclei. Movement of a rod in pure corn sirup (viscosity 20.1 poises), free of gas nuclei, left a large cylindrical cavity which collapsed in a few hundredths of a sec. The speeds attained without cavitation are far higher than those previously obtained, probably owing to the absence of all gas phases and hydrophobic surfaces. (CA-41-2952b)

667. Hsu, Y. Y.

ON THE SIZE RANGE OF ACTIVE NUCLEATION CAVITIES ON A HEATING SURFACE, J. Heat Transfer, 84, 207-16 (Aug. 1962).

The importance of surface condition on nucleate boiling is recognized. It is also known that only cavities of a narrow size range can be active nucleation sites. In order to define the size range of active cavities as a function of wall temperature or heat flux, a model is proposed. The model pictures a bubble nucleus at a site enveloped by a warm liquid. The nucleus will begin to grow into a bubble only when the surrounding liquid is sufficiently superheated. The time required for the liquid to attain this superheat is called the waiting period. The transfer of heat from the superheated liquid into the bubble is considered to be a transient conduction process. A cavity is considered effective only if the waiting period is finite. This criterion gives the limiting sizes of effective cavities. The equations show that maximum and minimum sizes of effective cavities are functions of subcooling, pressure of the system, physical properties, and the thickness of the superheated liquid layer. Comparison of theoretical prediction with experimental data from several sources was made. The fluids considered were ether, pentane, and water, with water under various degrees of subcooling. The theory did predict the incipience of boiling and size range of cavities successfully.

668. Hsu, E. Y. et. al.

WATER TUNNEL EXPERIMENTS ON SPHERES IN CAVITY FLOW, Cal. Inst. Tech. Hydrodynamics Lab., Rpt. E-24.9 (April 1954)

669. Kermeen, R. W., McGraw, J. T., and Parkin, B. R.

MECHANISM OF CAVITATION INCEPTION AND THE RELATED SCALE-EFFECTS PROBLEM, Trans. ASME 77, 533 (1955).

An experimental investigation of incipient cavitation is described and the relationship between these experiments and current theories is discussed.

Experiments have indicated that the cavitation number for inception varies with free-stream velocity and body size for both streamlined and bluff bodies. Preliminary studies of the mechanism of cavitation were conducted in order to understand the reasons for the variations in cavitation performance. Photographic investigations have disclosed the effect of the boundary layer on cavitation inception for both streamlined and bluff bodies. In addition, this study has shown that tensions exist in the flow of ordinary water at incipient cavitation.

670. Knapp, R. T., and Hollander, A.

LABORATORY INVESTIGATIONS OF THE MECHANISM OF CAVITATION, Trans. Am. Soc. Mech. Engrs. 70, 419 (1948).

Investigations at California Inst. Technology; study of formation of individual bubbles carried on by use of high speed motion pictures taken at rates up to 20,000 per sec; from these records calculations have been made of rate of formation and collapse; deductions as to physical mechanism of cavitation phenomenon. (Sci. Eng. Ind. Abst. 1948-p. 198)

671. Kogarko, B. S.

MODEL OF A CAVITATING LIQUID, Doklady Akademii nauk SSSR, 137, 1331-33 (1961).

A description is given of a model of a medium that may be designated, in some approximation, as a cavitating liquid. Expansion and compression of the bubbles are described by the usual equations of hydrodynamics. The beginning of cavitation depends essentially on the existence of strange particles (cavitation nuclei) in the liquid, the size of which is 10^{-3} - 10^{-5} cm. In the model under consideration, the cavitation nuclei are taken to be spheres of equal diameter, and to be distributed uniformly over the entire volume of the incompressible liquid with density ρ_0. Cavitation bubbles will be formed in the liquid only if the pressure is below p_{cr}. Pressure p_{cr} is assumed to remain constant in the bubbles with expansion and compression of the latter. The radial motion of all bubbles obeys the same as does the motion of a single spherical cavity with constant internal pressure in an infinite volume of the incompressible liquid. Then, for each individual bubble,

$$R\frac{d^2R}{dt^2} + \frac{3}{2}\left(\frac{dR}{dt}\right)^2 = \frac{p_{kp} - p}{\rho_0} \quad , \qquad (1)$$

where R denotes its radius at the time τ, and p is the pressure of the liquid. It is further assumed in this model that mixtures of vapor and liquid are a homogeneous medium with a mean density. The latter can then be described by

$$\rho = \frac{\rho_0}{1 + b\,(R^3 - R_0^3)} \quad , \quad b = \frac{4}{3}\,\pi n \rho_0 \quad . \qquad (2)$$

From these two equations it is possible to derive the function $p = f(\rho, d\rho/dt, d^2\rho/dt^2)$, which, together with the continuity equation and the equation of conservation of momentum, constitutes a closed system of equations. The free energy F can be defined as follows:

$$F\left(R, \frac{dR}{dt}, T\right) = \frac{3b}{2} R^3 \left(\frac{dR}{dt}\right)^3 - \frac{b}{\rho_0} p_{kp} R^3 + \phi(T) \quad ,$$

$$S = -\frac{\partial F}{\partial T} \qquad (4)$$

It is easy, on the basis of this system, to generalize the model taking account of the surface tension, viscosity, and change of pressure in the bubbles. The linear, steady motion of a liquid through a tube with local narrowings is finally dealt with. If the cross section in a zone of this tube is larger than a given minimum cross section S_{min}, the pressure in that zone will drop to below p_{cr}. Equations

$$\rho U \frac{dU}{dx} = -\frac{dp}{dx} \quad ,$$

$$\rho u S = Q = \rho_0 u_0 S_0 \quad ,$$

$$\rho = \frac{\rho_0}{1 + b\,(R^3 - R_0^3)} \quad , \qquad (6)$$

$$u^2\left[R\frac{d^2R}{dx^2} + \frac{3}{2}\left(\frac{dR}{dx}\right)^2\right] + uR\,\frac{du}{dx}\,\frac{dR}{dx} = \frac{p_{kp} - p}{\rho_0} \quad ,$$

hold for such a zone. Here, u denotes the flow velocity, and Q is the liquid consumption. These equations have been numerically integrated for the case of the cross section being a function of x, thus $S(x) = k_0 x^2 + k_1$. It has been found that, beginning from the initial value R_0, the bubbles attain a determined maximum size, and subsequently become smaller. The bubbles, furthermore, display a tendency toward a steady growth. This corresponds to the case of a supersonic flow through a nozzle. It has therefore not been possible to set up a continuous solution at the tube outlet for an arbitrary pressure, p_2. It has been found necessary to introduce a compression jump coinciding with the boundary of the region of cavitation. The coordinates of the compression jump are related to the pressure as follows:

$$p_{kp} - p_2 + \frac{\rho_0 u_0^2}{2}\left[1 - \left(\frac{S_0}{S_2}\right)^2\right]$$

$$= b\rho_0 u_0^2 S_0^2 \int_{x_0}^{x_c} \frac{R^3 - R_0^3}{S^3}\,\frac{dS}{dx}\,dx \quad . \qquad (9)$$

This relation is obtained by integration of the first equation of system (6), taking account of the compression shock. The expression at the right-hand side expresses the energy loss arising with cavitation.

672. Kustova, A. V., and Kudryavtsev, B. B.

BEHAVIOR OF CAVITATION BUBBLES, Primenenie Ul'traakustiki k Issledovaniyu Veshchestva, Moscow, Sbornik. No. 9, 107-15 (1959).

The impact waves arising from the bursting of steam bubbles was studied. The exptl. app. consisted of a

thermostatted cuvette filled with water, into which water vapor was passed, under a pressure up to 0.2 kg/sq cm, through a narrow glass nozzle (diam. 0.5 - 1.3 mm) placed at a depth of 1.5 - 2.0 cm from the surface of the water. The waves thus arising were detected on a hydrophone and recorded on an impulse oscillograph. In cavitation created by a stream of superheated steam, as in ultrasonic cavitation, an impact wave arose. The pressure on its front was about 1 kg/sq cm (at a distance of 4 cm from a nozzle with a diam. of 1.3 mm and a steam pressure of 0.1 kg/sq cm). As the distance between the hydrophone and the nozzle increased, the pressure (registered by the hydrophone) decreased; the decrease, however, was considerably less than would be expected for a spherical wave. It is suggested that the bubble has the form of a lens upon bursting. This causes a nonuniform distribution of the energy of the wave. The pressure of the impact wave increased almost linearly with increase in the diam. of the nozzle and the steam pressure. A max. pressure was discovered in the defined temp. region; this suggests the desirability of maintaining optimum temp. in physicochem. processes accompanying cavitation. From Referat. Zhur., Khim. 1960, Abstr. No. 73643.

673. Kuttruff, H., and Plass, K.

SONOLUMINESCENCE AND BUBBLE OSCILLATION IN ULTRASONIC CAVITATION, Acustica (Internat.), 11, 224-29 (1961).

By taking instantaneous photographs of cavitation bubbles in relation to the observation of incipient sonoluminescence, a time correlation of the light occurence was obtained with the cavitation process. The cavitation bubbles were produced at a plane metal surface of 2 mm diameter, which forms the end surface in ethylene glycol of an immersed "Mason-horn." The sound frequency was 30 kc/s. It appears that the sonoluminescence takes place at the precise moments in which the cavitation bubbles fall together under the influence of the sound field.

674. Lieberman, D.

RADIATION-INDUCED CAVITATION, Phys. Fluids, 2, 4, 466.

Measurements of the thresholds of radiation-induced acoustic cavitation in pentane and acetone are described. A resonator method was employed. It is concluded that the observed cavitation was nucleated by recoil carbon ions in pentane. The results are compared with calculations based on Seitz's model of the nucleation process. The agreement is within an order of magnitude.

675. Mundry, E., and Guth, W.

MOVIE PICTURES OF VIBRATIONAL CAVITATION, Acustica, 7, AMR, 1958, No. 2170, pp. 241-250 (1957).

Cavitation bubbles are produced from a nickel transducer of frequency 2.5 kc/s and photographed at 12,500 to 105,000 frames/sec. In aerated water and moderate sound fields, bubbles are observed to vibrate in a mode indicating a combination of nonlinear forced vibration and sudden excitation at the natural frequency. In strong fields, both in aerated and degassed water a large number of tiny bubbles, which almost disappear during the time-period of one oscillation, are seen. The strong shock waves accompanying this phenomenon are photographed in a schlieren system.

676. Negishi, K.

PHASE RELATION BETWEEN SONOLUMINESCENCE AND CAVITATING BUBBLES, Acustica (internat.), 10, 124 (1960).

Sonoluminescence and scattered light from bubbles in water were observed by means of a photomultiplier output displayed on an oscillograph triggered by the input voltage to the exciting transducer. The bubble size and sonoluminescence intensity were photographed successively and suggest that the luminescence occurs at the instant of cavity collapse. When a microphone was placed in the cavitation region it was seen that minimum size of the cavities corresponded to a sharp pressure maximum, presumably produced by superposed shock waves resulting from cavity collapse.

677. Neppiras, E. A., and Noltingk, B. E.

CAVITATION PRODUCED BY ULTRASONICS; THEORETICAL CONDITIONS FOR THE ONSET OF CAVITATION, Proc. Phys. Soc. (London) 64B, 1032-38 (1951).

A theoretical extension of a previous paper (see preceding review) in which equations were developed describing the motion of a gas-filled cavitation bubble subjected to alternating pressure. The theory is now extended to show that cavitation is restricted to a definite range of the parameters (a) alternating pressure amplitude, (b) frequency of the applied pressure, (c) radius of bubble nucleus, (d) hydrostatic pressure. It is shown that under certain conditions there is a sharply defined threshold for the onset of cavitation. In this treatment it was necessary to assume the pre-existence of bubble nuclei above a certain minimum size as a condition for bubble growth. Solutions of some equations were made with the aid of a differential analyzer. No experimental data are presented. (Abst. App. Mech. Rev.-5-1761)

678. Noltingk, B. E., and Neppiras, E. A.

CAVITATION PRODUCED BY ULTRASONICS, Proc. Phys. Soc. (London) 63B, 674-685 (1950).

The differential equation for bubble growth is derived using the assumptions: (1) Pre-existence of bubble nuclei; (2) constant quantity of gas in the bubble; (3) isothermal expansion of gas; (4) incompressible liquid; (5) surface tension constant; (6) sinusoidal pressure variation; (7) bubble diameter small compared to a wave length; (8) neglect of vapor pressure within the bubble.

The differential equation is solved by means of a differential analyzer for a wide range of pressure amplitudes, frequencies, and bubble nuclei sizes. It is predicted that cavitation will disappear above a certain frequency. The equation for the pressures resulting from adiabatically collapsing gas-filled spherical bubbles is derived. No experimental data are given. The theory is extended in a further paper (see following review). (Abst. App. Mech. Rev.-5-1760)

679. Olson, R. M.

CAVITATION TESTING IN WATER TUNNELS, AD 54981 (1954).

680. Parkin, B. R.

SCALE EFFECTS IN CAVITATING FLOW, Hydrodynamics Lab., Calif. Inst. of Tech., Pasadena, Calif. AD-15861 (July 31, 1952).

Scale effects in cavitating flow are considered for the so-called limited cavitation flow regime. The effects on cavitation scaling of nuclei and dissolved air in ordinary water are considered. Previous work by the author is summarized and a theoretical study is made to gain insight into the relationships that must hold between the parameters which affect the inception of cavitation. A simplified theory gives only rough qualitative agreement with experiment.

681. Pease, D. C., and Blinks, L. R.

CAVITATION FROM SOLID SURFACES IN THE ABSENCE OF GAS NUCLEI, J. Phys. and Colloid Chem. 51, 556-67 (1947).

Conflicting data in the literature on cavitation and bubble formation must be ascribed to the lack of distinction between false cavitation due to preexisting gas nuclei and true cavitation in the absence of any gas phase. Three procedures are described to remove all gas nuclei. Systems of water in glass under these conditions will not cavitate unless forces of 100-200 atm are used. In the absence of gases easy cavitation occurs on stable solid "hydrophobic" surfaces with exposed nonpolar groups, such as capric acid, caprylic acid, paraffin, and ethyl cinnamate. Ionic mineral salts (KNO_3, $K_2Cr_2O_7$, K_2SO_4) do not ordinarily cavitate, unless heavy sludges of crystals are present. Unstable surfaces of melting and dissolving crystals do not induce cavitation. (CA-41-3673g)

682. Plesset, M. S.

THE DYNAMICS OF CAVITATION BUBBLES, J. Appl. Mechanics 16, 277-282 (1949).

Experiment has shown that flow about a torpedo-shaped body in a water tunnel can be adjusted to produce a few small cavitation bubbles just aft of nose portion. Elsewhere the water flow is continuous. This regime, which is of great interest in connection with the damage-producing mechanism of cavitation, has been studied both experimentally and theoretically. In setting up the equation of motion it has been assumed that each bubble behaves as if isolated in a spherically symmetrical pressure field of incompressible frictionless fluid. In order to integrate this equation, pressure at bubble wall has been assumed equal to vapor pressure at ambient temperature less pressure equivalent of surface tension; pressure at a distance from a bubble has been assumed to be unaffected by bubbles and has been computed from the value of pressure coefficient determined under noncavitating conditions; maximum bubble radius (where velocity is zero) has been obtained from photographic data. Theoretical values of bubble radius as a function of time are compared graphically with actual measurements. Good agreement is found, except near beginning and end of the bubble life. To discuss the interesting phenomena of collapse and rebirth of a bubble, theory must be extended to include compressibility effects. (AMR-3-2697)

683. Plesset, M. S., and Hsieh, Din-Yu.

THEORY OF GAS BUBBLE DYNAMICS IN OSCILLATING PRESSURE FIELDS, Phys. of Fluids, 3, 882-92 (Nov.-Dec. 1960).

By using the inertia forces which are set up by the sudden deceleration of a fast-moving liquid column and produce very low pressures therein, spherical cavitation bubbles of over 1 cm diameter can be produced in water. Cinematograph studies were made of the formation, collapse, and rebound of the bubbles, as well as of the very strong shock waves set up by the implosion. Similar experiments give rise to luminescence in glycerine.

684. Pode, L.

THE DIFFUSION OF AIR INTO A PULSATING CAVITATION BUBBLE, DTMB-804 (1955), 17 p.

A calculation is made of the growth of a cavitation bubble through the diffusion of air induced by the spherically symmetrical mechanical motion of the pulsating bubble. The equation of motion of the boundary is derived from energy consideration. Kinetic theory is applied to determine the boundary conditions for the diffusion equation. The diffusion equation is treated by means of the approximation that the diffusion takes place in a very small layer of water about the boundary. Numerical results are obtained for one case of a strongly pulsing bubble. It is found that the growth per period is relatively small unless the bubble is extremely tiny. (App. Mech. Rev.-9-2959)

685. Portnov, I. G.

THE LEADING BOUNDARY CAVITATION REGION, Akademiia Nauk SSSR. Otdelenie Tekhnecheskikh Nauk, Izvestiia, No. 3, 99-107 (1957) (In Russian).

Study of the stability of the stationary temperature field in moving media, and application of results to the study of cavitation flows (AEI, 1957).

686. Portnov, I. G.

THE TEMPERATURE FIELD IN THE SHEARED CAVITATION REGION, Translated from Izvestiya Akademii Nauk SSSR, Otdelenie Khmicheskikh Nauk, No. 1, pp. 63-71, 1958), AEC-TR-3413 (1958), 20 p.

Corresponding cylic temperature intensifications are noted, which apparently play a substantial role during the appearance of cavitation shattering of the surface walls, adjacent to cavitation regions that have reached the fatigue limit. The temperature of this phase transition in the problem is assumed to be constant and equal to $\mu\xi$. The problem is reduced to determining the situations of the isotherm $\mu\xi$ as a function of time. It is assumed that the temperature changes are sufficiently small so that the density ρ, the thermal capacity under constant pressure c, and

the thermal conductivity k can be taken as constant. These changes must be such that the influence of the energy dissipation on the temperature field is negligible.

687. Raven, F. A., Feiler, A. M., and Jesperson, Anna

AN ANNOTATED BIBLIOGRAPHY OF CAVITATION, DTMB-R-81, (Dec 1947), 205 p.

The scope of the list has been limited neither by the classification nor the dates of the articles, as an attempt was made to cover all the work in the field dating from the first identifications of cavitation as an influencing factor in the performance of hydraulic machines. The entries are arranged first alphabetically by authors, and then chronologically under the name of the individual authors. A list of publications referenced is given, but no table of contents or indexes are included.

688. Rosenberg, M. D.

GASEOUS-TYPE CAVITATION IN LIQUIDS, AD 34119 (1953).

689. Schmid, J.

CINEMATOGRAPHIC INVESTIGATION OF SINGLE BUBBLE CAVITATION, Acustica, 9, 321-6 (1959).

The behaviour of a permanent gas bubble in a liquid with an oscillating pressure field is analyzed with a linearized theory. If the assumption is made that conditions within the bubble are uniform, the thermodynamic relations found are as expected; i.e., at low frequencies the bubble behaves isothermally and at high frequencies the behaviour becomes adiabatic. However, a more detailed analysis, which allows the bubble interior to vary not only in time but also in space, leads to an average isothermal behaviour for the bubble even in the high-frequency limit.

690. Self, M. W., and Ripken, J. F.

STEADY-STATE CAVITY STUDIES IN A FREEJET WATER TUNNEL, AD 71800 (1955).

691. Shalnev, K. K.

CRITERION FOR THE INCIDENCE OF BREAK-AWAY CAVITATION ON A CYLINDRICAL PROFILE, (Trans. from Doklady Adad. Nauk. S.S.S.R. 61, 799-802), AEC-TR-2094 (1948) 7 p.

In cavitation calculations for hydraulic machinery, a requirement is to determine the danger of cavitation developing on any component of the machine, given the distribution of pressures on the said component. Results are presented of research on a criterion for the incidence of cavitation of the break-away type in the region of break-away flow behind a cylinder. (NSA-9-3127)

692. Shalnev, K. K.

PRESSURE AND EROSION IN THE REGION OF COLLAPSE CAVITATION OF CIRCULAR CROSS SECTION, Izvest. Akad. Nauk. S.S.S.R. Otdel. Tekh. Nauk, No. 6, 111-20 (June 1954).

693. Shalnev, K. K.

SHAPES OF THE CAVITATION REGION ON A TRANSVERSE FOIL IN A NORMALLY INCIDENT STREAM, (Trans. from Doklady Akad. Nauk. S.S.S.R., 94, 1017-22) AEC-TR-2096 (1954), 7 p.

The conditions of formation of cavitation behind a foil placed normally to the flow axis are identical with the conditions of cavitation back of a circular profile. In a plane-parallel stream with a positive gradient or pressure, the shape of the cavitation hollow agrees only in the initial stages with the theoretical notion that the boundary of the cavitation region has an unidirectional curvature, and in the more developed stages, only in that part of the boundary line closest to the foil. In the extremely developed cavitation stages, the fact that the part of the surface which closes off the cavitation hollow breaks up into cavitating streams rules out the possibility of a counterflow of the boundary stream toward the hind side of the foil. In the cavitation region the mean pressure is not the same at all points; it depends on the structure of this region, and consequently, on the stage of cavitation. The pressure in the cavitation region is equal to the vapor pressure of water only in the gaseous zone of that region. (NSA-9-3128)

694. Shalnev, K. K.

STRUCTURE OF THE CAVITATION REGION, Izvest. Akad. Nauk. S.S.S.R. Otdel. Tekh. Nauk., No. 5, 119-46 (May 1954).

This extensive report of investigations on cavitation phenomena includes reproductions of motion pictures of the cavitation process. The experimental loop is illustrated, and the many data are graphed. 31 figures. 33 references.

695. Shalnev, K. K.

THE KINEMATIC STRUCTURE OF BREAK-AWAY CAVITATION ON A CIRCULAR PROFILE, (Trans. from Doklady Akad. Nauk. S.S.S.R. 97, 785-8) AEC-TR-2098 (1954), 9 p.

A study of break-away cavitation on a circular profile was made with high-speed motion pictures in a miniature hydrodynamic cavitation tunnel, the cavitation taking place on the walls of diffusors and on surface irregularities. (NSA-9-3217)

696. Shal'nev, K. K.

INTENSITY OF CAVITATION EROSION, Izvest. Akad. Nauk, S.S.S.R, Otdel. Tekh. Nauk, No. 1, pp. 3-20 (January 1956).

A shortened version of a paper presented by author at the internal symposium on "Cavitation in Hydrodynamics," National Physical Laboratory, Teddington, England, 1955 (see AMR v. 10, Rev. 176)(AMR 1958, No. 1665)

697. Strasberg, M.

THE INFLUENCE OF AIR-FILLED NUCLEI ON CAVITATION INCEPTION, DTMB 1078 (May 1957), 25 p.

This report was prepared for presentation at the American Towing Tank Conference held

September 1956 in Washington, D. C., and apparently represents a condensation of the author's Ph.D. dissertation submitted to Catholic University. Those who have a casual to active interest in the subject of cavitation, but without regard to too many details, will find this paper interesting reading as it represents some of the latest thinking on cavitation inception. Those working in the field who are interested in the details would probably find that the author's Ph.D. dissertation would better serve their purpose. More than half of the report comprises a theoretical discussion of the need for and the characteristics of cavitation nuclei in water. Also included is a theoretical review discussion of the two types of cavitation, namely, vaporous and gaseous cavitation.

The real contribution of the paper is a description of the author's experimental investigation of cavitation using ultrasonics. The results of the experimental investigations are somewhat limited because a quiescent undisturbed sphere of water was used as the experimental medium and it would be difficult to extrapolate results to flowing water. Nevertheless, the experimental results lend some support to the theoretical predictions for behavior of stabilized air nuclei. It is of interest to see a relatively new technique applied in studying cavitation.

698. Suquet, P.

DIFFUSION OF GASES IN THE VICINITY OF A CAVITATION BUBBLES, J. Phys. Radium, 18, 676 (December, 1957).

The diffusion of gases towards the liquid phase is observed during the period of contraction of an ultrasonic bubble. To a first approximation, the basic assumption is that the period of the vibratory motion is of sufficiently short order for the geometric centre of the bubble to be considered as immovable with respect to an axial system related to the container.

699. Sutton, G. W.

A PHOTOELASTIC STUDY OF STRAIN WAVES CAUSED BY CAVITATION, ASME, Summer Conf., Berkeley, Calif., Paper 57-APM-15 (AMR-92) (June 1957) 9 p.

In spite of the destructive effects of cavitation on marine propellers, the microscopic size of the phenomenon and its rapid transient nature have hindered its full understanding. A method of producing acoustic waves in water on a small scale was used to produce cavitation at the surface of a $\frac{1}{16} \times \frac{1}{16} \times \frac{1}{8}$-in. CR-39 specimen in the laboratory. Photoelastic effects were observed over an area 0.004 in. square just inside the surface of the plastic with a multiplier phototube and oscilloscope. The records indicate a periodic strain variation in the plastic due to the pressure variations and a sharp peak at the part of the cycle where the pressure becomes positive. The duration of this peak, which gives rise to a strain wave, is about 2 μsec. High-speed photographs were taken of the photoelastic pattern, and these also show the formation and disappearance of the bubble cloud. A disturbance of the pattern can be seen to be associated with the disappearance of the bubbles.

More than half the paper is devoted to a careful investigation of the mechanical and photoelastic properties of CR-39, both static and dynamic. Author concludes that in this material the birefringence is proportional to strain, not stress, an interesting result in itself. The dynamic modulus of elasticity was measured from the free-free vibrations of bars of various lengths and was found to increase rapidly and frequently. The dynamic fringe value was determined under impact loading in which the strain was applied in about 25 μsec. Extrapolating these quantities to the frequencies set up in the test, the calculated stresses due to cavitation are about 2×10^5 psi.

EFFECTS ON PHYSICAL PROPERTIES

700. Akselrod, L. S., and Dilman, V. V.

SPECIFIC GRAVITY OF A GAS-LIQUID EMULSION DURING BUBBLING (Udel'nyy ves gazo-zhidkostnoy emul'sii pre barbotazhe), Khimicheskaya promyshlennost (Chemical Industry), Nr 1, 28-33 (1954).

In the exptl. work a liquid was delivered into the tubular space above a perforated plate. Air was passed through the plate at a given rate and the height of the air-liquid emulsion formed was measured. At the same time were noted the resistance to the air flow, the temp. of the entering air, and the temp. in the emulsified layer. The sp. gr. of the emulsion was calcd. from $\gamma = [1 - 0.91 (w_0/\nu) (d_0/t)^2]\gamma_1$, where w_0 is the velocity of air in m/sec, ν rate of rise of an air bubble, d_0 is the diam. of the apertures in the plate in mm, t is the distance between apertures in mm, and γ_1 is the sp. gr. of the liquid. The liquids studied were distd. H_2O, 22-41% glycerol, C_6H_6, $MeCO_2$, EtOH, and $C_2H_4Cl_2$. For an air velocity (w_{cr}) at which the bubbling commences to change to streaming the relative sp. gr. (γ/γ_1) was calcd. to be $\gamma/\gamma_1 = (\gamma_{cr}/\gamma_1) 7(w - w_{cr})/(\sqrt{hg})(\sigma h/\gamma_1 t^3)^{1/6}$, where h is height of the liquid in the column in mm, and σ is surface tension of the liquid. $\gamma_{cr} = [1 - 0.606(d/t)^2]\gamma_1$, where d is the diam. of the bubble. Thus γ/γ_1 is independent of viscosity of the liquid and the diam. of the apertures in the plate. (CA-48-13306f)

701. Caw, W. A., and Wylie, R. G.

EFFECT OF DISSOLVED AIR ON THE VISCOSITY OF WATER, Nature, 198, 995-6 (1961).

The viscosity of air-saturated water was measured relative to that of air-free water, the temperature being controlled to within ±0.0007°C. Within a set, the flow-times agreed within 1 part in 50,000. The effect of air at atmospheric pressure on the kinematic viscosity of water does not exceed 13 parts in 10^5 at the 95% confidence level. This relates to the combined effects of the dissolved air and the pressure. The direct effect of the pressure of 1 atm is to change the viscosity by no more than a few parts in 10^5. These investigations were made at 20, 25, and 30°C.

702. Davis, G. E.

SCATTERING OF LIGHT BY AN AIR BUBBLE IN WATER, J. Opt. Soc. Amer. 45, 572-81 (1955).

Determination of angular description of intensity of light of 5893A wavelength scattered from collimated beam incident upon spherical air bubble in water;

intensity values are plotted with both rectangular and polar coordinates.

703. Martin, W. L.

TRANSIENT BEHAVIOR OF BUBBLES, p. 290 in PROCEEDINGS OF THE SECOND FLUID FUELS DEVELOPMENT CONFERENCE HELD AT OAK RIDGE NATL. LAB., CF-52-4-197 (Rev.) April 17-18 (1952)

An important factor in determining the transient behavior of homogeneous factors is the behavior of the density of the material in the core. When the core density is decreased by the presence of growing vapor bubbles due to temporary or permanent operation above the saturation temperature, the transient density of the liquid system must be evaluated to aid in determining the behavior of the reactivity. Research on bubble formation and growth in such liquid systems is described. The systems are subjected to heating similar to that in the reactor core. When this heating level is changed, as might occur during a corresponding change in reactivity, the density transient is recorded. The information will aid in evaluating the response of homogeneous reactors subjected to changes in operating power level.

704. Sugden, S.

THE DETERMINATION OF SURFACE TENSION FROM THE MAXIMUM PRESSURE IN BUBBLES, J. Chem. Soc. 121, 858-66 (1922).

The values obtained for the surface tensions of many common liquids by different observers using the maximum bubble pressure method not only differ among themselves, but are not in agreement with the results yielded by other methods, such as that in which capillary rise is measured. The causes of these discrepancies are principally as follows: (1) If the liquid has a finite angle of contact with glass, the maximum bubble pressure method, which is independent of the contact angle, will give the true surface tension, whilst the method of capillary rise will furnish lower values equal, for small tubes, to the product of the surface tension with the cosine of the angle of contact. (2) Inaccurate knowledge of the surface tensions of the liquids used for purposes of comparison. (3) The assumption that the surface tension is proportional to the pressure required to liberate bubbles from a given jet is not strictly accurate, but with the small tubes usually employed the error thus introduced is very small. (4) With the maximum bubble pressure method it is usually necessary to correct for the curvature of the larger surface of the liquid, since with most liquids the central portion of the meniscus has a negligible radius of curvature only when tubes several centimetres in diameter are used.

It is not easy to deal mathematically with the form of the surface of a liquid in a tube of circular cross-section with another tube placed at its axis, but the difficulty may be overcome in a manner similar to that employed by the author with the method of capillary rise. If two tubes of different radii are immersed to the same depth in a liquid and the pressure required to liberate bubbles from each is measured, the surface tension may be calculated from the difference between these pressures. The relationship between the capillary constant of the liquid, the radius of the tube, and the maximum pressure in the bubble is worked out for tubes up to several millimetres in diameter, and a simple form of apparatus devised which gives, for the surface tensions of water and benzene, values in satisfactory agreement with those obtained by the method of capillary rise. (CA-1627-8)

705. Taylor, G.

A DISCUSSION ON THE FIRST AND SECOND VISCOSITIES OF FLUIDS: THE TWO COEFFICIENTS OF VISCOSITY FOR AN INCOMPRESSIBLE FLUID CONTAINING AIR BUBBLES, Proc. Roy. Soc. (London), A226, 34-37 (1954).

Incompressible fluids possess only one coefficient of viscosity because, by definition, no changes in volume can occur. If such a fluid contains air bubbles it becomes compressible, and any changes in volume involve a contraction or expansion of the bubbles which is resisted by the ordinary viscosity of the surrounding fluid. The resulting second coefficient of viscosity is found to be $4\mu/3v$ where μ is the viscosity of the incompressible fluid and v the (small) proportion of the total volume which is occupied by the bubbles.

The effect of compressibility in the fluid is discussed in Notes by Taylor and Davis (abstracts following). In the second of these it is shown that a relaxation time must exist and in the first the volume viscosity of water containing air bubbles is calculated. This is found to reach a maximum value of 6700 times the viscosity of water when $v = 5 \times 10^{-5}$. (Sci. A. 58-83)

706. Taylor, G.

NOTE ON THE VOLUME VISCOSITY OF WATER CONTAINING BUBBLES, Proc. Roy. Soc. (London), A226, 38-9 (1954).

The theory given formerly is extended to a compressible liquid like water. (CA-49-1394e)

FORMATION (Other than Boiling)

707. Asanii, T.

THE FRACTURE MECHANISM OF LIQUIDS, Busseiron Kenkyu (Researches on Chem. Phys.), No. 57, 54-62 (1952).

The fracture of a liquid, which is phase sepn. in a closed vessel when the pressure is decreased to a crit. value p_c (fracture pressure), was studied by measuring the frequency of fracture at various p_c values with H_2O initially satd. with air. There are 3 regions in p_c: (A) in which vapor bubbles appear on the surface of the container in the vicinity of the vapor pressure; (B) the fracture occurs almost instantly and p_c, being neg. and of the order of several atm., greatly depends on the state of surface and its geometrical shape; and (C) p_c has numerically much larger neg. value. Theoretical calcns. of p_c by the theory of nucleation are given for various models. The following p_c values for water

at 300°K are needed for each process: -1390 atm to form a nucleus of vapor phase in a sec. inside the liquid; -1100, -980, -820, and -300 atm to form a nucleus on the plane surface of the container, the contact angle being 60, 90, 105, and 140°, resp.; -200 (γ = 10°, θ = 160°), -22 (10°, 120°), -3.3 (10°, 90°), -1.4 (10°, 80°) atm to form a bubble in a conical cavity whose vertical angle is γ, θ being the angle between the bubble surface and the cavity wall, when (μ = sin γ cos θ) is pos., where μ is 2 sin^2 $\gamma[1 - \sin(\gamma + \theta)]/\cos^2(\theta + \gamma)$; p_c becomes equal to the satd. vapor pressure of the liquid if (μ - sin γ cos θ) is neg. The correspondence of exptl. values of p_c with theoretical ones is examd. (CA-47-1448f)

707 A. Asanii, T.

NEGATIVE FRACTURE-PRESSURE OF LIQUIDS, Busseiron Kenkyu (Researches on Chem. Phys.) No. 57, 26-32 (1952).

The fracture pressure which causes the destruction and the phase sepn. of liquid is calcd. by the nucleation theory. Good agreement results with expts. if an assumption is made that the inhomogeneous solid-liquid interface accelerates the nucleation of vapor bubbles. (CA-46-10740i)

708. Bateman, J. B., and Lang, J.

FORMATION AND GROWTH OF BUBBLES IN AQUEOUS SOLUTIONS, Can. J. Research, 23E, 22-31 (1945).

Expts. on the evolution of N and CO_2 from various aq. solns. subjected, in a simple dilatometer, to decreased pressures support the view that all aq. solns. contain a small no. of foci for bubble formation, as shown by a rapid transient evolution of gas immediately after a large, rapid reduction of pressure. The nuclei are rather specific in character; most of the particles in suspensions of charcoal, blood corpuscles, and various hydrophobic substances cannot function in this manner. When decompression occurs in small steps, evolution of gas is mainly attributable to bubbles formed at preferred spots on the vessel wall. Variations in rate of growth are analyzed in terms of the nature of the dissolved gases (N or CO_2), the pressure gradient, and the relative importance of pure diffusion and convection under various conditions. The effect of CO_2 in accelerating the growth of N bubbles is attributed mainly to its high absorption coeff. rather than to any specific effect upon the no. of gas nuclei.

709. Benzing, R. J., and Myers, J. E.

LOW FREQUENCY BUBBLE FORMATION AT HORIZONTAL CIRCULAR ORIFICES, Ind. Eng. Chem., 47, 2087-90 (1955).

Cumulative bubble vols. were detd. for various orifice diams. and fluid systems. The relation between the bubble diam. and the properties of the systems are correlated by the equation $D/d = 1.82\,[(\sigma)/(gd^2\rho L)]^{0.25}$ where D = diam of bubble, cm; d = diam of orifice, cm; σ = surface tension of liquid, dynes/cm; g = acceleration due to gravity, 980 cm/(sec)^2; and ρL = liquid d., g/cc.

710. Bernath, L.

THEORY OF BUBBLE FORMATION IN LIQUIDS, Ind. Eng. Chem., 44, 1310-13 (1952).

The nucleation theory of Volmer, Becker, and Dŏring, as applied to the formation of vapor bubbles in pure liquids, is reviewed. An application of the theory to the calculation of the fracture pressures of pure liquids is presented. Recent experimental data are compared with fracture pressures calculated from the Volmer theory and with values calculated using the Eyring reaction rate process theory as applied by Fisher.

711. Bloomfield, M., et al.

BUBBLE FORMATION, A BIBLIOGRAPHY, NAA-SR-2551 (June 1958).

Bubble phenomena have been given a new meaning with their study in relation to the kinetic behavior of reactors. Prior to their study in relation to physics, the bulk of work on bubble phenomena concerned naval engineering problems of behavior in cavitation and water entry behavior. This bibliography is intended to fill the need of the reactor physicist as well as the naval engineer. An attempt has been made to include all available references on bubble phenomena and associated effects. A subject index has been purposely omitted. It is felt that the breakdown in content headings is sufficient to ascertain areas of interest. There will be overlapping of headings and to find all possible entries, a search through the headings may be desirable. To increase the usefulness of this bibliography the location of an abstract has been cited wherever possible following the reference. Classified reports are included; however, their titles contain no classified information. Sources used in compiling this bibliography are: Chemical Abstracts, Industrial Arts Index, Applied Mechanics Review, Nuclear Science Abstracts, the AEC Abstracts of Classified Literature, the AEC card catalogs available at Atomics International, and the bibliographic services of Armed Services Technical Information agency.

712. Bowers, R. H.

THE MECHANICS OF BUBBLE FORMATION. J. Appl. Chem., 5, 542-8 (1955).

Gas-to-liquid transfer rates were measured with paper pulp to stimulate the mycelial growth that causes bubbles to coalesce in industrial fermenters. Effective reduction of coalescence was achieved by high-speed mech. agitation.

713. Bowman, W. H., and Parish, G. T.

BUBBLE FORMATION IN INTERNALLY-HEATED AQUEOUS SOLUTIONS, KT 95 (Nov. 1950), 19 p.

A study was made of the transient and steady state phenomena taking place in an internally heated liquid. Complete discussions are included on results and procedures. Photographs of the bubble formation are also included.

714. Budge, E. A.

A NEW FORM OF BUBBLE COUNTER FOR MEASUREMENT OF GAS EVOLUTION, J. Am. Chem. Soc. 53, 2451-3 (1931).

A glass app. releasing uniform bubbles and operating an elec. counter is described. (CA-25-4446-1)

715. Datta, R. L.

THE DESIGN OF GAS LIFT PUMPS. I. THE FORMATION AND CHARACTERISTICS OF GAS BUBBLES, J. Imp. Coll. Chem. Eng. Soc. 4, 157-69 (1948).

Factors studied were the effect of nozzle or orifice diam. on the vol. of single gas bubbles rising in an undisturbed liquid (cf. Maier, C. A. 22, 846), the effect of bubble diam. (cf. O'Brien and Gosline, C. A. 30, 655[1]) and surface tension of the liquid on velocity of rise, and the effect of liquid η on bubble size and velocity of rise. (CA-44-4290i)

716. Datta, R. L., Napier, D. H., and Newitt, D. M.

THE PROPERTIES AND BEHAVIOR OF GAS BUBBLES FORMED AT A CIRCULAR ORIFICE, Trans. Inst. Chem. Engrs., 28, 3-16 (1950).

Expts. are reported covering the relation between the vol. of a bubble and the size of the orifice at which it is formed; the shape of gas bubbles formed at an orifice and rising in a column of liquid; the vol. of bubbles as a function of the rate of formation at various hydrostatic heads; the effect of surface tension of bubbles; and the absorption of gas from bubbles. Photographs show bubble formation and bubble action during ascension in a column. (CA-44-4748d)

717. Davidson, J. F., and Schuler, B. O. G.

BUBBLE FORMATION AT AN ORIFICE IN A VISCOUS LIQUID, Trans. Inst. Chem. Eng., 38, 335 (1960).

Theory of formation of bubbles in liquids of high viscosity with gas flow rates between 0 and 50 ml/sec; using theory it is possible to calculate volume of bubble by assuming that orifice acts as point source of gas supply and that motion and position of bubble is governed by viscous, inertia and buoyancy forces; effects of physical variables.

718. Davidson, L.

STUDY OF THE FORMATION OF GAS BUBBLES FROM HORIZONTAL CIRCULAR SUBMERGED ORIFICES, Ph.D. Thesis, Columbia University (1951).

719. Davidson, L.

A STUDY OF THE FORMATION OF GAS BUBBLES FROM HORIZONTAL CIRCULAR SUBMERGED ORIFICES, Univ. Microfilms, Pub. No. 3678, Dissertation Abstr. 12, 460-1 (1952), 221 p.

720. Davidson, Leon, and Amick, E. H., Jr.

FORMATION OF GAS BUBBLES AT HORIZONTAL ORIFICES, A. I. Ch. E, 2, 337-42 (1956).

Air bubbles were formed in water and in mineral oil by use of single, circular, horizontal, sq-edged orifices facing upward. Twenty orifices were tested, ranging from 0.017 to 0.79 cm in radius. Increasing the vol. of the gas chamber below the orifice (over the range of 4 to 4000 cc) was found to increase the bubble size. The tests were conducted at atm pressure. The gas-flow varied from about 0.01 to about 250 cc/sec. At relatively low flow rates, the orifices generally formed single "static" bubbles, the vols. of which were proportional to the surface tension and orifice radius and independent of the gas flow rate. At high flow rates the bubble frequency became high and the bubble vol. became proportional to the gas flow rate and independent of the surface tension. The bubble frequency reached a max. value for each orifice, this value being a function of the orifice radius. For air bubbles in water, the correlation of the max. bubble frequency, n_m bubbles/sec with the orifice radius, r cm, and the air flow rate, q cc/sec, was found to be $n_m = 9.1q^{0.13}/r^{0.43}$. The max. frequencies ranged from about 25 for the largest orifices to about 75 bubbles/sec for the smallest orifices used. Consecutive bubbles paired or coalesced in definite ways in certain ranges of the gas flow rate.

721. Dean, R. B.

THE FORMATION OF BUBBLES, J. Appl. Phys., 15, 446-451 (1944).

Extreme values for the neg. pressures and the degrees of superheat which water will withstand without forming bubbles are contrasted with the ease of forming bubbles by vibration or by turbulent flow. The subject of bubble nuclei is reviewed; such nuclei usually function by virtue of sorbed or trapped air which can be removed, rendering the nuclei ineffective. Methods of avoiding extraneous bubble nuclei are given, with some experiments on the formation of bubbles by mechanical action. Free vortices in liquids produce sufficient tension to rupture the liquid, and mechanical disturbance produces bubbles only in such vortices. (Sci. A. 47-1981)

722. Dempster, A. J.

PHYSICS DIVISION REPORT FOR MONTH ENDING APRIL 15, 1945, CF-2926 (1945), 36 p.

Procedures for preparing diborane and removing ethane from diborane are given. Geiger-Mueller tubes operating at very low potentials are described. Lattice dimensions and calculated densities are given for Np_2S_3, U_2S_3, Th_2S_3, Nb_2O_5, and Ta_2O_5. Lattice dimensions are also given for heavily irradiated and control samples of graphite. Some discussion on breeder reactors is given. A resonance formula for nuclear reactions was derived, assuming that the wave function of the compound nucleus independent of energy. The effect of bubble formation on k loss in reactors was studied. Critical size formulas and fertility and heat transfer calculations relative to resonance breeders are discussed. Neutron diffusion in finite bodies is considered by the statistical distribution of cord lengths. The mass transfer coefficient for water through a sphere bed of benzoic acid was studied. Formation of bubbles in supersaturated water during flow through pipes was observed.

723. Drossbach, P.

ANODE EFFECT, Z. Elektrochem. 55, 38-41 (1951).

This phenomenon is due to several effects. First, a strong gas bubble effect must be present at high c.d., after which a thermal effect may take place. The thermal effect starts with a heating and expansion of the gas bubble, which goes over into a "Leidenfrost" phenomenon because of the continuous rise of the c.d. An electrostatic effect follows owing to the change in the gases. In addn. to the ionization of the anode gases, the small ionization of the salt vapors also plays some sort of a role. Theoretical considerations are cited in addn. to some exptl. evidence. (CA-45-5543g)

724. Eversole, W. G., and Wagner, G. H.

THE FORMATION OF GAS BUBBLES IN LIQUIDS, Proc. Iowa Acad. Sci. 46, 193-4 (1939).

Gas bubbles which were formed by passing N through a glass capillary into liquids were studied by means of stroboscopic frequency measurements, rate of gas flow, and instantaneous (approx. 10^{-5} sec exposure) photographs. The size of the bubbles was detd. both from the frequency and rate of gas flow and from measurements of the photographic images of the bubbles. The following pure liquids and solns. were used at room temp.; C_2H_5OH, Pr alc., aniline, acetone, benzene, $CHCl_3$, CCl_4, CH_3OH, Bu alc., Et_2O, and 3 aq. solns. of C_2H_5OH. The pressures used were varied from the lowest pressure that would give a steady stream of bubbles (approx. 0.6 cm of Hg) up to about 2.3 cm of Hg. Capillary diams. were 0.0137-0.0341 cm. The bubble frequency was practically const. (45-50 bubbles/sec) for the pure liquids studied at all pressures and capillary diams. used. It follows, therefore, that the size of each bubble (cc) is directly proportional to the rate of gas flow (cc/sec) and is independent of the properties of the liquid and the capillary diam. in the range of exptl. conditions used. Higher pressures, larger capillary diam. and lower surface tension give larger bubbles as a result of the increased rate of flow. With 20.2, 70.7, and 40.7% aq. solns. of C_2H_5OH the bubble frequency was greater than with pure liquids and showed a much greater variation with pressure. (CA-34-6866-7)

725. Eversole, W. G., Wagner, G. H., and Stackhouse, E.

RAPID FORMATION OF GAS BUBBLES IN LIQUIDS, Ind. Eng. Chem. 33, 1459-62 (1941).

Gas bubbles were formed in pure liquids and solutions by passing nitrogen gas through submerged orifices (radii of 0.0069 to 0.017 cm) at rates of 0.125 to 0.7 cm/sec. Bubble size was determined from stroboscopic frequency measurements and rate of gas flow and from micrometer measurements of the photographic images. As the bubble frequency was relatively constant in all pure liquids, the bubble volume in pure liquids was found to depend principally on the rate of gas flow. (Sci. A. 45-394)

726. Farncomb, F. J.

THE INITIATION OF BUBBLES IN SUPERSATURATED SOLUTIONS OF GASES, Trans. Roy. Soc. Can. Sec. III (3) 19, 32 (1925).

$PbCl_2$ crystals, phenol globules, freshly pptd. AgI, colloidal As_2S_3 and $Fe(OH)_3$, starch and Pt wire had no appreciable effect on the initiation of bubbles. Crystals of C_6H_5COOH, salicylic acid and phthalide, Fe wire and paraffin wax globules had a small but decided effect. Pptd. AgI, $CaSO_4$ and boric acid crystal had a very strong effect. Many of the solids used were formed within the soln., thus eliminating preformed gas films. Bubbles are initiated chiefly by substances wetted with difficulty by the solvent. (CA-20-320-1)

727. Garabedian, P. R.

ON STEADY-STATE BUBBLES GENERATED BY TAYLOR INSTABILITY, Proceedings of the Royal Society of London, Series A, 241, pp. 423-431, PA, 1958, No. 534 (August 20, 1957).

A theory of the steady motion of a long bubble rising through an infinite plane vertical tube of liquid is presented. It is shown that, contrary to current belief, the flow is not uniquely determined by the width h of the tube and the acceleration of gravity g alone, but that the speed U of the bubble can also be prescribed. However, a criterion of stability singles out the unique physically significant flow of this type as the one which maximizes the velocity of the bubble. With the aid of a difference-differential equation derived from the free-boundary condition, the Froude number $U/(gh)^{1/2}$ for this latter case is estimated to exceed 0.2363, a value slightly higher than that indicated by earlier work on the problem.

728. Glaser, D. A.

SOME EFFECTS OF IONIZING RADIATION ON THE FORMATION OF BUBBLES IN LIQUIDS, Phys. Rev. 87, 665 (1952).

The effect of ionizing radiation on the stability of diethyl ether at 130°C indicates increase of bubble formation on exposure to the radiation. (Sci. A. 55-8529)

729. Harrison, D., and Leung, L. S.

BUBBLE FORMATION AT AN ORIFICE IN A FLUIDIZED BED, Trans. Inst. Chem. Engrs., 39, 409-14 (1961).

A study of the formation of air bubbles at an orifice located within a fluidized bed, for orifice gas flow rates (F), of 1-8000 ml/sec was reported. A capacitance method was used to det. the rate of bubble formation. From this rate and F, the bubble vol. (V) was calcd. The equipment used, a 6-in.-diam. bed, (1) with orifices of 4 diams., 0.125-0.94 cm, and a 2-ft-square bed (2) with a 1-in.-diam. orifice, is described. A Fielden type PM2 proximity meter, coupled to an oscilloscope, detd. capacitance changes between 2 probes placed near the orifice. The solids fluidized were sand particles (d = 2.64; 60-150 mesh) and spent alumina catalyst particles (d = 2.04; 170-350 mesh).

730. Harrison, D., and Leung, L. S.

BUBBLE FORMATION AT AN ORIFICE IN A FLUIDIZED BED, Nature 190, 433-4 (1961).

A capacitance measurement was used to det. the frequency of air bubble formation at an orifice in a fluidized bed. Bubble vol. at air flow rates below 10 ml/sec is given by equation: $V = 1.378\ G^{1.2}/g^{0.6}$; where G, ml/sec, is a const. gas flow rate through the orifice and g is the acceleration of gravity. The exptl. data deviates from the equation above 10 ml/sec; this is thought to be partly due to formation of "double bubbles." Over the exptl. range studied, bubble frequency is essentially independent of bed height, flow rate of fluidizing air, and nature and size of the particles.

731. Harvey, E. N., et al.

BUBBLE FORMATION IN ANIMALS. I. PHYSICAL FACTORS. II. GAS NUCLEI AND THEIR DISTRIBUTION IN BLOOD TISSUES, J. Cellular Comp. Physiol. 24, 1-34 (1944).

Bubbles rarely form in small resting animals under greatly decreased atm. pressure but do occur in blood vessels chiefly veins and occasionally in lymph vessels as a result of muscle contraction or injury to muscle. Bubbles form abundantly in both arteries and veins and can be seen in many tissues after compression-decompression (6-8 atms) expts. with resting animals. They occur occasionally in eye humors, cerebrospinal fluid and amniotic fluid but have never been observed in bladder urine. Bubbles in resting animals at high altitudes or after previous pressurization are believed to come from such minute gas nuclei, probably on the surface of cells rather than free in liquid. (CA-39-334-4)

732. Harvey, E. N., et al.

REMOVAL OF GAS NUCLEI FROM LIQUIDS AND SURFACES, J. Am. Chem. Soc. 67, 156-7 (1945).

Methods that prevent the bubbling of liquids supersatd. with gas (i.e., removal of gas nuclei) (1) strong centrifuging of liquid and container (this removes all gas nuclei that grow to bubbles at a P of 740 mm (gas macronuclei); however, gas micronuclei remain and bubbles form when the tube is given a light blow or is placed in a high-frequency sound field) and (2) subjecting H_2O and glass to high hydrostatic pressure (1000 atm) (this removes the micronuclei and the H_2O can be heated above 2000° without bursting into vapor; only a very severe blow will cause bubbles to form). (CA-39-1094-4)

733. Harvey, E. N., Cooper, K. W., and Whiteley, A. H.

BUBBLE FORMATION FROM CONTACT OF SURFACES, J. Am. Chem. Soc. 68, 2119-20 (1946).

Apparatus is described for making measurements which allow the stability of films in emulsions or foams to be evaluated. The method involves the measurement of the maximum length of the film before rupture, when being drawn out from the liquid at a constant rate. Results are reported on the stretching in a water medium of films of vaseline oil added to oleic acid. (Sci. A. 51-546)

734. Harvey, E. N., et al.

THE EFFECT OF MECHANICAL DISTURBANCE ON BUBBLE FORMATION IN SINGLE CELLS AND TISSUES AFTER SATURATION WITH EXTRA-HIGH GAS PRESSURES, J. Cellular Comp. Physiol., 28, 325 (1946).

Bubbles were never observed within undisturbed living cells of Amoeba, Paramecium, Arbacia, and Asterias eggs, or Nitella on decompression after satn. with N_2 at 76-152 atm, but bubbles did form within Nitella cells when gently pinched or twisted. Bubbles formed on the outside of cells; this is presumably due to contamination with gas nuclei. Nitella cells killed with $CHCl_3$ or CH_2O did not form bubbles within the cells but spontaneously dead or previously injured cells did so occasionally. Rat omentum, abdominal muscle, postcava and clotted blood, previously freed of gas nuclei and satd. with 80 atm of N_2, formed bubbles at rest on decompression. Mesentery and unclotted blood did not form bubbles. The origin of these bubbles is discussed. (CA-41-5158c)

735. Hatcher, J. B., and Sage, B. H.

NON-EQUILIBRIUM BEHAVIOR IN HETEROGENEOUS HYDROCARBON SYSTEMS, Ind. Eng. Chem., 33, 443-452 (1941).

A thermodynamic criterion for the existence of bubbles in supersaturated liquids is discussed. Diffusion constants for n-butane in a hydrocarbon liquid were determined experimentally as a function of composition at 100°F. The influence of natural and forced convection upon the transfer of n-butane to and from hydrocarbon liquids was investigated. The usual concept of an effective film thickness was found to be a useful means of comparing experimental results of this nature. Experimental work indicated that turbulence was of nearly controlling importance in determining the degree of supersaturation obtainable in hydrocarbon liquids. The results are presented in graphical form. (Sci. A. 44-2477)

736. Helsby, F. W., and Tuson, K. R.

BEHAVIOR OF AIR BUBBLES IN AQUEOUS SOLUTIONS, Research, 8, 270-5 (1955).

The formation of air bubbles from capillary jets 0.10 and 0.17 cm in diam. submerged in aq. solns. varying in viscosity from 0.5 to 10.0 centipoises with a surface tension of 66 to 70 dynes/cm is described. As the air-flow rate is increased, several stages of bubble formation are observed. At low air-flow rates, the bubbles are evenly spaced and uniformly sized oblate spheroids. At medium air-flow rates, the bubbles are no longer spheroidal, the bottoms of the bubbles become flat, the tops remain spherical, and the bubbles assume a helmet shape. As the air-flow rate is further increased, the bubbles begin to form in pairs and subsequently quartets. A variety of complex phenomena are assocd. with multiple formation. In some cases, the second bubble of a pair rises into the first one, maintaining its own liquid film and becoming partially enveloped by the first bubble. In cases of multiple bubble formation, each bubble takes with it an envelope of liquid which sets into motion the adjacent liquid layers and

so produces a rapidly rising column of liquid at the jet vertical axis. A downward motion of liquid at the vessel wall is assocd. with the center jet, and at the horizontal plane of the capillary jet the liquid from the vessel wall is swept into the center jet. This system comprises a combined vortex consisting of a forced vortex at the jet axis and a free vortex in the body of the liquid. (CA-49-13714c)

737. Higuchi, I., and Takamura, T.

LIMITING CONCENTRATION OF BUBBLE FORMATION IN THE LIQUID PHASE, J. Chem. Soc. Japan, 76, 566-9 (1955).

The solns. of CO_2 having various degrees of supersatn. were prepd. by changing the relative amts. of the reacting substances, i.e., $KMnO_4$, oxalic acid, and H_2SO_4. The modes of bubble formation out of the solns. were described. (CA-49-15318d)

738. Hopwood, F. L.

WATER BELLS, Proc. Phys. Soc. (London), 65B, 2-5 (1952).

The author shows that when water is discharged through an annular slit above a plane water surface, the sealed "water bells" thus formed exhibit some novel and remarkable properties not hitherto described. The primitive water bell is a dome-shaped bubble whose dimensions increase with increased rates of flow. If this is perforated with a finger the maximum diameter of the bell suddenly doubles itself. On continuously reducing the flow the expanded bubble contracts and assumes an alternating sequence of stable and semi-stable forms of great beauty. All these, when perforated, contract slightly. The semi-stable forms have the general appearance of a hyperboloid surmounted by a saucer-shaped depression with the annular slit at the bottom. On inflating an expanded bubble by a slow stream of small air bubbles, semi-stable forms similar to the above are produced, but possessing an additional inflection in their contours. During these changes the maximum differences of pressure do not exceed one-tenth of a millimetre of water above or below atmospheric pressure. The author shows how the apparatus can easily be modified to produce enclosing water bells. It may also be adopted to produce sonic and ultrasonic underwater vibrations. (Sci. A. 55-2459)

739. Hughes, R. R., et al.

THE FORMATION OF BUBBLES AT SIMPLE ORIFICES, Chem. Eng. Progr. 51, 557-63 (1955).

Experimental and theoretical work which also shows complexity of extrapolating simple scale findings to process conditions; principal experimental data are on influence of volume of gas train below orifice, chamber volume, on volume of bubbles formed at finite rates of gas flow in region of regular bubble formation.

740. Jackson, I. R. W.

THE FORMATION OF GAS BUBBLES FROM ORIFICES, I., Ind. Chemist, 28, 341-5 (1952).

A review.

741. Kenrick, F. B., Gilbert, C. S., and Wisner, K. L.

THE SUPERHEATING OF LIQUIDS, J. Phys. Chem., 28, 1297-1307 (1924).

Expts. have been made on the superheating of liquids by heating the liquids in open capillary tubes at atm pressure and by reducing the pressure on the liquids in closed tube at const. temp. The highest temps. that could be maintained for 5 secs without explosion at 1 atm were: Et_2O, 143°; EtOH, 201°; MeOH, 180°; $CHCl_3$, 173°; CH_3COCH_3, 174°; CS_2, 168°; H_2O, 270°; SO_2, 50°; C_6H_6, 203°; C_6H_5Cl, 250°; C_6H_5Br, 261°; $C_6H_5NH_2$, 262°; m-xylene, 235°. In freshly drawn capillaries neither dissolved gases in the liquid, nor, apparently, adsorbed gases on the glass are important factors in initiating bubbles. The radius of bubbles which could exist in equil. with the liquids at the above temps. varies from 2.5×10^{-7} to 16×10^{-7} cm. The relation between the external pressure p_m and the vapor pressure of the liquid at the max. temp., p_v, is as follows: $p_m = (p_v/760) - [2\gamma/(1.36 \times 980 \times r)] + 1$, in which p_m and p_v are in atms., γ is the surface tension in dynes per cm, and r is the radius of the bubbles that could exist in equil. with the vapor at the max. temp. If r be taken as 4.57×10^{-7} this relation holds for Et_2O from -72 atms. to 26.8 atms. (CA-19758-5)

742. Kennedy, H. T., and Olson, C. R.

BUBBLE FORMATION IN SUPERSATURATED HYDROCARBON MIXTURES, J. Petroleum Technol., 4, 271-8 (1952).

In many investigations of the performance of petroleum reservoirs the assumption is made that the liquid, if below its bubble-point pressure, is at all times in equil. with gas. On the other hand, observations by numerous investigators have indicated that gas-liquid systems including hydrocarbon systems may exhibit in the lab. supersatn. to the extent of many hundred lb. per sq in. Lab. expts. were made in mixts. of CH_4 and kerosene in the presence of silica and calcite crystals. Bubbles formed on crystal-hydrocarbon surfaces in preference to the glass-hydrocarbon surfaces in preference to the glass-hydrocarbon interface or to the body of the liquid. It was found that the no. of bubbles formed per sec per sq cm of crystal surface was a function of the supersatn. only. Supersatns. were observed up to 770 lb. per sq in., the bubbles forming quickly and violently. With decreasing degrees of supersatn., the frequency of bubble formation became less, until at 30 lb per sq in. supersatn. and lower, no bubbles formed. Silica and calcite crystals had identical effects, within exptl. error, in accelerating the formation of bubbles, and small amts. of H_2O and crude oil had no effect on the results. (CA-47-1367g)

743. King, J. L.

THE FORMATION AND SUBSEQUENT MOTION OF WATER VAPOUR CAVITIES IN WATER, AD 67170 (1950).

744. Kling, G.

DYNAMICS OF BUBBLE FORMATION IN THE GASSING OF LIQUIDS UNDER PRESSURE, Internat. J. Heat Mass Transfer, 5, 211-23 (1962).

The author describes experiments for the treatment of water with helium, argon and nitrogen at pressures of 1 to 80 atm abs. The greater kinetic energy possessed by gases at elevated pressures causes considerable deformation of the bubbles, and more rapid disintegration of the gas stream into bubbles than in gassing at normal pressure. Striking discontinuities are observed; a sudden rise in bubble frequency occurs at increased gas rates. Photographs show the bubble shapes and bubble ascent in various ranges of pressure, varying between introduction of the gas as single bubbles and as a coherent stream at high rates of throughput.

745. Krause, B.

THE STABILITY OF SUPERSATURATED CARBONIC ACID SOLUTIONS, ESPECIALLY THAT OF BEER, Svenska Bryggarefören. Manadsbl. 51, 221-36 (1936), Chem. Zentr. II, 2249 (1936).

The phys.-chem. conditions necessary for the formation of bubbles in the liquid are discussed. To prevent the development of so-called "following the stopper" beer the addn. of special hydrophilic colloids is recommended.

746. Krevelen, D. W., van Heftijzer, P. J.

GAS BUBBLE FORMATION. CALCULATION OF INTERFACIAL AREA IN BUBBLE CONTACTORS, Chem. Eng. Progress 46, 29 (1950).

Two types of formation and rising of gas bubbles in liquids can be distinguished, viz. bubbles formed separately or in series (chain bubbling). In the first case the diam. of the bubbles is independent of the flow rate and proportional to the cube root of the orifice diam. Chain-bubbling takes place above a certain crit. flow rate. Here bubble diams. are independent of the orifice diam. and increase with increasing flow rate. Dimensionless expressions are derived, enabling a rapid calcn. of crit. gas velocity, bubble diam., rising velocity, and interfacial area.

747. Lane, J. A.

THE BUBBLE PROBLEM IN THE HOMOGENEOUS REACTOR, ORNL-728 (Aug. 5, 1949), 9 p.

Studies reported on the solubility of H in reactor at high pressures and temperatures, and the formation and collapse of bubbles supplied data to be used to determine the amount of liquid purge to eliminate or reduce bubbles by flash vaporization of a portion of the homogeneous reactor solution. (NSA-10-6424)

748. Larson, R. F.

OCCURRENCE OF METASTABLE STATES OF LIQUID AND VAPOR, Ind. Eng. Chem., 37, 1010-16 (1945).

A thermodynamic theory is advanced for the requirement and mechanism of bubble formation in a heated liquid. Trial calculations using estimated thermodynamic properties of superheated water indicate that the nucleus bubble in the transformation state consists of a single molecule. The theory is extended to condensing water vapour with similar results. The literature is reviewed for supporting evidence. The similarity between the supposed action of the ebullator and of a catalyst is pointed out. (Sci. A. 49-1067)

749. Mann, W. B., and Stephens, R. W. B.

BUBBLE FORMATION IN GLASS TUBES, Phil. Mag. 15, 143-6 (1933).

A study has been made of the rate of flow and mechanics of bubble formation from single submerged orifices $\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{16}$, and $\frac{1}{8}$ in. in diameter installed in an 8-in. I.D. column operating in the air-water system. The coefficients of discharge obtained for sharp-edged orifices operating with this system indicate that the effective orifice discharge area for this type of operation is greater than that for an orifice of the same size and type operating at the same pressure ratio in the air-air system. The effective orifice discharge areas for a round-edged orifice operating in either the air-water or air-air systems appear to be identical at the same pressure ratio. The thick-plate orifice operating in the air-water system influences the effective orifice discharge area, liquid physical properties may be expected to be important in determining the rate of flow from this type of orifice for other gas-liquid systems. Photographic studies of bubble formation reveal that nonuniformity of bubble size is initiated by the onset of turbulence in the air stream flowing through the orifice. In the section of the laminar-flow range studied in this investigation (200 N_{Re} 2,100) the frequency of bubble formation is nearly constant with respect to Reynolds number. The bubble size is relatively uniform at a given Reynolds number and depends markedly upon orifice diameter. Stroboscopic examination reveals that as turbulence is fully developed for the air flow through the orifice, a counterclockwise spiraling, swirling motion of the air jet is initiated. In the turbulent-flow range the bubblesize-distribution data are fitted reasonably well by a logarithmic-normal-probability distribution. (NSA-10-11787)

750. Metais, B.

EFFECT OF GAS EVOLUTION UPON HEAT TRANSFER IN THE HEATING OF LIQUIDS, Chem.-Ingr. Tech., 33, 182-4 (1961).

The dissolved air which evolves from water with increasing temp. continually destroys the thermal boundary layer due to gas-bubble formation. The net result is an increase in heat transfer.

751. Miyake, Y.

THE POSSIBILITY AND THE ALLOWABLE LIMIT OF FORMATION OF AIR BUBBLES IN THE SEA, Papers Meteorol. & Geophysics (Japan), 2, 95-101 (1951).

An equation is given for computing the amt. of dissolved O_2 and N_2 in sea water. The satn. of H_2O by air in the sea and the possible causes (temp.,

chlorinity, mixing, and other factors) of the formation of air bubbles are discussed. A graphic method is presented for the calcn. of the quantity of air bubbles and of the depth of their generation. (CA-47-11823d)

752. Naake, H. J., et al.,

OBSERVATION OF THE FORMATION AND GROWTH OF BUBBLES IN WATER CONTAINING AIR, BY OPTICAL METHODS, Acustica, 8, 193 (1958).

With the help of a movie-camera the formation of bubbles in water after a reduction of the static pressure was examined. A suspension of solid particles to act as nuclei was added to the water. The number of bubbles formed per unit time, the rate of growth, and the time interval between reduction of pressure and the moment when the bubbles can first be seen were measured. From these data the number and size of the bubble-generating nuclei can be deduced.

753. Newman, P. C., and Whelan, P. F.

RELATION OF VOLUME OF BUBBLE TO DIAMETER OF ORIFICE AT WHICH IT IS FORMED, Nature 169, 326-7 (February 1952).

The ratio v/d has been determined for bubbles of air blown very slowly at an orifice of glass with d varying from 0.474 to 0.0131 cm (v = vol. of bubble, d = dia. of orifice), v/d stays constant at 0.19 cm (cf. theory = 0.231) except for the smallest orifices where the bubbles can no longer cling, even momentarily, to the surface.

754. Pattle, R. E.

THE AERATION OF LIQUIDS. I. SOLUTION OF GAS FROM RISING AIR BUBBLES. II. FACTORS IN THE PRODUCTION OF SMALL BUBBLES, Trans. Inst. Chem. Engrs. (London), Advance Copy, 17-27 (Feb. 14, 1950).

I. Expts. were made with various aeration devices such as $\frac{1}{16}$-in. holes, Schott glass, and crit. orifices that produced large bubbles and demonstrated low aerating efficiency. Capillary tubes of glass or steel bent into the form of a P so that the orifice is obstructed by the stem (P-jets) and porcelain candles produce very fine uniform bubbles that are required for high efficiency. Theoretical equations are given for the soln. of gas from a stream of bubbles.

II. The bubbles produced in liquids by porous aerating media are often much smaller than can be accounted for by the normal mechanisms for the detachment of a bubble. Small quantities of org. substances added to the liquid may reduce the bubble size very disproportionately. The effect of irregularities in the orifices of the pores in allowing bubbles to be detached without the aid of gravity is explained and demonstrated. The effect of added org. substances on bubble size is due to their preventing bubbles from recombining once they are formed. Photographs of bubbles jostling one another after leaving an orifice are shown. Devices for the production of uniform small bubbles are described. (CA-44-4728i)

755. Pike, F. P.

GAS EVOLUTION IN A HOMOGENEOUS PILE, CF-50-6-162 (June, 1950).

756. Plesset, M. S.

RATE OF FORMATION OF VAPOR IN A UNIFORMLY HEATED LIQUID, AECU-707 (1949), 11 p.

An approximate method for the calculation of the rate of growth of vapor bubbles within the volume of a uniformly heated liquid is developed. The method is directly applicable to the situation in which the effective initial size of the nucleus from which the bubble grows is large enough so that surface tension effects may be neglected. An example is presented in which the temperature rise of the liquid is exponential, and it is shown that the approximate procedure presented here is quite accurate.

757. Riepe, G., and Hahn, B.

INVESTIGATION OF THE MECHANISM OF BUBBLE FORMATION IN FREON-12 AND PROPANE BY ALPHA RAY RECOIL, Helv. Phys. Acta, 34, 865-92 (1961).

The mechanism of bubble formation in superheated liquids can be described by a simple thermal model for particles whose range is smaller than the "critical" bubble diameter. The bubble formation by recoils from α-disintegrations (Po^{210}, Th C, Th C') was investigated for CCl_2F_2 between 30°C and 80°C and for C_3H_8 at 18.5°C using a temperature and pressure stabilized bubble chamber. The dependence on the degree of superheat of the bubble formation leads to the conclusion, that the energy needed to form a critical-size bubble (where the evaporation term represents the main part) agrees within 5% with the recoil energy. Values obtained for the bubble formation by Auger-electrons from A^{37} can be explained qualitatively by the same model.

758. Siemes, W.

GAS BUBBLES IN LIQUIDS. I. FORMATION OF GAS BUBBLES FROM VERTICAL CIRCULAR JETS, Chem. Ing. Tech. 26, 479-96 (1954). [For Part II see Siemes, W., Chem. Ing. Tech., 26, 614-30 (1954)].

Bubble size of slowly forming bubbles was investigated in relation to jet size, gas rate, and pressure variation. In rapid bubble formation the bubble frequency was detd. by stroboscopic measurement and recording of the elec. resistance of the liquid above the jet opening. Theoretical aspects, exptl. procedures, and data covering many variables are given. 45 references. (CA-49-33g)

759. Sigwart, K.

THE PRESSURE AT A BUBBLE CAP SLOT OPENING AT THE START OF BUBBLE FORMATION, Z. Ver. daut. Ing., Verfahrentech. No. 4, 116 (1943).

Expts. are reported for a bubble cap made of Al sheet 1 mm thick. The slots were rectangular with widths of 1, 2, 3, 4, 5, and 6 mm and heights of 10, 15, and 20 mm. Liquids used were: tap water, distd. water as such and with 1% Nekal wetting agent, and EtOH. The pressure at bubble formation was independent of

the liquid height over the slots but followed a hyperbolic course as a function of the slot width and was strongly affected by the surface tension. On the basis of simplifying assumption the exptl. data could be correlated by the equation for initial pressure drop $\Delta p_s - \Delta p_0 = (2\sigma/b) + \sqrt{4\sigma\gamma F}$, where Δp_s = pressure inside the cap at the moment of bubble formation; $\Delta p_0 = h_0\gamma F$ = pressure due to the liquid level h_0 above the top of the slot; γF = liquid d; σ = surface tension; and b = slot width. (Sci. A. 44-8705a)

760. Silberman, E.

PRODUCTION OF BUBBLES BY THE DISINTEGRATION OF GAS JETS IN LIQUID, University of Michigan, Proceedings of the Fifth Midwestern Conference on Fluid Mechanics, pp. 263-284 (April 1957).

A gas jet issuing from a nozzle into liquid breaks up into discrete bubbles because of the instability of the jet. The bubbles may be of various sizes but the largest ones correspond to the volume of gas pinched off from the jet by a wave length of the unstable disturbance. A theory is presented to predict the largest bubbles, with experimental confirmation obtained in liquid moving relative to the orifices that produced the jets. Size distribution of bubbles below the largest can be obtained only by experiment. The equations developed show that, when the liquid moves relative to the orifices, the maximum bubble diameter equals 2.4 times the square root of gas-flow rate per jet divided by the liquid velocity. When there is no relative motion, the diameter is proportional to the 0.4 power of the gas-flow rate. The bubble diameter is independent of gas and liquid properties and of orifice characteristics, as long as the gas issues as a jet from each orifice. By applying the relations developed to systems of gas orifices discharging into moving liquid, the gas-flow rate and liquid velocity may be selected so that bubbles may be produced of any desired maximum diameter, from several inches to a few thousandths of an inch.

Test equipment is described and illustrated; flash photographs of bubbles are shown; charts of bubble-size distribution are shown as function of rate of air flow divided by water-flow velocity. (AMR, 1958, No. 2181)

761. Spells, K. E., and Bakowski, S.

A STUDY OF BUBBLE FORMATION AT SINGLE SLOTS SUBMERGED IN WATER, Trans. Inst. Chem. Engrs. (London), 28, 38-51 (1950).

High speed motion pictures were made showing the formation of bubbles by air flow through single rectangular slots submerged in water. The conditions studied included air rates between 43 cc/sec and 730 cc/sec, depths of immersion (to the top of the slot) between 1 cm and 7 cm, and slot widths between 2 mm and 10 mm. By examn. of the films in detail it was found that the bubbling could take place by either of two mechanisms. When the submergence of the slot was sufficient, an important part of the bubble development takes place after it had risen above the top of the slot, owing to the formation of a channel connecting slot and bubble. Bubble vols., their time periods of formation, and channel length increased with increasing air rate, at least for the lower rates of flow. Increasing the air rate, or decreasing the slot submergence, often caused a change of mechanism. Instead of a bubble followed by a channel, a series of more or less similar bubbles was obtained, forming a fairly continuous connection between the slot and the water surface. Over the range studied, no important effects were observed which could be attributed to changes in slot width. The bubbles from closely spaced multiple slots may show some of the characteristics which have been observed for single slots, but the crowding together of the bubbles, and their consequent interference with each other, would also be expected to produce some marked differences. (CA-44-4729c)

762. Spells, K. E., and Bakowski, S.

THE FORMATION OF BUBBLES AT CLOSELY SPACED SLOTS SUBMERGED IN WATER, Trans. Inst. Chem. Engrs., 30, 189-96 (1952).

Air-bubble formation at multiple slots was studied by high-speed photography with air rates 72-372 cc/sec per slot, immersion to top of slots 1-5 cm, slot width 3 mm, and slot spacing 0.6, 1.0, and 1.5 cm between centers. Comparison is made with a previous study of bubble formation at single slots. The bubbles formed were somewhat narrower than their counterparts at single slots, although neighboring bubbles showed a tendency of overlap. The bubble vols. and time periods were smaller than for single slots under similar conditions. Except at the lowest air rate, the bubbling resembled the shallow mechanism observed with single slots, in which there was copious air leakage between slots and water surface. Increase in bubble vol. was obtained by increasing the slot submergence at the const. air rate of 302 cc/sec per slot and by increasing the air rate at the const. slot submergence of 2 cm. (CA-47-6713c)

763. Spells, K. E.

BUBBLE FORMATION BY RAPID AIR FLOW THROUGH SLOTS SUBMERGED IN WATER, Trans. Inst. Chem. Engrs., 32, 167-73 (1954).

Bubbling produced by rapid air flow through vertical rectangular slots submerged in water was studied

by use of high-speed motion pictures. Two distinct mechanisms of bubble formation are postulated, the "deep" and "shallow," with the choice of prevailing mechanism dependent upon the magnitude of the slot submergence (cf. C.A. 47, 6713a). Bubble formation by the "shallow" mechanism occurs at low values of slot submergence. The air leaving the slot forms a channel jetting through the liquid with no formation of discrete bubbles. In this case, the slot submergence is less than the max. attainable or crit. channel length. For bubble formation by the "deep" mechanism, the slot submergence is greater than the max. attainable or crit. channel length, and discrete bubble formation occurs with bubbles breaking away from the end of the channel.

In this case, the channel constitutes a tail through which air is fed to the bubble until buoyancy and induced liquid circulation cause detachment. An equation is developed which indicates that the crit. slot submergence for change of mechanism should increase as the liquid surface tension is decreased. Equations are also derived to show the effect upon bubble formation of chamber vol. upstream from the slot. It is shown that the rate of bubble growth should be uniform when the chamber vol. upstream from the slot is small and that the pressure upstream from the slot should approach a const. as the chamber vol. upstream from the slot approaches infinity. (CA-49-9989b)

764. Stewart, C. R., et al.

ROLE OF BUBBLE FORMATION IN OIL RECOVERY BY SOLUTION GAS DRIVES IN LIMESTONE, J. Petroleum Technol. 6, 21-8 (1954).

The lab. recovery efficiency for soln. gas drive oil used in limestone of nonuniform porosity increases with an increase in the no. of gas bubbles formed. The no. of gas bubbles formed is controlled by the pressure decline rate. No practical lab. test is available to measure the soln. gas drive oil recovery performance at field rates of pressure decline. Possibly increased field oil recoveries can be obtained by rapidly reducing the reservoir pressure for a short time. (CA-49-4268h)

765. Van Krevelen, D. W., and Heftijzer, P. J.

GAS BUBBLE FORMATION CALCULATION OF INTERFACIAL AREA IN BUBBLE CONTACTORS, Chem. Eng. Progr. 46, 29-35 (1950).

Two types of formation and rising of gas bubbles in liquids can be distinguished, viz. bubbles formed separately or in series (chain-bubbling). In the first case the diam of the bubbles is independent of the flow rate and proportional to the cube root of the orifice diam. Chain-bubbling takes place above a certain crt. flow rate. Here bubble diams. are independent of the orifice diam. and increase with increasing flow rate. Dimensionless expressions are derived, enabling a rapid calcn. of crit. gas velocity, bubble diam., rising velocity, and interfacial area. (CA-44-3308f)

766. Wilkens, J. E.

THE EFFECT OF BUBBLING ON THE MULTIPLICATION CONSTANT, CP-2709 (February 1945), 16 p.

The evolution of gas bubbles in a homogeneous converter or breeder pile makes it necessary to have a somewhat higher multiplication constant than would otherwise be required. In this paper, a formula is derived for the change δk in the multiplication constant.

767. Wilkens, J. E.

THE EFFECT OF BUBBLING ON THE MULTIPLICATION CONSTANT II, CP-3067 (June 1945), 9 p.

768. Willis, W., Fowler, E. C., and Rahm, D. C.

BUBBLE DENSITY IN A PROPANE-BUBBLE CHAMBER, Phys. Rev., 108, 1046-47 (1957).

The measured no. of bubbles per cm (a bubble-spacing technique insensitive to bubble counting inefficiency is used) is consistent with the rate of δ-ray formation.

769. Wilson, R. H.

LITERATURE SURVEY RE: BUBBLE FORMATION, CF-50-4-148 (1950), 5 p.

Bubble formation in a mock-up of the Homogeneous Reactor Experiment core is discussed. A literature survey of bubble formation is included. 17 refs.

GENERATION (See FORMATION, NUCLEATION)

GROWTH

770. Aleksandrov, Y. A., et al.

THE GROWTH AND EMERGENCE RATE OF BUBBLES IN A PROPANE CHAMBER, Pribori I Tekh Ekspt, No. 6, 118 (Nov.-Dec. 1960).

Two illumination sources and two pulsed lamps were used in the experiment. The lamps were pulsed with consequent delays of 7, 14, 22, and 30 μsec; the growth and emergence of bubbles was measured between two ignitions. Twenty-seven events were selected from four sets of measurements with initial bubble radii of $0.10 > r_{init} < 0.20$ mm. The final magnitudes were $0.20 < r_{final} < 0.36$ mm with $C_{exp} = (5.8^{+2.6}_{-1.2}) \times 10^{-2}$; the theoretical constant was $C_{theor} = 1.7 \times 10^{-1}$. The emergence rate was 3.6×10^{-2}/msec $\lesssim W_{exp}$ 11.7×10^{-2} mm/msec; the rate of emergence is faster than the bubble growth.

771. Bakanov, S. P., Rukhadze, A.A., Sandomirskii, V. B.

THE THEORY OF EXPANSION OF A GAS BUBBLE IN A VISCOUS LIQUID, Inzhen. fiz. Zh. (USSR), Vol. 4, 109-12 (July 1961).

The problem of the motion of a viscous fluid arising as a result of the expansion in it of a gas bubble under the action of inner pressure forces is formulated and

solved. The solution is investigated in two boundary cases: viscous and inertia conditions. It is shown that the first of these pertains in the production of light building materials. Assumptions are made on the analogous operation mechanism of a bubble chamber.

772. Bankoff, S. G., and Mikesell, R. D.

GROWTH OF BUBBLES IN A LIQUID OF INITIALLY NONUNIFORM TEMPERATURE, Paper 58-A-105, ASME Annual Meeting (1958), 20 p.

Plesset-Zwick solution for asymptotic-growth phase of bubble originating-uniformly heated liquid of infinite extent is extended to case of bubble originating from heating surface in contact with liquid whose bulk temperature is at or below saturation temperature.

773. Bankoff, S. G., Mikesell, R. D.

BUBBLE GROWTH RATES IN HIGHLY SUBCOOLED NUCLEATE BOILING, Chem. Eng. Progr. 29, 95-102 (1959).

By comparison of the Rayleigh solution for bubble growth and collapse with experimental data, it is found that the pressure of the vapor within bubbles arising in very subcooled nucleate boiling is less by a small, fairly constant amount than the pressure at a great distance. The effect is the same as if the bubble surroundings were imparted by an initial impulse while the minute bubble was still entirely within the laminar-wall layer. The kinetic energy imparted by this initial impulse and the restraining pressure difference determine the bubble trajectory. These parameters are computed for Gunther's data. It is then postulated that the heat flux from the portion of the bubble projecting into the turbulently-flowing core depends primarily upon turbulent and convective heat flow rather than laminar heat conduction and hence is relatively constant during the bubble lifetime. The proposed mechanism gives qualitative agreement with the observed trends. It is suggested that latent heat transport may be an important mode of heat transfer in subcooled nucleate boiling.

774. Benjamin, J. E., et al.

BUBBLE GROWTH IN NUCLEATE BOILING OF A BINARY MIXTURE, International Developments in Heat Transfer, Part II, ASME, 1961, pp. 212-218.

For the long-range viewpoint, research in the microscopic details of boiling may lead to an understanding of the macroscopic behavior of boiling liquids. A matter of immediate interest is the experimental evaluation of a recent theory by Scriven which predicts the rate at which a bubble will grow in binary liquid mixtures. Boiling bubble growth rates in mixtures of water and ethylene glycol were measured at 1 atmosphere. Boiling took place at a 0.004 in. dia. artificial nucleation site in a vertical copper surface at 4, 8, and 18 degree centigrade superheat. Measurements were made from movies taken with a high speed camera through a metallographic microscope. The movies were made with 3 diameters magnification at 6,000 frames per second using a D.C. arc for light. The resulting diameter and time measurements were fitted by a digital computer to an equation of diameter proportional to time raised to an exponent. The exponent averaged about 0.4 rather than the theoretical value of 0.5, and showed a decided statistical variation. The coefficient in the growth equation varied statistically, but depended on liquid compositions as predicted. Most significantly, the minimum coefficient occurred at about 5 w/o water as predicted.

775. Berry, V. J.

EFFECT OF A LIQUID PHASE VELOCITY ON THE GROWTH AND COLLAPSE OF GAS BUBBLES, J. Chem. Phys., 20, 1045 (June 1952).

A discussion of the rates of growth and collapse of bubbles when the translatory motion of the liquid phase is such that the time required for a particle to diffuse a distance equal to the bubble radius R is small compared with the time for convective transport through the same distance. See also Abstr. 2428, 4158 (1951). (Sci. A. 55-6327)

776. Birkhoff, G., Margulies, R. S., and Horning, W. A.

SPHERICAL BUBBLE GROWTH, Phys. of Fluids 1, 201-204 (1958).

Plesset and Zwick [J. Appl. Phys. 23, 95-98, (1952); 25, 493-500 (1954); J. Math. Phys. 33, 308-330 (1955)] have calculated the rate of growth of vapor bubbles in slightly superheated steam under constant external pressure. Their calculation assumes that the temperature drop is localized in a thin "boundary layer" near the bubble wall; the predicted bubble radius $R(t)$ is asymptotically proportional to $t^{1/2}$ when R is large enough for surface tension to be negligible. An analysis of this asymptotic phase is given, which avoids the above "boundary layer" assumption, and contains that part of the analysis of Plesset and Zwick dealing with this phase as a limiting case. The analysis is shown to be (approximately) applicable also to gas bubbles in supersaturated liquids.

777. Chambre, P. L.

ON THE DYNAMICS OF PHASE GROWTH, Q. J. of Mech. Appl. Math., 9, 224-33 (1956).

The growth of a solid, starting from negligible initial dimensions with either a plane, cylindrical, or spherical boundary, into a surrounding supercooled fluid is discussed. The densities of the solid and fluid are assumed to be unequal. As a consequence a convective motion occurs in the fluid having the characteristics of a source or sink flow because of the fact that a unit mass of fluid occupies, on solidification, a volume differing from the volume originally occupied. The effects of this motion on the rate of growth of the solid phase have been analyzed.

779. Chernyak, Ya. N.

THE EXPANSION OF GAS BUBBLES IN LIQUIDS OF HIGH VISCOSITY, Zh. Tekh. Fiz., 29, 1273-76 (Oct. 1959).

A cavity in a liquid of viscosity η will disappear in time $t = 4\eta r_0/3\sigma$ under the action of the surface tension σ; r_0 is the initial radius of the cavity. Were

the cavity filled with a gas, then the contraction would only proceed until equilibrium was reached between the gas pressure and the capillary pressure. Where a chemical reaction produces gas in a liquid and where a coalescence of gas bubbles takes place, as, for example, during the baking of a fusible clay, the viscosity of the melt controls the rate of growth of the bubbles in it. Only in a narrow range of viscosities will the rate of expansion of the bubbles be relatively large.

780. Dergarabedian, P.

THE RATE OF GROWTH OF VAPOR BUBBLES IN SUPERHEATED WATER, J. Appl. Mechanics 20, 537-45 (1953).

Calcns. are presented for the dynamic stability of vapor and air bubbles in superheated vapor. These calcns. indicate that the values of the bubble radii for which the equil. is unstable are restricted to a finite range of radii whose values are governed by the temp. of the water and the initial air content in the bubble. Two theoretical solutions for the rate of growth of these unstable bubbles are considered: (a) solution of the equation of motion of the bubble radius with the assumption that there is no heat diffusion across the bubble wall; (b) solution which includes the effect of heat diffusion. These solutions differ appreciably. These two solutions are then compared with the exptl. data obtained from high-speed photographs of the growth of vapor bubbles at various degrees of superheat. This comparison shows agreement with solution b. (CA-48-1753g)

781. Dergarabedian, P.

OBSERVATIONS ON BUBBLE GROWTHS IN VARIOUS SUPERHEATED LIQUIDS, NAVORD-5009 (1956), 24 p.

Experimental data are presented for the growth of vapor bubbles in various superheated liquids, such as carbon tetrachloride, benzene, ethyl alcohol, and methylalcohol. These data are compared with the theoretical results obtained by Plesset and Zwick who derived these results by taking into account the heat diffusion across the bubble boundary. The agreement in all cases between experiment and theory is found to be good. The growth of vapor bubbles in slightly superheated water is also presented in the form of experimental data for bubbles just beginning to grow from a point of equilibrium which is presumed to be dynamically unstable. The radii corresponding to the points of equilibrium are of the same order of magnitude as predicted by theoretical considerations.

782. Dergarabedian, P.

OBSERVATION ON BUBBLE GROWTHS IN VARIOUS SUPERHEATED LIQUIDS, J. of Fluid Mech., 9, 39-48 (Sept. 1960).

Analysis of high speed photographs of growth of vapor bubbles in water, carbon tetrachloride, benzene, and ethyl and methyl alcohol, at superheat, confirms Plesset-Zwick theory for bubble growth; analysis for calculating range of radii for which bubbles are stable or unstable is presented in detail; relevance to problem of cavitation in underwater ordnance.

783. Flatt, H. P.

TRANSIENT BUBBLE GROWTH IN A HOMOGENEOUS REACTOR, NAA-SR-3923 (1960), 33 p.

A mechanism for shutting off a power excursion in a homogeneous reactor by the rapid formation of bubbles was investigated. Equations are derived which give upper and lower bounds for the radius of a bubble, as a function of time, under conditions present in a reactor. Deduction of the bubble nuclei growth rate from observations of void volume and pressure can be made.

784. Forster, H. K., Zuber, N.

GROWTH OF A VAPOR ON A SUPERHEATED LIQUID, J. Appl. Phys. 25, 474-8 (1954).

The integro-differential equation for the growth of a vapor bubble for a superheated liquid is formulated and discussed. It is shown that two distinct time domains exist: one, of the order of 10^{-4} second, during which the effect of the hydrodynamic forces may be an important factor in the growth of the bubble, and another, during which time effect is unimportant. An integral equation is formulated for the latter domain. A solution of the problem, in closed form, valid for the entire interval of interest is presented; it agrees very well with experimental data for various superheats.

785. Forster, H. K.

ON THE CONDUCTION OF HEAT INTO A GROWING VAPOR BUBBLE, J. App. Phys. 25, 1067-8 (1954).

A theoretical paper which gives the derivation of the expression used for the temperature of the moving wall of a bubble growing in a superheated liquid.

786. Forster, K. E.

GROWTH OF A VAPOR-FILLED CAVITY NEAR A HEATING SURFACE AND SOME RELATED QUESTIONS, Physics of Fluids, 4, 448-455 (1961).

The growth of a vapor bubble on a heating element immersed in a liquid which is at saturation temperature or subcooled far from the heating surface but which is superheated near the heating surface, was treated as a problem of heat conduction with evaporation on a boundary. Initially, a one parameter negative exponential dependence of liquid temperature on distance from the heating surface was assumed and the distortion introduced by the growth of the cavity was neglected. The results showed, in agreement with experiment, that in a liquid at saturation temperature the radius grows as $t^{1/2}$ at first (t is time) and as $t^{1/4}$ for $t \to \infty$; for a subcooled liquid the radius as a function of time is given as an infinite series in terms of a quantity H, later identified with the thickness of the thermal boundary layer. For the simpler case of uniform initial temperature of the liquid, the method is shown to give results identical to those known for several years for low pressure while yielding a small correction for large pressure. Several relations between boundary layer thickness in a boiling liquid, maximum radius

attained by the cavity before collapse, and superheat and subcooling were derived and compared with experiment. For large subcooling the boundary layer thickness is shown to be about one-half (or less) the size of the maximum radius. Physical considerations concerning the mechanism of heat transmission to a boiling liquid led to the definition of a heat diffusivity, the exchange diffusivity $a^* = M^2 a$, with M the dimensionless ratio of enthalpies of superheated liquid and of saturated vapor. The dimension of the thermal boundary layer is shown to be the diffusion length for the exchange diffusivity.

787. Fricke, R.

GROWTH OF GAS BUBBLES SUSPENDED IN LIQUIDS WHICH ARE SUPERSATURATED WITH THE SAME GAS, Z. physik. Chem. 104, 363-402 (1923).

Formulas are given for the diffusion and hydrodynamic relations of growing gas bubbles rising in liquids which are supersatd. with the gas. These relations have been investigated for CO_2 by a photographic method. The growth of the bubbles relative to the path traversed divided by the radius is more rapid the larger the bubbles. The velocities of CO_2 bubbles in water supersatd. with CO_2 are appreciably greater than in water which is only satd. with the gas. (CA-17-2979-7)

788. Fricke, R., and Blencke, W.

THE GROWTH OF FREELY FLOATING GAS BUBBLES IN LIQUIDS SATURATED WITH THE SAME GAS, Z. physik. Chem. 107, 136-9 (1923).

Improvements in the app. have enabled the study of bubbles of larger diam. than was previously possible. (CA-18-924-1)

789. Gamble, D. P.

A PROPOSED MODEL OF BUBBLE GROWTH DURING FAST TRANSIENTS IN THE KEWB REACTOR, Nuclear Sci. and Eng. 2, No. 1, Suppl., 213-14 (1959).

Experimental evidence indicates that the dominant shutdown mechanism operating in the KEWB Reactor during short-period transients is void production from radiolytic gas evolution. Growth of bubbles required to produce the observed reactivity changes appears inexplainable on the basis of thermodynamics. Since the dissipation of large amounts of energy occurs in a small volume, a mechanism is proposed for the bubble formation which involves fission fragments. Excellent qualitative correlation is observed between predictions based on the model and experimental observations.

790. Gilmore, F. R.

THE GROWTH OR COLLAPSE OF A SPHERICAL BUBBLE IN A VISCOUS COMPRESSIBLE LIQUID, Heat Transfer and Fluid Mech. Inst. Held at Univ. of Calif., Los Angeles (June 24-26, 1952), p. 53.

791. Griffith, P.

BUBBLE GROWTH RATES IN BOILING, NP-6188 (June, 1956), 35 p.

The conditions determining the growth rate of a bubble on a surface in boiling are considered and a mathematical model framed in the light of these conditions. The growth rate is then calculated for bubbles growing under a range of conditions of pressure, wall superheat and bulk fluid temperature. The average growth rate of a bubble is found to decrease with increasing maximum size and to decrease with increasing pressure. At high pressure the maximum size of the bubble is found to be independent of pressure and primarily a function of the thickness of the superheated layer near the surface. The calculated bubble growth velocities are then used to correlate some burnout data for a variety of fluids under a range of pressures in pool boiling. Bubble growth pictures are presented for water at atmospheric pressure under a variety of conditions.

792. Griffith, P.

BUBBLE GROWTH RATES IN BOILING, Trans. Am. Soc. Mech. Eng. 80, 721 (1958).

The conditions detg. the growth rate of a bubble on a surface in boiling are considered and a math. model framed in the light of these conditions. The growth rate is then calcd. for bubbles growing under a range of conditions of pressure, wall superheat, and bulk temp. The av. growth rate of a bubble is found to decrease with increasing max. size and to decrease with increasing pressure. At high pressure, the max. size of the bubble is found to be independent of pressure and primarily a function of the thickness of the superheated layer near the surface.

793. Hendricks, R. C., and Sharp. R. R.

ON THE INITIATION OF COOLING DUE TO BUBBLE GROWTH ON A HEATING SURFACE. For presentation at A. I. Ch. E. Meeting, Los Angeles, Calif., Feb. 4-7, 1962. 28 p.

The surface temperature profile of a Nichrome heater strip during nucleate boiling was matched to high-speed photographic data. The initiation of surface cooling due to bubble growth was investigated and discussed in relation to existing models of nucleate boiling. Experimental data indicate that both the vapor-liquid exchange mechanism and the surface film evaporation mechanism must be considered in constructing a model of ebullition.

794. Mache, H.

THE DIFFUSION AND TRANSITION OF GASES INTO LIQUIDS. I. SOLUTION AND GROWTH OF AIR BUBBLES IN WATER, Sitzb. Akad. Wiss. Wien., Abt. IIA, 138, 529-556 (1929).

A method is described for the measurement of the diffusion coefficients in liquids which are not gas free and whose equilibria are altered by adjusted pressures; its advantages over other methods are discussed. The variations of the gas bubbles with alterations in pressure are studied and a theoretical

treatment included. The apparent dependence of the diffusion coefficient on the gas bubble radius is shown to indicate that the absorption coefficient of water for air in the concave surface layer of the bubble is lower than in the interior of the liquid. The effect of capillary pressure is investigated and experimental confirmation given to the theoretical result that the bubbles decrease by equal volumes in equal times. In moving water under constant excess pressure, the radius of the bubble diminishes in equal times by equal amounts, and the same holds good for the surface when only the capillary pressure is exerted. (CA-1555-4)

795. Plesset, M. S., and Zwick, S. A.

A NON-STEADY HEAT DIFFUSION PROBLEM WITH SPHERICAL SYMMETRY, J. Appl. Phys. 23, 95-98 (1952).

As a bubble of vapor in a liquid changes size, heat flows across the interface. If spherical symmetry is assumed and appreciable temperature changes are present only in the immediate vicinity of the bubble, a solution is found in successive approximations for heat diffusion across the interface in terms of the temperature of the liquid at infinity and the temperature gradient at the spherical boundary. The effects of translational motion of the spherical boundary have not been considered and the solution is applicable to time intervals in which no significant translation occurs.

The zero-order solution obtained represents the "plane approximation" to the problem. Authors present expressions for the bounds of this solution by which the rapidity of the convergence of the approximation theory may be estimated. (AMR-5-1874)

796. Plesset, M. S., and Zwick, S. A.

GROWTH OF VAPOR BUBBLES IN SUPERHEATED LIQUIDS, J. Appl. Phys. 25, 493-500 (April 1954).

The integro-differential equation for the growth of a vapor bubble in a superheated liquid is formulated and discussed. It is shown that 2 distinct time domains exist: one, of the order of 10^{-4} sec, during which the effect of the hydrodynamic forces may be an important factor in the growth of the bubble, and another, during which this effect is unimportant. An integral equation is formulated for the latter domain. A solution of the problem, in closed form, valid for the entire interval of interest is presented; it agrees very well with exptl. data for various superheats. (CA-48-7372a).

797. Pode, L.

THE DEAERATION OF WATER BY A SOUND BEAM, DTMB-854 (1953), 30 p.

The rate of growth of a gas bubble in a sonically irradiated liquid containing dissolved gas is shown theoretically to be proportional to the sound intensity. The calculations are limited to the case of an isolated bubble in a weak sound beam of wave length much greater than the bubble radius and of frequency below the resonant frequency of the bubble. The effects of surface tension, viscosity, and energy dissipation are neglected. The gas compression is assumed adiabatic, although for bubbles below resonant size it is actually more nearly isothermal (Daniels, J. acoust. Soc. Amer. 19, 4, 569-71, July 1947). Diffusion at the moving boundary surface of the bubble is calculated approximately by a perturbation method. In neglecting surface tension, author finds no threshold effect for bubble growth. He presents growth curves for radii down to 10^{-7} cm, although stating results should not be used much below 10^{-3} cm. Author attributes experimental observation of no definite threshold in fresh tap water, in contrast to usually observed threshold in aged water, to formation of an organic bubble skin in the aged water rather than to supersaturation of dissolved air in the fresh water.

Author's results differ from those of reviewer, (Acoustics Res. Lab., Harvard Univ. Tech. Mem. No. 12, Sept. 1949), who included surface tension but omitted resonance effects and motion of boundary in diffusion equation, and from those of M. D. Rosenberg (ibid., Tech. Mem. No. 25, Aug. 1952, and No. 26, Aug. 1953), who in a very thorough discussion added the effects of viscosity, heat conduction, sound scattering, and transients. Author compares his results of resonance with reviewer's for zero surface tension, finds them similar in form but differing slightly in numerical constants. Besides removing threshold effect, neglecting surface tension makes calculated rate of growth decrease rather than increase as bubble grows larger. (AMR-7-3613)

798. Rosenberg, M. D.

PULSATIONS AND GROWTH OF GAS-FILLED BUBBLES IN SOUND FIELDS, AD 4142 (1952).

799. Saneyoshi, J., and Murimura, S.

GROWTH AND EXTINCTION OF BUBBLES IN WATER, Oyo Butsuri (Applied Phys.) 12, 384-391 (1943).

A rise of bubbles in water produced by its electrolysis was telescopically sighted to note that even in supersatn. small bubbles disappear by the internal pressure overcoming the surface tension. There exists a boundary radius inversely proportional to the supersatn. Bubbles with a greater radius than that will grow; those with a smaller radius will disappear. The velocity of growth or extinction is calcd. from the dispersion velocity detd. by the concn. gradient of air surrounding the bubbles. At the moment of extinction the bubbles show a sudden shrinkage in size before they disappear totally. The extinction velocity of bubbles whose radius is larger than 0.02 mm is larger than that calcd. from the dispersion because they rise more quickly. Bubbles of radius less than 0.005 mm rarely exist in water because they will disappear in less than 1 min if they are generated at all, except in excessive supersatn. (CA-41-4993h)

800. Scriven, L. E.

ON THE DYNAMICS OF PHASE GROWTH, Chem. Eng. Sci. 10, 1-13 (1959).

The equations governing spherically symmetric phase growth in an infinite medium and first formulated for the general case and are then simplified to describe growth controlled by the transport of heat

and matter. All assumptions and restrictions are recounted. Exact solutions of the equations are obtained for conditions typical of bubble growth in the nucleate boiling of (a) pure materials, and (b) binary mixtures. The effect of radial convection resulting from unequal phase densities is established and the regions of applicability of previously reported approximate solutions are determined.

801. Scriven, L. E.

DYNAMICS OF PHASE GROWTH, Chem. Eng. Sci. 10, 1 (1959).

The growth rate of a spherical vapor bubble in a quiescent, superheated liquid of infinite extent is detd. by the difference between the pressure in the bubble and the ambient pressure, liquid inertia and viscosity, surface tension, and transport of heat and volatile material through the liquid to the bubble surface. With suitable assumptions and restrictions, exact solutions of equations are obtained for conditions typical of bubble growth in the nucleate boiling from pure materials and from binary mixts. New measurements of bubble growth at extreme pressures and in mixts. are needed to test the new theoretical results.

802. Staniszewski, B.

NUCLEATE BOILING BUBBLE GROWTH AND DEPARTURE, Archiwum Budowy Maszyn, 7, 3 (1960).

803. Strenge, P. H., Orell, A., and Westwater, J. W.

MICROSCOPIC STUDY OF BUBBLE GROWTH DURING NUCLEATE BOILING, A.I. Ch. E. Journal. (Accepted for publication).

804. Westerfield, E. C., and Pietenpol, W. B.

VISCOSITY IN AN EXPANDING BUBBLE, Phys. Rev., 55, 306-7 (1939).

The rate of doing work per unit volume in a homogeneous medium is shown to be $d\omega/dt = \nabla(v:\psi)$ where v is the velocity vector and ψ the stress dyadic. For an incompressible fluid this becomes $d\omega/dt = 2\mu\phi:\phi + (\rho/2)dv^2/dt$ where μ is the coefficient of viscosity, ϕ the symmetric rate of strain dyadic and ρ the mass density. From this relation, it is shown that the pressure difference between the inside and outside of a steadily expanding bubble composed of an incompressible viscous fluid, is given by $\rho_1 - \rho_2 = 2\gamma(r_1^{-1} + r_2^{-1}) + 4\mu K(r_1^{-3} - r_2^{-3})$ where γ is the surface tension, r_1 and r_2 the inner and outer radii of the bubble, respectively, and K is the expansion constant r^2v for any point in the material of the bubble. (CA-33-6672-5)

805. Westwater, J. W., and Benjamin, J. E.

HIGH SPEED MICROSCOPIC STUDY OF PHASE CHANGES., Motion Picture., University of Illinois, Urbana, 1960.

806. Zavoiskii, V. K.

GROWTH OF A VAPOR BUBBLE MOVING IN A LIQUID HEATED THROUGHOUT ITS VOLUME, At. Energ. (USSR), 10, 272-4 (1961).

The growth of a moving vapor bubble at not too high heat fluxes is detd. generally by convective heat transfer from the surrounding liquid. Vols. of vapor bubbles in boiling water were detd. photographically in a specially-constructed electrolyzer, in which the water was heated by 2 metal electrodes (0.4-3.8 kw/l), and the validity was proved of the theoretically deduced formula for the vol. of a bubble: $V = k_2^2(c\gamma'/r\gamma'')^2(a/u)\Delta T^2 z^2$, where k_2 = const., c and γ' = sp. heat and d. of the liquid, resp., r and γ'' = heat of formation and d. of vapor, resp., a = thermal diffusivity, u = emersion velocity of the bubble as it moves to the surface, ΔT = temp. difference between the surface of the bubble and bulk of the liquid, z = vertical distance the bubble travels to the surface. The relation of the evolved vapor (ϕ) on distance z at different vapor velocities was detd. in an electrolyzer with a Co^{60} source and a counter. The latter measured changes in γ-ray absorption by the water-vapor mixt. effected by changes in d. of the mixt. The exptl. data were correlated as follows: $\phi = k_2^2(c\gamma'/r\gamma'')^2(a/u)N\Delta T^2 z^2$ (N = no. of bubbles in a unit of vol., s = cross sectional area of the vessel).

807. Zuber, N.

THE RATE OF BUBBLE GROWTH IN A SUPERHEATED LIQUID, MS Thesis, Dept. of Eng., Univ. of Calif. (1954), L. A., Calif.

808. Zuber, N.

THE DYNAMICS OF VAPOR BUBBLES IN NONUNIFORM TEMPERATURE FIELDS, Internat. J. Heat Mass Transfer, 2, 83 (1961).

The physical principles governing bubble growth in a superheated liquid were originally formulated by Bosnjakovic (1930) and Jakob (1932). Using these principles, Fritz and Ende (1936) derived an approximate formula for the growth of a bubble in a uniformly superheated liquid. It is shown below that the energy considerations in the Bosnjakovic - Jakob analysis enable the approximate rate of growth of a bubble on a heated surface in a liquid at saturation to be calculated. Account need only be taken of the heat flux from the heated surface to the liquid. Improvements can be made on the agreement with experimental data by making corrections which have already been applied by other authors to bubbles in a uniformly superheated liquid. Experimental data for bubbles growing and collapsing in subcooled boiling can be approximated similarly by considering the growth and collapse process separately. The growth rate is given by the extended Bosnjakovic-Jakob analysis described above. As shown by Bankoff and Mikesell (1958), the collapse rate can be predicted by the solution of Rayleigh's equation for an isothermal process. The growth and collapse process can be combined by matching them at the maximum bubble radius, thus giving a complete picture of the life history of bubbles formed in subcooled boiling.

809. Zwick, S. A.

THE GROWTH AND COLLAPSE OF VAPOR BUBBLES, Ph.D., Diss. Calif. Inst. of Tech. (1954); Hydr. Lab. Rept. No. 21-19, Calif. Inst. Tech. (1954), ONR(NRO 62-059).

810. Zwick, S. A.

THE GROWTH AND COLLAPSE OF VAPOR BUBBLES, AD-54059 (Dec. 1954), 106 p.

A theory is developed which describes the behavior of a vapor bubble in a liquid. Its physical basis is the assumption that the heat transfer effects which accompany the evaporating occurring at the bubble wall when the bubble grows, or the condensation that occurs there when the bubble collapses, are dynamically important. The basic equations of hydrodynamics are shown to reduce, for the problem under consideration, to a dynamic equation which described the behavior of the bubble wall, and a heat convection equation for the liquid which is coupled to the dynamic equation by a boundary condition at the bubble surface. A solution for the heat problem is obtained under the assumption that significant temperature variation in the liquid occurs only in a thin thermal boundary layer surrounding the bubble wall. An estimate of the correction to the temperature solution is also derived. Once the temperature at the bubble wall is given, the vapor pressure within the bubble is known and the dynamic problem becomes determinate. The theory is applied to the cases of the growth of a vapor bubble in a superheated liquid, and the collapse of a vapor bubble in a liquid below its boiling temp. at the external pressure. The simplifying physical assumptions made in the course of the investigation are justified for the specific example of vapor bubble behavior in water. A comparison of the theory with experiment is given for the observable range of bubble growth in superheated water, and the agreement is found to be very good.

811. Zwick, S. A.

GROWTH OF VAPOR BUBBLES IN A RAPIDLY HEATED LIQUID, Phys. of Fluids, 3, 685-92 (September-October, 1960).

The earlier theory (Abstr. 5541 of 1954) of the growth of vapour bubbles in superheated liquids is extended to the situation in which the rate of temperature rise of the liquid is large. Numerical solutions are presented for the early stages of bubble growth for various rates of liquid temperature rise. The asymptotic behaviour of a bubble is found explicitly for a temperature rise of the liquid which is linear in time. In this case the bubble radius grows initially as $t^{1/2}$, as in asymptotic solutions found previously for small rates of temperature rise, but then deviates toward a late $t^{2/3}$ variation.

MOTION

812. Akselrod, L. S., et al.

BUBBLE CHARACTERISTICS AT LOW GAS VELOCITIES, Zhur. Priklad. Khim. 27, 485-92 (1954).

The diam. d of an air bubble rising through a depth, h, of H_2O over a plate with perforations of d_0 diam. and spaced checker-board fashion at a distance t from one another is given by $d = 0.183 \sqrt[3]{\sigma d_0/\gamma_l}$, cm, where σ and γ_l are the surface tension and the d of the continuous phase, resp. Values calcd. by this equation are somewhat higher than those obtained by the more involved relations of Smirnov, et al., and Hayworth, et al. (C.A. 44, 10415f and 7095i), but agree very closely at crit. gas velocities $W_{cr} = (2/3)V(d/d_0)^2$ m/sec across the perforation; V is the bubble velocity, cm/sec. The height H of the dispersed phase, formed during bubbling and subsiding to the original height h of the continuous phase, is given by $H = h/[1 - (0.91\ W_0/V)(d_0/t)^2]$ where $0 \leq W_0 \leq W_{cr}$. Calcd. and exptl. values of H fall on a straight line with a max. scattering of ±15%. Plots of W_{cr} versus d_0 are asymptotic to both axes, with W_{cr} practically negligible at $d_0 > 2$ mm; the curve for alc. is below that of H_2O and that for liquid O below both. A plot of V vs. d rises almost linearly very sharply up to $d < 0.4$ cm; for larger values of d, V varies within a narrow range and approaches a const. value. (CA-48-11148b)

813. Alty, T.

CATAPHORESIS OF GAS BUBBLES IN WATER, Proc. Roy. Soc. (London) 106A, 315-40 (1924).

The results of numerous measurements show that the velocity of a gas bubble in water exposed to an electric field is independent of the character of the gas, but varies widely with the diameter of the bubble, the maximum velocity being 4.1×10^{-4} cm per sec per volt per cm for the diameter about 0.1 mm. The velocity is proportional to the strength of the field applied throughout the whole range of bubble-diameters. Some little time elapses after introduction of the bubble into the water before it acquires its full charge. The bubble attains its highest velocity only in water of specific conductivity $8.5 \times 10^{-6}\ \text{ohm}^{-1}$, and when the value is $1.8 \times 10^{-6}\ \text{ohm}^{-1}$ the charge on the bubble is very small and is occasionally reversed during the course of an experiment. The rate at which a bubble is absorbed by the water exerts a marked influence on the velocity, and two bubbles appear to repel one another.

These results are not in accord with the mathematical theory of the double layer as worked out by Lamb and Helmholtz, which indicated that the velocity of the bubble should be independent of its size. They agree, however, moderately well with Mukherjee's suggestion that the double layer is a direct result of the selective adsorption by the particle of ions of one sign. (CA-19-198-6)

814. Azizyan, A. G., Melikyan, R. A., and Smirnov, N. I.

HYDRODYNAMICS OF BUBBLING PROCESSES. I. RATE OF BUBBLING THROUGH A LIQUID OF A LARGE QUANTITY OF GAS BUBBLES IN RELATION TO THE NATURE AND HEIGHT OF THE LIQUID LAYER AND THE DISPERSION AND VELOCITY OF THE GAS, Izv. Akad. Nauk Arm. SSR, Ser. Tekh. Nauk, 14, 31-42 (1961) (In Russian).

A device for studying the rise of air bubbles, at room temp., through a column of liquid (H_2O and aq. solns. of EtOH and glycerol) is described. Krevelen's method was also utilized (K. and Hoftijizer,

CA 44, 3308f). The results of both series of expts. are given by plotting the mean velocity of the gas bubbles with respect to the liquid medium $[(W_s)_{av}]$ against the mean velocity W_M of the gas-liquid mixt. $(W_s)_{av} = W_M[h/(H-h)]$, and $W_l = W_M/[1 - W_M/(W_s)_{av}]$, where h and H are initial and final heights of the liquid column, resp. (measured visually on the glass cylinder), W_l is the av. velocity of the downward flow of the liquid. The effect on $(W_s)_{av}$ of h, of the no. and diam. of perforations in the plate at the bottom of the column, and of the viscosity of the liquid was also studied.

815. Azizyan, A. G., Melikyan, R. A., and Smirnov, N. I.

HYDRODYNAMICS IN BUBBLING PROCESSES. II. DEVELOPMENT OF EQUATIONS FOR BULK MOVEMENT OF GAS BUBBLES TO THE SURFACE IN A LIQUID MEDIUM FOR A BUBBLING AND A COMPOSITE REGIME, Izv. Akad. Nauk Arm. SSR Ser, Tekh. Nauk, 14, 59-69 (1961).

A study was made to develop dimensionless equations for the calcn. of $(W_s)_{av}$ (av. velocity of gas bubbles rising through a liquid layer) and of H (height of the gas-liquid column) for regions of a bubbling and a composite fluid regime. For gas velocities up to 0.35 m/sec in a layer of different liquids, 2 fluid regimes develop. These were called: (1) bubbling regime (the free floating of bubbles to the surface in a liquid medium), and (2) composite regime (an alternate bubbling and jet stream flow in the same liquid layer). The transition from one fluid regime to another depends not only on the magnitude of the Reynolds no., but also on other criteria. Log plots of Re_{com} vs. the ratio of $(W_s)_{av}$ to W_{com} (velocity of the gas-liquid stream) and vs. $[1-(h/H)](h$ initial height of the liquid layer) show a change in slope. The transition region from a bubbling regime to a composite regime corresponds to the point at which the slope changes on these graphs. The transition proceeds gradually and at different times along the height of the gas-liquid column.

816. Bakh, N., and Gilman, A.

ELECTROKINETIC POTENTIAL AT GAS-LIQUID INTERFACES. I. CATAPHORETIC VELOCITY OF GAS BUBBLES IN SOLUTIONS OF INORGANIC ELECTROLYTES. Acta Physicochim. U.R.S.S., 9, 1-26 (1938).

The true cataphoretic velocity v of H bubbles in H_2O (I), and in aq. KCl (II) and aq. $ThCl_4$ (III) was detd. by a method which takes into account the electro-osmotic flow of the liquid in a cell. In I and II the charge on the bubbles is neg. and v corresponds with a ζ-potential of about -30 mv. In. III the charge on the bubble remains neg. at all concns. up to 10^{-3} N, and the apparent reversal of charge at 10^{-5} N is caused by the carrying away of bubbles by H_2O, which moves toward the cathode with a velocity greater than that with which the bubbles move toward the anode; v_{III} approximates v_I and v_{II}. Changes in KCl concn. and $ThCl_4$ concn. have little effect on v.

817. Bakh, N., and Gilman, A.

ELECTROKINETIC POTENTIAL AT GAS-LIQUID INTERFACES. II. CATAPHORESIS OF GAS BUBBLES IN SOLUTIONS OF CAPILLARY-ACTIVE ORGANIC ELECTROLYTES., Acta Physicochim., U.R.S.S., 9, 27-38 (1938).

The bubble has a pos. charge in aq. NBu_4Cl and $N(C_5H_{11})_4Cl$ at concns. (c) of more than 10^{-6} mol. per l. The ζ-potential (and hence v) is approx. proportional to log c. The ratios of NBu_4Cl concn. and $N(C_5H_{11})_4Cl$ concn. which correspond with the same effects are const. and = 9. Na Palmitate gives the bubble a neg. charge which increases with concn.; the ζ-potential also increases at the liquid-glass interface.

818. Behringer, P.

VELOCITY OF STEAM BUBBLES RISING IN TUBES, V.D.I., Forschungsheft 365, Ausgabe B 5, 4-12 (Mar./Apr. 1934).

Relative speed with which steam bubbles rise in tubes of various diameters at pressures up to 40 atm. was measured; experimental arrangement and measuring apparatus; analysis of results. Bibliography.

819. Benfratello, G.

MOTION OF AN AIR BUBBLE THROUGH A FLUID AT REST, Energia elett., 30, 80-97 (Feb. 1953).

First part of a series of studies of the bibliography on bubble motion existing in early 1953 is presented. Author begins with the researches on the formation of a single bubble through a nozzle submerged in a liquid. Then, conditions for the starting of motion are discussed and the movements are classified into four classes: (a) Bubbles with less than 6-mm radius have straight paths; (b) for radius between 0.6 and 1.5 mm (in water), the form of bubbles is still more or less spherical but the paths are ellipsoidal; (c) for radius up to 2.5 mm, the form of bubbles is elliptical, with the minor axis parallel to the mean motion, which is still an ellipsoidal one; (d) when radii increase, the forms are flatter, especially at the lower portion of the bubbles. Author studies the physical behavior of the "shell" which limits the air portion and the liquid, and the volume and weight variations during the motion.

Theoretical studies on motion of bubbles in an infinite fluid are presented, starting with Stokes' formula, which has been found quite applicable to the smallest bubbles. The Oseen formula, which was derived considering the inertia terms in the equation of motion, is discussed and compared to Stokes' formula. Then, author analyzes Basset's formula, derived considering the sliding between the bubble and the liquid. Hadamard's formula is discussed and compared to the previous ones, and the same for Boussinesq and Levic formulas.

The paper ends with a list of 45 references. Reviewer thinks that the main purpose of author, i.e., to furnish a review of existing studies on the subject, is well achieved and that, although not completely original, must be welcome as a help to people connected with these researches. (AMR-8-1040)

820. Birkhoff, G., and Carter, D.

RISING PLANE BUBBLES, Journal of Mathematics and Mechanics, 6, 769-779 (November 1957).

Authors treat the plane flow problem of an isolated bubble rising steadily under the influence of gravity in an infinitely long vertical tube of incompressible, inviscid fluid. Adapting methods of Levi-Civita and Viliat, they use techniques of conformal mapping to reduce this free boundary problem to a nonlinear integral equation. The integral equation is attacked numerically by a procedure based on equal-spaced interpolation and truncation of certain Fourier series. However, in contrast with the situation without gravity, the convergence is found to be not really satisfactory. Several unexpected difficulties are brought to light and discussed in the hope that they may be resolved by further analysis.

821. Bleich, H. H.

EFFECT OF VIBRATIONS ON THE MOTION OF SMALL GAS BUBBLES IN A LIQUID. APPENDIX I, II - EFFECT OF VISCOSITY, Jet Propulsion, 26, 958-978, AEI-1957 (Nov. 1956).

Derivation of basic equations for the motion of small gas bubbles in an inviscid liquid in the presence of harmonic vibrations and explanation of the mechanism which may make bubbles more contrary to gravity forces. The case of similar bubble phenomena in missile fuel tanks due to heavy vibrations caused by the rocket engine is considered.

822. Bogdanov, O. S., Kizavalter, B. V., and Moslova, S. G.

EFFECT OF THE FROTHING AGENT ON THE AIR CONTENT IN THE FLOTATION PULP, Izvest. Akad. Nauk SSSR Otdel Tekh. Nauk, 412-16 (1950).

The rate of movement of gas bubbles in a liquid in the presence of surface-active agents was expressed by the equation: $U = \frac{2}{3}((\rho - \rho')ga^2/\mu)(\mu + \gamma/3/2\mu + \gamma)$ where $\gamma = (2\Gamma_0\delta/Da)(\partial\sigma/\partial c)$; Γ_0 is the amt. of substance adsorbing on a unit of the bubble surface; σ is the surface tension at the boundary of the bubble; δ is the av. thickness of the diffuse layer; D is the coeff. of diffusion of surface-active substance in water; a is the bubble radius; μ is the coeff. of viscosity of water; c is the concn. of the soln. near the bubble surface; $\rho - \rho'$ is the d of the liquid; and g is the acceleration of gravity. It was concluded that the frothing agent reduced the rate of rise of the bubbles but prevented them from coalescing. A diagram of the app. used for detg. the rate of rise of bubbles in a liquid medium is provided. (CA-45-9431h)

823. Bryn, T.

SPEED OF RISE OF AIR BUBBLES IN LIQUIDS, DTMB-TRANS-132 (1933), 9 p.

The rate of rise of air bubbles of different volumes in glycerin - water and alcohol - water is determined by their size and Laplace's constant. Small or spherical bubbles do not behave as solid spheres. Their rate of rise depends on the manner in which replacement of their boundary layer occurs.

824. Buchanan, R. H., et al.

CYCLIC MIGRATION OF BUBBLES IN VERTICALLY VIBRATING LIQUID COLUMNS, Ind. Eng. Chem. Fundamentals, 1, 82-6 (1962).

A procedure was developed for bringing gas, liquid, or solid phases into contact to promote exchange phenomena. When liquid columns 5-15 cm in diam. are subjected to vertical vibrations of amplitudes of 0.05 - 1.0 cm and frequencies of 1200-2900 rpm, bubbles migrate cyclically from the surface to the bottom, where they aggregate and then move back up the column. The result is violent and rapid mixing of the gas with the liquid and with suspended solids. An equation is derived which permits accurate prediction of the min frequency for cyclic migration for the air-H_2O system at atm pressure. Some deviation occurs with liquids whose properties differ markedly from H_2O and at pressures other than atm.

825. Chao, B. T.

MOTION OF SPHERICAL GAS BUBBLES IN A VISCOUS LIQUID AT LARGE REYNOLDS NUMBERS, Phys. Fluids, 5, 69-79 (1962).

An analysis is made for the motion of a gas bubble rising steadily in a quiescent liquid of infinite extent. The disturbed layer of the fluid, due to viscosity, on either side of the interface is thin when the Reynolds number is sufficiently large and thus makes possible a considerable simplification of the governing equations of motion. Simultaneous solutions of the boundary-layer equations for the flow outside and inside of the bubble are obtained considering that the tangential velocity components and the shear stresses on both sides of the interface are equal. From the calculated external stress field, the drag of a spherical bubble with negligible flow separation is evaluated. Good agreement is obtained with published data for spherical air bubbles in four different organic liquids. The experimental drag curve due to Haberman and Morton for air bubbles rising in filtered water deviates from that predicted from the present theory. The theoretical results are applicable to any fluid sphere moving steadily in a substantially immiscible, viscous liquid provided that the internal circulation is complete, the flow separation is negligible, and the Reynolds number is sufficiently large.

826. Chertock, G.

THE FLEXURAL RESPONSE OF A SUBMERGED SOLID TO A PULSATING GAS BUBBLE, J. Appl. Phys. 24, 192-7 (Feb. 1953).

A bubble in a liquid pulsates and generates a changing pressure field. This reacts with a submerged flexible solid and induces elastic motions. Equations are derived which show how the vibration modes and frequencies of the solid are modified by the presence of the water, and how each mode is excited by the bubble pulsation. The generalized force for each mode is proportional to the volume acceleration of the bubble. The initial analysis presupposes incompressive flow, but it is shown that the results remain applicable if the duration of any compressive

phase is small compared with the pulsation period of the bubble and the vibration period of the solid. (Abstr. 3029-3035)

827. Coester, E.

THE VELOCITY OF ASCENT OF GAS BUBBLES IN LIQUIDS OF VARYING VISCOSITY AND SURFACE TENSION, Z. Angew., Phys. 13, 254-9 (May 1961).

The velocity of ascent of air bubbles was studied in glycerine and in water. The velocity increased at first with the volume and tended then towards a constant value. The air bubbles were practically spherical in the range for which the velocity increased with their volume. Larger bubbles were of an oblate shape. The spherical gas bubbles encountered a smaller resistance than rigid spheres of similar volume. For small Reynold's numbers the resisting force was only two-thirds of the Stokes value. A dimensional analysis was made for the purpose of deriving an equation which can be applied to estimate the velocity of ascent gas bubbles in any liquid.

828. Dal, V. I., and Vitkina, M. A.

THE MECHANISM OF ABSORPTION DURING BUBBLING, J. Appl. Chem. (USSR) 23, 609-13 (1950).

The motion of a gas bubble in a viscous medium is given by

$$\nu = \sqrt{\left(\frac{4DG}{3\psi}\right)\left(\frac{\gamma_1 - \gamma_g}{\gamma_1}\right)(1 - e^{-3\psi\gamma_1/2D\gamma_g H})}$$

where ν is the rate at which the gas bubble rises, in m/sec; D is the bubble diam., in m; H is the height of the bubbling layer, in m; ψ is the coeff. of resistance of the medium; γ_g and γ_1 are the densities of the gas and the liquid, resp., in kg/cu m; and G is the acceleration of gravity in m/sec^2. The coeff. of absorption rate $K = 6.95 D^{1.067} V^{1.2H} H^{-0.5}$ kg/(sq m hr mm Hg), where D = diam. of the bubble, ν = rate of flow of gas in cu m/hr, and H = height of the bubbling layer in m. K increases as the bubbling depth diminishes and the bubble diam. increases. Near the surface of a rising bubble, the gas moves with the surrounding medium, and inside, in the opposite direction. The surface of the bubble is subjected to tension at the top and compression at the bottom. The eddying motion inside the bubble causes particles of the moving gas to rupture and pass through the boundary layer. With increasing velocity, the boundary becomes thinner and the interchange of the substances involved improves. (CA-46-10792e)

829. Davidson, J. R., et al.

RISE OF BUBBLES IN FLUIDIZED BED, Instn. Chem. Engrs. - Trans, 37, 323-8 (Dec. 1959).

Rate of rise of bubble in air-fluidized bed of particles was measured by observing time interval between release of shot of air injected at base of bed and its arrival at surface as bubble; injected bubble of air rises at same rate as it would in inviscid liquid of zero surface tension; U (rate of rise) is given in terms of volume of bubble by semi-empirical formula derived for gas bubble in inviscid liquid by R. M. Davies and G. Taylor.

830. Davies, R. M., and Taylor, G.

THE MECHANICS OF LARGE BUBBLES RISING THROUGH EXTENDED LIQUIDS IN TUBES, Proc. Roy. Soc. A 200, 375-90 (1950).

Describes measurements of the shape and rate of rise of bubbles varying in volume from 1.5 to 200 cm^3 when they rise through nitrobenzene or water. (Sci. A. 53-2952)

831. Dementiev, B. A., Lepilin, R. S., and Loginov, A. A.

AN INVESTIGATION OF THE HYDRODYNAMIC PROCESS OF BUBBLING THROUGH A VAPOR-LIQUID MIXTURE OF CONSIDERABLE HEIGHT, Nauch. Dok. Vish. Shkol. - Energetika, no. 2, p. 251 (1959).

832. Devin, C., Jr.

SURVEY OF THERMAL, RADIATION, AND VISCOUS DAMPING OF PULSATING AIR BUBBLES IN WATER, J. Acoust. Soc. Amer., 31, 1654-67 (December, 1959).

A theoretical discussion is presented on the fundamental processes by which pulsating gas bubbles in liquids dissipate their energy. The survey is limited to the case where the amplitude of the volume pulsations are assumed to be sufficiently small that the pulsations may be described by linear equations. A portion of the energy of the bubble system is lost by the radiation of spherical sound waves, a part is lost by heat conduction due to the polytropic compressions and expansions of the enclosed gas, and a portion is lost by viscous dissipation attributed to viscous forces acting at the gas-liquid interface. A survey is made of the procedures for measuring the resonant damping constant as described in the methods of successive oscillations, width of the resonance response, standing-wave ratios, and resonance absorption. Experimental results verify that the damping at resonance is due to thermal and radiation, and possibly viscous damping.

833. Donaldson, M. S.

INITIAL VELOCITY OF BUBBLES IN A PNEUMATIC FLOTATION CELL, Mining Sci. Press 120, 940-2 (1920).

In order to det. if the bubbles issuing from the porous diaphragm of a pneumatic flotation cell possessed any initial velocity the path of bubbles issuing from a vertical diaphragm was detd. Obviously any initial velocity would give the path a horizontal component. Photographs of the bubble paths at various pressures show no indication of an initial velocity. (CA-14-2458-3)

834. Dyk, K.

THE CATAPHORESIS OF SMALL GAS BUBBLES IN VARIOUS ORGANIC LIQUIDS, Phys. Rev. 31, 913 (1928).

By use of a new technic, the simple behavior observed for bubbles in water was not observed in org. liquids up to fields of 15,000 v/cm. (CA-24-4685-2)

835. Exner, M. L.

MEASUREMENT OF THE DAMPING OF OSCILLATING AIR BUBBLES IN WATER, Akust. Beih. No. 1, AB-25-AB-33 (1951).

A new technique has been developed by which the bubble is allowed to rise freely in a water-filled tube under the influence of a plane progressive wave. Reflection of this wave from the free surface is prevented by an absorption device. The bubble acts as a centre of reflection and as it passes a microphone, the pressure distribution before and behind the bubble is registered. From the reflected power, measured in this way, the damping factor for the bubble may be estimated. From measurements made for the case of resonance, it appears that within the frequency range of the experiment the damping of the bubble may be completely explained through the effects of heat transfer and radiation. (Sci. A. 55-1583)

836. Exner, M. L., and Hampe, W.

EXPERIMENTAL DETERMINATION OF THE DAMPING OF PULSATING AIR BUBBLES IN WATER, Acustica 3, 67-72 (1953).

The experiments showed that the damping of pulsating air bubbles in water for bubbles with resonant frequencies up to 100 kc/s can be explained theoretically by the energy losses due to sound radiation and heat conduction. From the result of the first part of the measurements, the validity of Minnaert's relation between radius and resonant frequency of the bubbles for frequencies higher than 50 kc/s became doubtful. Further investigations including direct measurements of the radii showed that the resonant frequencies of bubbles are considerably influenced by dust particles at higher frequencies. By association of dust particles at the surface of a bubble in the frequency range of 100 kc/s, the resonant frequency may rise up to 1.5 times the value given by Minnaert's formula. The damping of air bubbles is not influenced by association of dust particles. In liquids with small surface tension, where no dust particles remain at the surface, all bubbles showed normal properties. The damping due to viscosity seems to be considerably smaller than would be expected from Lamb's theory. (Sci. A-57-2173)

838. Flint, O.

ELECTROLYTIC CURRENT FLOW BY BUBBLE MIGRATION, AERE-M/R-1470 (1954), 20 p.

The anodic oxidation of tantalum in various ethylene glycerol electrolytes containing common acid radicals shows a complex relationship between potential and time at constant current density. The departure from a rectilinear relationship which obtains in aqueous media, is shown to be due to the migration between the electrodes of electrolytic bubbles carried with them liquid of high and low pH created at the electrode surface, other controllable variables having little significant effect.

839. Gorodetskaya, A.

THE RATE OF RISE OF BUBBLES IN WATER AND AQUEOUS SOLUTIONS AT GREAT REYNOLDS NUMBERS, Zhur. Fiz. Khim. 23, 71-7 (1949).

The equation $\nu = gR^2(\rho - \rho_0)/9\eta$ [cf. Levich, J. Exptl. Theoret. Phys. U.S.S.R. 19, (1949)] was tested for air in H_2O at Reynolds no. 10-450. In it ν is the rate of rise, R radius of the bubble, ρ and ρ_0 d of liquid and gas, and η viscosity of the liquid. The movement of the bubbles was observed visually or cinematographed. In H_2O boiled with $KMnO_4$ and twice distd. ν was only 30% smaller than the theoretical value. In tap water ν was little different at R = 0.03 cm but much smaller at R = 0.07 cm. Butanol, pentanol, hexanol, and octanol start to lower ν in 10^{-4}, 5×10^{-5}, 10^{-5}, and 3×10^{-6} M solns. and reach the max. lowering (2.5 times) at the tenfold concns. At this concn. the mobility of the liquid-air boundary is reduced to zero and the region of turbulency behind the bubble is as great as for solid spheres. In agreement with this, glass marbles had values of $\nu/(\rho - \rho_0)$ equal to those of air bubbles in contaminated H_2O. (CA-43-4082b)

840. Gorring, R. L., and Katz, D. L.

BUBBLE RISE IN A PACKED BED SATURATED WITH LIQUIDS, A.I.Ch.E. J. 8, 123-6 (1962).

Exptl. data were obtained for drag coeffs. on fluid bubbles rising in a satd. packed bed and in clear liquids. Air and benzene were used to form bubbles in glycerol soln., H_2O, and n-heptane. The bed was formed from 1-in.-diam. glass spheres in hexagonal, random, and cubic packings. The range of Reynolds no. was 0.1-1000. The drag coeffs. in the hexagonal and random arrays were 2-3 times those in clear liquors, while the drag on bubbles rising in cubic packings was the same as that for clear liquids. The method of correlation involved the use of the minor diam. in the drag coeff. and the major diam. in the Reynolds no. The innovation improved the correlation for bubble rise in clear liquids. 25 references.

841. Gosline, J. E.

THE GAS LIFT, University of California, Ph.D. Thesis, December 1933, 77 p.

General relationship between the motion of the bubbles, the physical properties of the liquids and the size of the tubes are given.

842. Gould, R. K., and Nyborg, W. L.

VISCOUS DAMPING OF BUBBLES, J. Acoust. Soc. Amer., 32, 775-6 (June, 1960).

An expression is derived for the spatial distribution of viscous energy losses in the body of liquid surrounding a vibrating spherical bubble.

843. Guth, W.

NONLINEAR OSCILLATION OF AIR BUBBLES IN WATER, Acustica, 6, pp. 532-538 (1956).

The vibration characteristics of bubbles excited to large amplitudes in water are investigated. Both in free and forced vibration, the changes of frequency, mean bubble radius and, especially, the mean internal air pressure are calculated in their dependence on amplitude. Approximate solutions for the nonlinear vibration are calculated in both cases. The resonance curves under forced vibration are calculated. Finally, a plausible explanation of the incidence of the often observed subharmonies is given.

844. Haberman, W. L., and Morton, R. K.

AN EXPERIMENTAL INVESTIGATION OF THE DRAG AND SHAPE OF AIR BUBBLES RISING IN VARIOUS LIQUIDS, DTMB-802 (1953) 57 p.

In connection with other investigations at the David Taylor Model Basin, detailed information became necessary on the motion of air bubbles in variable pressure fields. Since no information on the subject was available, a fundamental study of the motion of bubbles was undertaken. As an initial step, experiments were conducted to determine the drag and shape of single air bubbles rising freely in various liquids. The results of the experiments show that a complete description of the motion of air bubbles is not possible by use of dimensionless parameters containing the usual physical properties of the liquid (viscosity, surface tension, density). Three types of bubble shapes were observed in each liquid, namely spherical, ellipsoidal, and spherical cap. For a specific liquid, the shape of the bubble was a function of its volume. For tiny spherical bubbles, the drag coefficients coincide with those of corresponding rigid spheres. With increase in bubble size, a decrease in the drag as compared to that of rigid spheres occurs in some liquids. Thus, the drag curves of the spherical bubbles rising in various liquids fall between two limiting curves, namely the drag curve of rigid and fluid spheres, respectively. It was not possible to determine a criterion for the transition of the bubbles from "rigid" to fluid spheres. The region of ellipsoidal bubbles extends over different ranges of Reynolds numbers for the various liquids. The drag coefficients of spherical cap bubbles are independent of bubble size and have a constant value of 2.6. For bubbles (equivalent radius 0.03 to 0.30 cm) rising in tap water or in water containing certain surface-active substances, experiments show an increase in drag as compared to bubbles in pure water. Results of tests to determine the effect of the container walls on the velocity of rise are presented. A description of the experimental apparatus is given. A summary of the theoretical and experimental work of other investigators is also included. (NSA-9-6244)

845. Haberman, W. L., and Morton, R. K.

AN EXPERIMENTAL STUDY OF BUBBLES MOVING IN LIQUIDS, Proc. Am. Soc. Civil Eng. 80, Separ. No. 387 (January 1954), 25 p.

Drag and shape of single air bubbles rising freely in various liquids; three types of bubble shapes were observed in each liquid, namely, spherical, ellipsoidal, and spherical cap; tests to determine effect of container walls on velocity of rise; distribution of experimental apparatus.

846. Harmathy, T. Z.

VELOCITY OF LARGE DROPS AND BUBBLES IN MEDIA OF INFINITE OR RESTRICTED EXTENT, A.I.Ch.E. Journal 6, 281-8 (1960).

A new theory gives a simple method of calcg. the terminal velocity of fluid particles moving in media of either infinite or restricted extent. Empirical and semi-empirical formulas and a graph over the interval $0 \leq d/D \leq 1.3$ yield satisfactory results for gas or liquid particles moving in liquid media. In the case of liquid drops falling through gaseous media they give only a rough approxn. Graphs showing the variations in the drag coeff. and the shape of fluid particles with Eoetvoes no. are given. A semi-empirical equation for the terminal velocity of solid spheres in restricted media was also developed. 50 references.

847. Kaissling, F.

THE VELOCITY OF RISING OF BUBBLES OF VAPOUR IN BOILER TUBES, AERE-Lib/TRANS-510 (1943), 9 p.

The measurements of Behringer prove that the flow of vapor through stationary boiling water in a vertical tube obeys the law of analogues and that the characteristic quantity which contains the velocity of the vapor is dependent on each of the other three characteristic quantities; they also show that there is no more simple law. The effect of the vapor content of the tube and the effect of the vapor pressure (characterized by the distance from the critical point) are the strongest. The effect of the characteristic quantity containing the tube diameter becomes greater as the quantity itself decreases (thus for example, the tube diameter) and as the vapor pressure decreases and as the vapor content increases. Limits are thus set on the use of tubes of small diameter at low vapor pressure or at high vapor content. The transformation of operational experiences from one region into another is not advisable without a knowledge of the relationships presented. The tube was not heated in the exp. here and no vapor bubbles were formed on the walls of the tube; this is in contrast to many cases of practical operation. (NSA-9-7400)

848. Klemm, A.

KATAPHORESIS OF GAS BUBBLES, Phys. Zeits. 39, 783-93 (1938) (Translated in DTMB-T-137).

The theory of the kataphoresis of solid spherical particles is extended to include spheres of any viscosity. A value is deduced for the velocity of kataphoresis of gas bubbles, more especially in water, and the theoretical results are compared (satisfactorily) with Alty's experimental results and are used to discuss the synthesis of the gas-water interface.

849. Kocho, V. S.

THE NATURE OF THE CHANGE OF THE STATE OF A GAS IN BUBBLES RISING IN A LIQUID, Doklady Akad Nauk. SSSR., 66, 605-7 (1949).

Gas bubbles of const. initial diam. rising through a column of liquid of the height H, sp. gr. γ, at const. temp., undergo an expansion that causes a displacement L of the liquid meniscus in a horizontal capillary attached to the main body of the liquid. If the process is polytropic, there should be an addnl. displacement ΔL due to continuing heat exchange between the gas and the liquid. Expts. in H_2O and in oil at 16° showed the coeff. $n = \log [1 + (H\gamma/P_0)] / \log \{1 + [LH\gamma/(L + \Delta L)P_0]\}$ to increase with the initial diam. of the bubbles, and not to exceed 1.001; this means that the process is very nearly isothermal. (CA-43-6480i)

850. Kozlov, B. K., and Mologin, M. A.

CONCERNING THE VELOCITY OF RISE AND HYDRODYNAMIC RESISTANCE OF GASEOUS BUBBLES IN LIQUIDS, Translated from: Izv. akad. Nauk. S.S.S.R., Otd. Tekh, Nauk, No. 8, 1188, AEC-tr-3274 (1951).

Results of an investigation on the determination of velocity of rise of air bubbles in water and the determination of how their resistance coefficients depend upon the dispersion of bubbles and the diameter of the tubes in which the experiments were performed are presented.

851. Ladyzhenskii, R. M.

INVESTIGATION OF USE OF AIR BUBBLES IN WATER AT HIGH REYNOLDS NUMBERS, J. Appl. Chem. (USSR), 27, 17-25 (1954).

The rate of rise of smaller bubbles, up to 3 cc, was previously investigated by Gorodetskaya (CA 43, 4082a) and by Smirnov, et al. (CA 46, 4320a). L. investigates larger bubbles up to 20 cc and larger. The correlation of exptl. and calcd. values is in closer agreement as the bubble vol. and Reynolds no. increase to 20 cc and 12800, resp. Bubble deformation in its movement is analyzed in detail. (CA-48-6780b)

852. Lauer, H.

ON THE THERMAL DAMPING OF BUBBLES OF VARIOUS GASES IN WATER, Akust. Beih. No. 1, AB-12-AB-24 (1951).

The causes influencing the damping of spherical oscillations of gas bubbles in water are calculated, especially those due to thermal effects within the bubble when it is placed in an acoustic field. The thermal conductivity of the gas is an important factor of the damping. Measurements on resonance-bubbles of the gases air, H, A, Ne and He in the frequency-range from 1 to 7 kc/s are in good agreement with theory. (Sci. A. 55-1582)

853. Leibson, I., et al.

RATE OF FLOW AND MECHANICS OF BUBBLE FORMATION FROM SINGLE SUBMERGED ORIFICES, AIChE Journal 2, 296-306 (1956).

A study has been made of the rate of flow and mechanics of bubble formation from single submerged orifices $\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{16}$, and $\frac{1}{8}$ in. in diameter installed in an 8-in. I.D. column operating in the air-water system. The coefficients of discharge obtained for sharp-edged orifices operating with this system indicate that the effective orifice discharge area for this type of operation is greater than that for an orifice of the same size and type operating at the same pressure ratio in the air-air system. The effective orifice discharge areas for a round-edged orifice operating in either the air-water or air-air systems appear to be identical at the same pressure ratio. The thick-plate orifice operating in the air-water system exhibits a constancy of discharge coefficient at ratios of the downstream to upstream pressures less than 0.33. Inasmuch as bubble formation occurring close to the downstream face of a sharp-edged orifice operating in the air-water system influences the effective orifice discharge area, liquid physical properties may be expected to be important in determining the rate of flow from this type of orifice for other gas-liquid systems. Photographic studies of bubble formation reveal that nonuniformity of bubble size is initiated by the onset of turbulence in the air stream flowing through the orifice. In the section of the laminar-flow range studied in this investigation ($200 < N_{Re} < 2{,}100$) the frequency of bubble formation is nearly constant with respect to Reynolds number. The bubble size is relatively uniform at a given Reynolds number and depends markedly upon orifice diameter. Stroboscopic examination reveals that as turbulence is fully developed for the air flow through the orifice, a counterclockwise spiraling, swirling motion of the air jet is initiated. In the turbulent-flow range the bubblesize-distribution data are fitted reasonably well by a logarithmic-normal-probability distribution. (NSA-10-11787)

854. McLaughlin, T. A.

CATAPHORESIS OF AIR BUBBLES IN VARIOUS LIQUIDS, Roy. Dublin Soc. Proc., 17, 13-17 (1922).

The paper commences with a notice of previous work on gas suspensions in liquids. Quincke studied the motion of air-bubbles under an electric field and found that in water they moved towards the positive pole, but in carbon disulphide and turpentine towards the negative pole. McTaggart verified Quincke for water, but found no motion of air-bubbles under an electric field in the pure alcohols, methyl, ethyl, propyl, and isobutyl. In the present research the plan has been to make preliminary investigations into the charge on air-bubbles in pure liquids, with special reference to badly conducting ones. The apparatus used has been of the McTaggart type and is

fully described in the paper. Under the conditions employed, air-bubbles were found to show no cataphoresis in the following liquids: Methyl, ethyl, and butyl alcohols, xylol, benzene, toluene, bromobenzene, benzyl alcohol, benzaldehyde, aniline, cinnamic aldehyde, ethyl malonate, lactic acid, oleic acid, ethyl acetate, and turpentine. The results on turpentine are not in accordance with those obtained by Quincke. It was not found possible to trap an air-bubble in acetone and such volatile liquids as carbon-disulphide. In impure acetone, foreign matter moved towards the positive pole. In distilled water, air-bubbles moved towards the positive pole; in impure benzene, towards the negative pole. In "pure" nitrobenzene air-bubbles moved to the negative pole, whilst in the impure substance the motion may be to either pole. The solution of an air-bubble in methyl alcohol under an electric field previously noted by McTaggart was confirmed. (CA-16-4103-1)

855. Manley, R. S. J., and Mason, S. G.

PARTICLE MOTIONS IN SHEARED SUSPENSIONS. III. FURTHER OBSERVATIONS OF COLLISIONS OF SPHERES, Can. J. Chem. 33, 763-73 (1955).

Rigid spheres of varying diam. ratio and air bubbles of approx. equal size were studied to det. whether the two particles forming a doublet come into true physical contact. Glass spheres with diams. between 5 and 180 μ were suspended in corn sirup of viscosity approx. 50 poises. Systems of narrow and tabulated size distribution could be prepd. Dil. suspensions of air bubbles were made by stirring, and allowed to stand so as to permit larger bubbles to rise and leave behind spheres of size about 150 μ and fairly uniform. The interaction of a pair depends on the ratio diams., a_1/a_2. For $a_1/a_2 < 2$, the behavior is similar to that of a uniform system. For larger ratios, the particles remain always sepd. The smaller particle moves usually in a widening spiral upwards around the other until it reaches a latitude approx. equiv. to the initial one. Then it seps. with a velocity about equal to that of approach. This motion persists upon reversal of the velocity field. It may be due to differential sedimentation. Also, zig-zag motions in a roughly const. X-Z plane were noted. The collision frequencies were observed over a range of concns. and velocity gradients. The exptl. and calcd. values agree within 8% for a total of 857 collisions. Air bubbles do not deform under the gradients used; they spin around the Z-direction like rigid spheres. This is analogous to the behavior in sedimentation at low Reynolds nos. Two approaching bubbles form a doublet, which performs up to 60 rotations before the bubbles suddenly coalesce into a single sphere. However, in a no. of instances, doublets without contact and subsequent complete sepn. were found. The observed periods of rotation exceed those calcd. for an ellipsoid of twofold axis ratio by 69%. The details of the orbits of touching bubbles are in quant. accord with Jeffery's theory. The steady-state concn. of doublets is $8c^2$, with c the vol. fraction of equally sized spheres. Corresponding expressions for heterodisperse systems are presented. The observations are of interest in connection with the known increase of coagulation rates with shear, although the question posed about the nature of the contacts is not definitely answered. (CA-49-15364d)

856. Marchessault, R. N., and Mason, S. G.

FLOW OF ENTRAPPED BUBBLES THROUGH A CAPILLARY, Ind. Eng. Chem. 52, 79-84 (1960).

The effective film thickness surrounding moving air and liquid bubbles in glass capillary tubes contg. aq. liquids was measured conductimetrically and correlated with the measured hydrodynamic resistance to flow of the bubble. The phenomena described are of interest in connection with 2-phase flow of fluids through porous media.

857. Margulova, T. H.

AN EXPERIMENTAL INVESTIGATION OF THE RELATIVE VELOCITY OF VAPOR IN BUBBLING THROUGH A LAYER OF WATER AT HIGH PRESSURES, Trans. of the Power Inst. M. V. Molotov, Vol. 11, Moscow, (1953).

858. Melikyan, R. A.

HYDRODYNAMICS OF EMERSION ASCENT OF SINGLE BUBBLES IN A LIQUID MEDIUM, Journal of Applied Chemistry of the USSR, 29, 1792-1802 (December 1956) [Trans. of Zhurnal Prikladnoi Khimmii, 29, no. 12, pp. 1929-1938 (1956)].

The hydrodynamics of the ascent of a single gas bubble in a liquid medium is discussed. Thermodynamic conditions are selected such that the energy of expansion released by the gas bubble in its ascent is equal to the energy converted by friction into heat. The interaction among bubbles in an ascending series of bubbles is also treated. The crowding effects tend to accelerate the ascent but this is somewhat compensated for by additional friction. The coalescence of small bubbles and the fragmentation of large ones introduce further complications. It is concluded that the ascent of bubbles is accompanied by an upward flow of continuous phase in the immediate vicinity of the bubbles and a downward flow of the remainder of the continuous phase. The theory is quantitatively supported by experimental data. (AMR, 1959) #4562

859. Meyer, E. and Tamm, K.

CHARACTERISTIC VIBRATION AND DAMPING OF GAS BUBBLES IN LIQUIDS, Akust. Z., 4, 145-52 (1935).

The characteristic frequencies f_0 and the damping decrements δ of gas bubbles (H_2, O_2, air) in water, glycerol and aq. glycerol solns. were measured for the frequency ranges 1.5-7 and 15-35 kilocycles per sec. The relation $f_0/d = 0.66$ was obtained, in which d = the diam. of the bubble in cm. The detn. of f_0 was accomplished in the lower-frequency range by photoelec. measurement of the amplitude of the bubble in relation to the frequency. For the higher-frequency range, the detachment of electrolytically produced gas bubbles from an electrode under the influence of sound waves was observed. δ was shown to be made up of 2 parts - a const. fraction of the radiation damping and a factor that is proportional to the frequency. At 25 kilocycles per sec. δ amounts

to about 0.9. Finally, by the use of a high-toned analyzer the sound spectra were obtained for the ascent of gas bubbles from a nozzle. (CA-35-4257-9)

860. Meyer, E., and Tamm, K.

NATURAL VIBRATION AND DAMPING OF GAS BUBBLES IN LIQUIDS, Trans. from Akust. Z, 4, No. 3, DTMB-T-109 (1939).

The coefficients of actual vibration, the natural frequency, and the damping decrement were determined for gas bubbles in liquids over a range of frequency from 1.5 to 35 kc.

861. Miyagi, Otagoro

THE MOTION OF AN AIR BUBBLE RISING IN WATER, Phil. Mag., 50, 112-140 (1925).

Air bubbles of various sizes moving up in still water are carefully treated experimentally and then theoretically. Their terminal velocities are determined in relation to their sizes, and the changes of their shapes during their motion are investigated.

The mass of water carried up with a moving bubble and the resistance to its motion are determined, and the most probable equation of motion is proposed. It is also proved that there are two different kinds of motion of a bubble in water exactly analogous to the stream-line and the turbulent flows of a viscous fluid, which passes from the one to the other distinctly at the critical radius of the bubble. (CA-19-3844-5)

862. Moore, D. W.

THE RISE OF A GAS BUBBLE IN A VISCOUS LIQUID, Journal of Fluid Mechanics, 6, 113-130, (July 1959).

The rise of a gas bubble in a viscous liquid at high Reynolds number is investigated, it being shown that in this case the irrotational solution for the flow past the bubble gives a uniform approximation to the velocity field. The drag force experienced by the bubble is calculated on this hypothesis and the drag coefficient is found to be $32/R$, where R is the Reynolds number of the bubbles rising motion. This result is shown to be in fair agreement with the experiment. The theory is extended to nonspherical bubbles, which enables both bubble shape and velocity of rise to be predicted. Finally an inviscid model of the spherical cap bubble involving separated flow is considered.

863. Nodtvedt, H.

THE EFFECT OF SOUND WAVES ON THE ASCENDING VELOCITY OF AIR BUBBLES IN VISCOUS LIQUIDS, Beretn. Michelsens Inst. Vidensk., 12, No. 5, 13 (1948).

Small-scale experiments have shown that the properties of very viscous liquids (e.g. molten glass or Canada balsam) are changed if sound energy is introduced. In the present work it is shown that air bubbles in Canada balsam ascend with a velocity up to four times that of the original state when the sound energy is about 0.05 watt/cm^2 at a frequency of 9.3 kc/s. Clusters of small bubbles collapse into one larger bubble under the influence of sound waves. (Sci. A. 55-91).

864. O'Brien, M. P., and Gosline, J. E.

VELOCITY OF BUBBLES IN VERTICAL TUBES, Ind. Eng. Chem. 27, 1436-40 (1935).

As part of investigation of oil-gas lift pumping; experiments were performed on motion of air bubbles in water and in two colorless petroleum oils using three sizes of glass tubing; comparison of results with other experiments shows reasonable agreement at bubble radius of 3 mm. Bibliography. (CA-30-655-1)

865. Pearcey, T., and Hill, G. W.

THE ACCELERATED MOTION OF DROPLETS AND BUBBLES, Austral. J. Phys., 9, 19-30 (March 1956).

The drag force acting upon small particles such as droplets and bubbles, moving through a viscous medium, depends upon the rate of change of the state of motion of the medium and upon the diffusion of vorticity from the surface of the particle. For accelerated particles the drag force changes with time and depends upon all previous accelerations. The equation of motion of a particle takes the form of an integro-differential equation, which has been solved numerically in the case of deceleration to rest from uniform motion with no impressed body forces. In any experiments designed according to the principles of dynamical similarity, the ratios of viscosities and densities of the medium and the particle must be maintained constant in the scale transformations involved. (Sci. A. 14-59-6411).

866. Peebles, F. N.

THE MOTION OF GAS BUBBLES IN THE HRE REACTOR CORE, ORNL-1171 (Jan. 18, 1952), 46 p.

A theoretical study of the motion of gas bubbles in a rotating liquid is presented to make comparison with experimental data from an investigation concerning their removal (ORNL-630). The literature on the motion of gas bubbles in liquids is reviewed and a summary of extensive experimental studies at the University of Tennessee on this topic is presented. These results are presented in the form of quantitative expressions for the drag coefficients of gas bubbles in terms of the bubble size and physical properties of the system. An expression for the radial velocity of a gas bubble in a rotating liquid based on principles of mechanics is presented. This expression includes the effects of liquid velocity, drag coefficient of the gas bubble and the physical properties of the system. Computations of the maximum gas bubble residence time for the HRE mock-up studies were made based on this relation. The results of these computations are presented and are found to agree favorably with experimental data described in ORNL-630. A method for computing the steady-state gas hold-up in the HRE reactor core under power-producing conditions is presented. The results of computations based on this method are presented. It is concluded that the relations and methods presented are general in scope, and could be applied to any size of reactor core provided basic data on liquid-velocity distribution, gas-bubble size and physical properties are known.

867. Peebles, F. N., and Garber, H.

STUDIES ON THE MOTION OF GAS BUBBLES IN LIQUIDS, Chem. Eng. Prog., 49, 88-97 (Feb. 1953).

The motion of gas bubbles is an important factor in mass- and heat-transfer operations involving the contact of liquids and gas bubbles. The flow characteristics of single gas bubbles in liquids are described, with particular emphasis on the steady-state velocity and the drag coeff. Exptl. work consisted of detg. the steady-state velocity of air bubbles in 22 liquids. The liquids were chosen so that the effect of variation of liquid d, viscosity, and surface tension on the gas motion was evident. The effect of gas-bubble size was shown by the use of gas bubbles of 0.002-0.025 ft equiv. spherical radius. Four distinct types of bubble motion in liquids were noted, 2 corresponding to the viscous and transition regions and 2 to the turbulent region. Two types of motion within the turbulent region result from the variation of gas-bubble deformation. Quant. relations for the steady-state velocity and drag coeffs. in terms of liquid properties and gas-bubble size were developed for the 4 types of motion. In the viscous and transition regions, the Reynolds no. was found to be the important independent variable in analyzing exptl. data. For the other 2 regions where the gas-bubble deformation was significant, combinations of the Weber and Froude nos. into new dimensionless parameters were used to describe the data. The limits of each of the 4 regions of bubble behavior were also detd. as functions of the dimensionless groups cited. (CA-47-3623h)

868. Pekeris, C. L.

THE RATE OF RISE AND DIFFUSION OF AIR BUBBLES IN WATER, Office of Scientific Research and Development, No. 976, 1942, pp. 29.

A review of the results obtained by several investigators of relevant problems to the general study of the rate of rise and diffusion of air bubbles in water is presented in this article. A curve constructed using the data of previous investigators presents the rate of rise of air bubbles in water as a function of the radius of the bubble. For radii less than 0.04 cm, the bubble movement is like the movement of solid spheres. According to the author, this is due to the existence of a surface viscosity.

The rate of solution of bubbles depends upon whether they are stationary or moving. In the case of stationary bubbles, the experiments of Mache show that for large bubbles the rate of decrease of the square of the radius is constant, in accordance with the Mache-Epstein theory. Smaller bubbles dissolve at a less rapid rate and it is found that in this case the interpretation of Mache's data can be improved by assuming that there exists a specific resistance to diffusion at the surface of the bubble. The magnitude of this surface resistance to diffusion has been approximately determined from Mache's data, and its effect on the lifetime of stationary bubbles is shown in a figure. It is seen that the effect is considerable, amounting to a doubling of lifetime in an extensive range of bubble radii.

In the case of moving bubbles it has been found experimentally that the radius decreases uniformly with time. The available experimental evidence on the rate of decrease of the radius is collected in a table. It is seen that even minute velocities of the order of 0.01 cm per sec markedly increase the rate of diffusion. The last calculation in the study presents the theoretical maximum rate of solution which results from the existance of a surface resistance to diffusion. The data are too meager to allow a determination of a solution-time radius-curve of moving bubbles.

869. Pfriem, H.

ON THERMAL DAMPING IN SPHERICALLY SYMMETRIC VIBRATING GAS BUBBLES, Trans. from Akust. Z. 5, 202-12, DTMB-T-158 (July, 1940)

870. Plesset, M. S., et al.

ON THE DYNAMICS OF VAPOR BUBBLES IN LIQUIDS, J. Math and Phys 33, 308 (1955).

In this paper, the equations of motion for a spherical vapor bubble will be derived and applied to the cases of a bubble expanding in superheated liquid and a bubble collapsing in liquid below its boiling points. Because of the inclusion of the heat transfer effects, the equations are nonlinear, integrodifferential equations. In the case of the collapsing bubble, large temp. variations occur; therefore tabulated vapor pressure data were used, and the equations of motion were integrated numerically. Analytic solutions are obtainable for the case of the expanding bubble if the period of growth is subdivided into several regimes and the simplifications possible in each regime are utilized. The growth is considered here only during the time that the bubble is small. An asymptotic solution of the equations of motion, valid when the bubble becomes large (i.e., observable), has been presented previously, together with experimental verification.

871. Poppendiek, H. F.

BUBBLE BEHAVIOR WITHIN LIQUIDS FLOWING IN TUBES CONTAINING "U" PENDS, CF-52-3-20 (1952), 3 p.

872. Publes, F. N., and Gurber, H. J.

THE MOTION OF GAS BUBBLES IN LIQUIDS, Chem. Eng. Prog., 49, 88-97 (1953).

The motion of gas bubbles is an important factor in mass- and heat-transfer operations involving the contacting of liquids and gas bubbles. The present paper describes work on the flow characteristics of single gas bubbles in liquids with particular emphasis on the steady state velocity and the drag coefficient.

Experimental work consisted of determination of the steady state velocity of air bubbles in twenty two liquids. The choice of the liquids was such that the effect of variation in liquid density, viscosity, and surface tension on the gas motion was evident. The effect of gas-bubble size was shown by the use of gas bubbles of 0.002 to 0.025 ft equivalent spherical radius.

873. Rattray, M., Jr.

PERTURBATION EFFECTS IN BUBBLE DYNAMICS (1951). Thesis, Calif. Inst. Tech.

874. Robinson, J. V.

THE RISE OF AIR BUBBLES IN LUBRICATING OILS, J. Phys. and Colloid Chem. 51, 431-7 (1947).

In order to expose the mechanism by which additives in a lubricating oil stabilize the emulsified air entrained by the oil of a high-speed gear pump, R. carried out expts. on the rise of air bubbles (up to 2 mm in diam.). The bubbles in oil without additives followed Stokes' law, the rate being proportional to the square of the apparent diam. and inversely proportional to the viscosity of the oil. In oils contg. additives the rate was slower and decreased as the length of path traversed by the bubbles increased. A method was derived for computing the thickness of the liquid shell which would have to move with the bubbles to account for the abnormally slow velocity. The max. thickness of this shell as calcd. from the observed velocities was equal to the bubble radius. (CA-41-3947i)

875. Scorer, R. S., et al.

BUBBLE THEORY OF PENETRATIVE CONVECTION, Quart. J. Roy. Meteorol. Soc. 79, 94-103, January; 288-92, April (1953).

The process of convection is described in terms of a unit or proton of convection-the bubble. A rising bubble of warm air sheds its outer skin steadily into a disturbed wake until it becomes exhausted completely or spreads out at a stable layer. The wake is a region where the ascent of further bubbles is favoured. The wakes of small bubbles close to the ground are aggregated into larger bubbles, which are more dilute, up to a level where they begin to penetrate hitherto undisturbed air, and then they waste away as they ascend further. The air above a bubble is lifted (and cooled) as the bubble approaches and then drains down the outside, the air close to the bubble being mixed into the wake. The wake of a clear bubble is buoyant but that of a cloudy bubble may sink if it is sufficiently chilled by dilution with surrounding clear air. The drag on a bubble is estimated from observations on rising cumulus towers, and a linear relation between buoyancy and limiting velocity is proposed. From this the horizontal velocity of the bubble relative to the surrounding air is deduced to be about the same as the vertical velocity when it ascends through strong shear. A bubble is a compact stable configuration for a rising element. Near the ground the heat is transported by small bubbles, which are less efficient, and therefore require a greater lapse rate, than the larger ones which can operate higher up. The process of aggregation is again renewed within large clouds so that the bubbles found at the top may be more dilute than if they had ascended directly from the base. Clouds growing in a shearing current will grow into the shear. Malkus comments critically and the authors reply. (Sci. A. 57-6171)

876. Siemes, W.

GAS BUBBLES IN LIQUIDS. II: THE RISE OF BUBBLES IN LIQUIDS, Chem. Ing. Tech. 26, 614-30 (1954).

Formation of bubbles on circular nozzles, directed upward; bubble frequencies determined stroboscopically and by electric resistance of liquid above nozzle opening; how to obtain uniform ascent of bubbles. Nov: Ascent of bubbles; model experiments with variable gas distribution and rate of flow; relative gas content of bubble column, average duration of bubbles in liquid and conditions of flow.

For Part I see Siemes, W., Chem. Ing. Tech., 26, 479-96 (1954).

877. Smirnov, N. I. and Poliata, S. E.

AIR BUBBLE DISCHARGE INTO A LIQUID MEDIUM, Zhurnal Prikladnoi Khimii, 22, 1208-10 (1949) (In Russian).

878. Sterman, L. S.

THE GENERALIZATION OF EXPERIMENTAL DATA CONCERNING THE BUBBLING OF VAPOR THROUGH LIQUID, Zhurnal Tekhnicheskoi Fiziki 26, 1519-1524 (1956). English translation in: Soviet Physics - Technical Physics 1, 1479 - 1485 (1956).

879. Strasberg, M.

THE PULSATION FREQUENCY OF NONSPHERICAL GAS BUBBLES IN LIQUIDS, J. Acoust. Soc. Amer. 25, 536-7 (1953).

The effect of non-spherical shape on the pulsation frequency of a gas bubble in a liquid is calculated. The frequency is expressed in terms of a stiffness constant independent of shape and an inertial constant mathematically equivalent to the reciprocal of the electrostatic capacitance of a conductor having the same shape as the bubble. The calculation is carried out for an oblate spheroid, and the variation of the pulsation frequency with shape is shown to be small. The effects of a rigid wall and of a free surface on the the pulsation frequency are also calculated by the same method. (Sci. A. 56-5325)

880. Strasberg, M.

DAMPING OF PULSATING AIR BUBBLES IN WATER, Acustica 4, 450 (1954).

Remarks on a paper on this subject by Exner and Hampe [Abstr. 2173 (1954)]. These authors refer to anomalous bubbles in which (1) the measured resonant frequency does not agree with the calculated value, (2) the damping at the measured resonant frequency is abnormally low, and (3) the measured resonant frequency may suddenly change. It is now suggested that this anomalous behavior may be due to surface oscillations of the bubble. It is shown that such surface oscillations may be of the same order of frequency or may even exceed the volume-pulsation frequency. (Sci. A. 58-141)

881. Stuke, B.

THE BEHAVIOR OF THE SURFACE OF GAS BUBBLES MOVING IN LIQUIDS, Naturwissenschaften 39, 325-6 (1952).

The rate of rise of oxygen bubbles in pure water conforms with Stokes' law at bubble diameters <0.1 mm, rises to a max. at 1.7 mm dia., and then decreases to a finite limit with further increase in dia. The presence of a trace of surface-active material causes a spectacular decrease in the rate of rise: at a concentration of 4.5×10^{-4} g mol/l caproic acid the max. in the rate-diameter curve is no longer observed. The phenomenon is explained in terms of the energy needed to produce a continual rearrangement in the interfacial layer as the bubble rises, if the bubble is big enough for the viscous forces called into play to disrupt an initial surface rigidity. Spiral motion of the bubble can occur when there is internal circulation. (Sci. A. 55-7992)

882. Tadaki, Teiriki, and Maeda, Shiro

SHAPE AND VELOCITY OF SINGLE AIR BUBBLES RISING IN VARIOUS LIQUIDS, 1961, Kagaku Kogaku, 25, 254-64 (1961).

The shape and velocity of bubbles rising in various liquids were measured on stroboscopic photographs. The liquids used were alcs., toluene, EtOAc, $PhNO_2$, aq. soln. of NaCl, glycerol, AcOH, and EtOH. Up to Reynolds' no. of $2/M^{0.23}$, the bubble was almost spherical and traveled in a rectilinear path, where M is a dimensionless parameter defined as $g\mu^4/\rho\sigma^3$, where g = acceleration of gravity, μ = liquid viscosity, ρ = liquid d, and σ = surface tension. In the range of $2<ReM^{0.23}<16.5$, the bubble was ellipsoidal and, as the bubble size increased, the shape became flatter. In the range of $ReM^{0.23}>16.5$ the bubble was of mushroom shape. These changes in shape are handled in terms of d/a and $ReM^{0.23}$, where d = equiv. spherical diam., a = major axis of bubble, and Re = Reynolds' no.

883. Taylor, G. I.

THE VERTICAL MOTION OF A SPHERICAL BUBBLE AND THE PRESSURE SURROUNDING IT, DTMB-510 (August 1943), 33 p.

The upward motion of the spherical hollow which is formed in water by an explosion is discussed on the assumption that the spherical form is preserved. During the expanding stage the buoyancy of the hollow gives a large amount of vertical momentum to the surrounding water. During the contracting stage this momentum is concentrated around a rapidly diminishing volume. An intense concentration of vertical momentum is thus produced in the neighborhood of the vertical line through the charge. The pressure at points above the charge and near this line rises to considerable values owing to two causes: when the hollow is near its greatest contraction at the end of its first oscillation its center is nearer to points vertically above the seat of the explosion than it was at the time of the explosion, but farther from points on the level of the explosion; and, the pressure due to the combination of vertical motion and expansion on the second expansion is in certain circumstances large. For comparison with observation, the maximum displacements to be expected in a rectangular plate 6 feet by 4 feet by 0.173 inch attacked by 4.65 pounds of TNT placed 14 feet below the plate and 14 feet away horizontally, are calculated. They are found to be 4.3 inches and 1.5 inch respectively. The observed displacements were 4.35 inches and 1.15 inch.

884. Tuson, K. R.

SINGLE EXPOSURE PHOTOGRAPHY OF A HIGH SPEED EVENT, Brit. J. Appl. Phys. 6, 99 (March 1955).

A method is described whereby conventional stroboflash and photoflash equipment can be used to provide a series of photographs of a recurrent event which cannot be mechanically linked to trigger the flash. Photoelectric triggering capable of accurate visual control and adjustment is therefore provided and the method has been satisfactorily applied to a study of the formation and behaviour of bubbles rising from a submerged orifice. (Sci. A. 58-4277)

885. Uno, S., and Kuiter, R. C.

EFFECT OF WALL PROXIMITY ON THE RATE OF RISE OF SINGLE AIR BUBBLES IN A QUIESCENT LIQUID, AIChE, Journal 2, 420-6 (1956).

The terminal velocity of air bubbles rising through distd. water, 61% glycerol, diethylene glycol, and a soln. of a surface-active agent was measured in vertical cylindrical tubes of 2.09, 3.64, 4.91, 6.90, 9.50, and 15.25 cm. av. internal diam. An equation was developed to express a velocity-correction factor in terms of the ratio of bubble diam. to tube diam. and an empirical const. The const. was a function of tube diam. and of the surface tension of the liquid. It seemed to be independent of liquid viscosity.

886. Verschoor, H.

SOME ASPECTS OF THE MOTION OF A SWARM OF GAS BUBBLES RISING THROUGH A VERTICAL LIQUID COLUMN, Trans. Inst. Chem. Engrs. (London), (Advanced Copy), 42-6 (February 14, 1950).

The gas content of this gas-liquid system increases to a min. and then gradually increases again. On increasing the overall gas rate 3 regions can be distinguished: at first, the gas content rises at more or less const. bubble velocity; seconds, the bubble velocity increases at more or less const. gas content; and third, the gas content and bubble velocity increase simultaneously. Pure liquids, water as well as org. liquids, all show coalescence of the small bubbles emerging from a porous plate. The presence of some solute in the liquid may under special circumstances prevent coalescence. (CA-44-4729f)

887. Vitkina, M. A.

MOTION OF GAS BUBBLES IN THE BUBBLING PROCESS, Zhur. Priklad., Khim, 24, 1041-4 (1951).

Expts. in a vertical tube 1.2 m long, 0.05 m in diam., gave for gas bubbles entering the bottom of the liquid column through openings 3, 5, and 8 mm in diam., upward velocities v of 0.245, 0.243, 0.239 m/sec, resp., independently of the height of the liquid column,

and diminishing somewhat with increasing size of the bubble. Soln. of the differential equation for the upward motion of a bubble in a viscous liquid under the action of a dynamic pressure, conferring to the bubble an initial velocity v_i, shows that the final const. velocity v_f, established very soon after a short initial deceleration, is independent of v_i and is detd. only by the diam. of the bubble D; with D = 0.001 m, and v_i = 10 m/sec, the final v_f = 0.243 is established at a height of 0.001 m. Some dependence of v_f on v_i could, at most, be expected with very high v_i; it did not occur in practice. For v_i within the limits of 10-30 m/sec, the "crit." height at which v becomes const. is of the order of a fraction of a mm. (CA-47-5212e)

888. Wigner, E. P.

THE RATE OF RISE OF BUBBLES, AECD-1983 (April 7, 1944), 3 p.

It has been observed that the bubbles rising in boiling water acquire, in the course of their rise, a definite size and velocity. Smaller bubbles tend to grow, larger bubbles to split up until an equilibrium condition is reached. On the basis of dimensional considerations, formulas are proposed for these quantities.

889. Young, N. O., et al.

MOTION OF BUBBLES IN VERTICAL TEMPERATURE GRADIENT, J. Fluid Mechanics 6, 350-6 (October 1959).

It has been observed experimentally that small bubbles in pure liquids can be held stationary or driven downwards by means of sufficiently strong negative temperature gradient in vertical direction; effect demonstrated to be due to stresses resulting from thermal variation of surface tension at bubble surface; flow field within and around bubble is derived, and expression for magnitude of temperature gradient required to hold bubble stationary is obtained.

890. Zwick, S. A., and Plesset, M. S.

NOTE ON THE DYNAMICS OF SMALL VAPOR BUBBLES IN LIQUIDS, AD-40932 (Feb. 1954), 37 p.

The equations of motion for a spherical vapor bubble in a liquid are obtained and applied to the cases of a bubble growing in superheated liquid and a bubble collapsing in a liquid below the boiling point, under the assumption that heat transfer effects accompanying the bubble growth of collapse are dynamically important. The liquid is taken to be incompressible and nonviscous; the vapor is assumed to be in thermal and dynamic equilibrium with the liquid.

891. Zwick, S. A., and Plesset, M. S.

ON THE DYNAMICS OF SMALL VAPOR BUBBLES IN LIQUIDS, J. Math. Phys. 33, 308 (1955).

The equations of motion for a small (not observable) spherical vapour bubble, are derived and applied to cases of a bubble expanding in a superheated liquid and a bubble collapsing in a liquid below its boiling point. The heat transfer across the bubble boundary is considered. An asymptotic solution of the equation of motion, valid when the bubble becomes large (observable) has been presented previously together with experimental verification. (Sci. A. 58-5913)

NUCLEATION

892. Bakal, R., and James, D. L.

THE DESIGN, CONSTRUCTION, AND TESTING OF A SYSTEM FOR THE STUDY OF BUBBLE FORMATION AT HIGH POWER DENSITIES, MIT, Oak Ridge, Tenn. Engineering Practice School, KT-97 (1950), 19 p.

893. Bankoff, S. G.

EBULLITION FROM SOLID SURFACES IN THE ABSENCE OF A PRE-EXISTING GASEOUS PHASE, Trans. ASME 79, 735 (1957).

The Nucleation theory of Volmer (C.A. 24, 5208; 33, 5276[6]) and Fisher (J. Applied Physics 19, 1062-7 (1948)) is extended to the superheating of liquids in contact with various solid boundaries. Nucleation in bulk phase, at flat surfaces, at sharp projections, or in wetted cavities can be dismissed from consideration as possible explanations for experimentally observed superheats. Unwetted cavities are preferred nucleation points, but the difficulty of filling these completely with liquid are so great that it is probable that nucleation almost always occurs at a preexisting gaseous phase in static stressing of the liquid. Nucleation in dynamic-stress phenomena, such as ebullition, cavitation, or effervescence, always occurs at the boundaries of gas or vapor entrapped in surface cavities.

894. Benjamin, J. E.

BUBBLE GROWTH IN NUCLEATE BOILING OF A BINARY MIXTURE, Ph.D. Thesis, U. of Ill., 84 pp. (1961).

895. Bertanza, L., and Martelli, G.

INFLUENCE OF IONS ON THE NUCLEATION PROCESS IN LIQUID, LIQUIDS UNDER POSITIVE PRESSURE IN METASTABLE THERMODYNAMICAL EQUILIBRIUM (OVERHEATED LIQUIDS), Nuovo Cimento 1, 324-36 (February 1955).

The behavior of liquids in metastable equilibrium under positive pressure has been investigated, and an expression for the total flux of critical bubbles carrying different number of ions has been found. A comparison between results and the data of some experiments shows that in some cases the contribution of the ions at the nucleation processes in overheated liquids cannot be neglected. The total flux of bubbles is larger than that obtained when the effect of the ions is neglected; therefore the waiting times are shorter and, in some cases, become zero effectively. (NSA-9-2663)

896. Clark, H. B.

NUCLEATION DURING BOILING, Ph.D. Thesis, U. of Ill., 85 pp (1957).

897. Clark, J. A.

THE THERMODYNAMICS OF BUBBLES: NP-6186 (1956), 41 p.

This paper outlines those conditions demanded by the laws of thermodynamics for equilibrium between the vapor in a bubble and the surrounding liquid and then employs these concepts with a nucleation theory in an attempt to arrive at an expression relating the nucleating superheat in a pure liquid to other fluid properties. The first part of the paper deals with the phase equilibrium across a curved interface and some of its consequences. In the second part recourse is made to the kinetic theory of "Heterophase" thermal fluctuations given by Frenkel for nucleus formation which is extended and employed to derive a relationship between a superheat at nucleation and other fluid properties.

898. Courtney, W. G.

REMARKS ON HOMOGENEOUS NUCLEATION, J. Chem. Phys. (USA), vol. 35, No. 6, 2249-50 (Dec. 1961).

Presents a correction to the classical liquid-drop theory of the kinetics of homogeneous nucleation from the vapour phase, to allow for the partial pressure of the clusters (considered to be "molecules"). It is shown that the values for equilibrium concentration of clusters and for the rate of nucleation found by Frenkel (1955) are both too high by a factor equal to the supersaturation of the monomer; the correction is insignificant in practice. (SA 62-2934)

899. Courtney, W. G.

NON-STEADY-STATE NUCLEATION, J. Chem. Phys., 36, 2009-17 (1962).

The non-steady-state nucleation of water vapor is examined by an exact mathematical approach which solves on a computer the 100 or so simultaneous differential equations which describe nucleation. This approach avoids the numerous mathematical approximations of Kantrowitz, Probstein, and Collins. The customary kinetic and thermodynamic assumptions of the classical liquid-drop theory of steady-state nucleation were used. The times for the concentration of the nucleus of liquid water to reach 95% of steady state at -10°, -40°, and -60°C are 1.4, 19, and 27 sec with supersaturations of 5, 10, and 20, respectively, and are only 10% longer than the "time lags" estimated by the approximate methods. Since the surface tensions of small clusters and the accommodations coefficients are unknown, the approximate methods, although incorrect by greater than 100%, are sufficiently accurate for most purposes. The results of Frisch are shown to be incorrect. The steady-state concentrations of water clusters are equal to their equilibrium concentrations for clusters which contain up to about 15 and 5 molecules less than the nucleus at -10° and -60°, respectively. Contrary to general opinion, the equilibrium concentrations of liquid-drop clusters do not decrease sharply in the vicinity of the nucleus.

900. Dzhanzhgava, Sh. G.

FORMATION OF STEAM BUBBLES IN HEATING SURFACES, Dokl. Akad. Nauk. SSSR., 70, 417 (March 1950).

901. Fisher, J. C.

THE FRACTURE OF LIQUIDS, J. Appl. Phy. 19, 1062-67 (1948).

A liquid subjected to negative pressure is metastable; vapor bubbles form spontaneously and grow until the pressure of the system rises to the equilibrium vapor pressure. The rate of bubble formation is calculated from the theory of nucleation, and the negative pressure p_t that gives one bubble (i.e., fracture) in t seconds is determined. p_t is very nearly independent of t, and is proportional to $\sigma^{3/2}$ where σ is the surface tension. Subcooled liquids such as glass also are metastable under negative pressure; cracks form spontaneously and grow until the pressure rises to the equilibrium vapor pressure. Nucleation theory leads to an expression for the fracture stress of glass that is proportional to $(E^2\sigma^3)^{1/4}$ where E is the elastic modulus. The transition from high temperature cavity-nucleated fracture to low temperature crack-nucleated fracture is examined.

Fracture strengths calculated from nucleation theory agree satisfactorily with the maximum experimental values, and are an order of magnitude smaller than the forces required for simultaneous separation of all atomic bonds cut by a plane surface. The frequent occurrence of premature failure is associated with the presence of pre-existing surface cracks in glass, and of positive contact-angle impurity in contact with liquids.

902. Frisch, H. L.

TIME LAG IN NUCLEATION, J. Chem. Phys., 27, 90-4 (July, 1957).

A definition for the time lag L in the Zeldovich modified Becker - Dõring theory of nucleation is introduced which is in accord with the commonly used definition of L in diffusion theory. This L can be obtained exactly without solving for the transient concentration of embryos of the new phase. L is found to be the time required to set up the steady-state distribution of embryos from a given initial distribution by means of the steady-state flux of embryos. The numerical evaluation of L from various initial distributions, for at least vapour - liquid transition, exhibits the importance of the homophase fluctuations in the initial embryo distribution in allowing us to observe the transition within the experimental observation time. The implications of this result for the general theory of phase transitions and for "memory" effects in nucleation are discussed.

903. Fritz, W.

MAXIMUM VOLUME OF VAPOUR BUBBLES, Phys. Zeits., 36, 379-384 (1935).

The tables of Bashford and Adams are applied to find the volume of a bubble of vapour formed on a flat surface. Curves between volume and diameter show

that (a) there is a maximum value after which the bubble bursts and (b) for each diameter there can be two volumes. A general dimensionless equation is obtained for the maximum volumes of gas and vapour bubbles depending upon the angle of contact.

904. Ghormley, John A.

NUCLEATION OF BUBBLES IN SUPERHEATED AQUEOUS SOLUTIONS BY FAST PARTICLES, J. Nucl. Energ., 6, 300-2 (1958).

Energy loss along the track of a fission recoil or α-particle in superheated uranyl sulphate solution or the recoil from a fast-neutron collision in superheated ether can account for evaporation of sufficient liquid to form bubble nuclei under conditions where nucleation is observed. The contribution of charge repulsion cannot be determined from experimental results.

905. Greenwood, G. W., et al.

THE ROLE OF VACANCIES AND DISLOCATIONS IN THE NUCLEATION AND GROWTH OF GAS BUBBLES IN IRRADIATED FISSILE MATERIAL, AERE R-2863 (April 1959), 49 p.

It is shown that fine-scale bubbles are to be expected in reasonably pure uranium, the bubbles nucleating either homogeneously with a spacing less than a micron or on any suitable nucleation sites that may exist on this or a finer scale. The precise value of the homogeneous nucleation spacing depends on the diffusion coefficient of the gas atoms, which is modified during irradiation by the excess concentration of vacancies produced by the fission process. The dislocation lines and nodes should provide suitable nucleation sites as they have about the right spacing and their stress fields should attract the large inert gas atoms to form Cottrell atmospheres. The bubbles when once nucleated grow by a vacancy diffusion mechanism, the vacancies being created by the fission process or possibly diffusing from the grain boundaries in very small grains. At temperatures above some value, which in certain cases may be as low as,about 300°C, the influx of vacancies is sufficient to prevent the gas pressure in a bubble from exceeding the surface energy restraining force by more than an order of magnitude, in which case dislocation mechanisms of plastic deformation should not operate. The fission process enhances the concentrations of both vacancies and interstitials in the solid with the result that bubble growth is governed by the thermal equilibrium of vacancies, but an enhanced growth will occur at the lower temperatures if the sinks for point defects accept interstitials more readily than they do vacancies.

906. Hickman, B. S.

NUCLEATION AND GROWTH OF GAS BUBBLES IN IRRADIATED METALS, J. Australian Inst. Metals, 5, 173-81 (August 1960).

Several metals undergo nuclear reactions when subjected to neutron irradiation which result in the formation of gases in the metal. At elevated temperatures these gases tend to nucleate and form gas bubbles which result in over-all increases in volume in the material, and which can have important technological implications. The available experimental data on this phenomenon are summarized, attention being concentrated on the cases of krypton and xenon in uranium and helium in beryllium. Current theories of nucleation and growth, developed for the case of the rare gases in uranium, are reviewed. Some comments are made on the application of these theories to beryllium.

907. Jacoby, A. L., and Bischmann, L. C.

STEAM BUBBLE FORMATION, Effects of Heating Surface and Use of Antifoams, Ind. Eng. Chem. 40, 1360, 1948.

The authors present a photographic study of the formation of steam bubbles at atmospheric pressure from smooth heated surfaces and surfaces coated with a calcium carbonate scale. Film boiling from a nonwettable surface is also shown. In studying the effect of a polyamide antifoam was shown to begin at the heating surface, causing not only collapse of the foam but also coalescence of the otherwise small bubbles before their detachment from the heating surface. Similar experiments at pressures of 70 and 250 pounds per square inch are also reported.

908. Katz, D. L.

NUCLEATION AND RATE OF BUBBLE GROWTH IN HOMOGENEOUS REACTOR EXPERIMENT, CF-51-8-266 (1951), 35 p.

A series of experiments for determining the rate of bubble growth in HRE solutions is described. General considerations of bubble growth, nucleation, gas solubility, and bubble behavior in the reactor core are discussed. A lab method for measurement of bubble growth is given. (NSA-10-10927)

909. LaMer, V. K.

NUCLEATIONS IN PHASE TRANSITIONS, Ind. Eng. Chem. 44, 1270-1277 (1952).

A detailed review of conceptual and phenomenological aspects of nucleation processes including the historical development, Ostwald's clarifying views, the Volmer extension of Gibbs' fundamental equations for the work involved in forming a new phase, the statistical approach to the characterization and work of formation of embryos and nuclei, the rate of nucleus formation, heterogeneous nucleation and the application to the stability of polydisperse colloidal dispersions, the prepn. of monodisperse aerosols and hydrosols, and the time lag in the supersaturation of $BaSO_4$.

910. Lothe, J., and Pound, G. M.

RECONSIDERATIONS OF NUCLEATION THEORY, J. Chem. Phys. 36, 2080-85 (1962).

There are quantum statistical contributions to the free energy of formation of embryos and critical nuclei in transformations to condensed phases. They

arise from consideration of the absolute entropy of the embryos or nuclei. In the case of homogeneous nucleation of water droplets from vapour the factor of increase in equilibrium concentration of critical nuclei is about 10^{17}, resulting in a discrepancy of corresponding magnitude between the Becker-Döering equation (1935) and the critical supersaturation measurements of Wilson and Powell. It is suggested that some of this disagreement may be removed by treating the problem as a transient rather than a steady-state situation and considering non-accommodation in the smaller size classes. Also there is an appreciable quantum statistical effect in homogeneous nucleation of crystals from the supercooled liquid and a related effect in nucleation from the vapour of crystals on substrates.

911. Martelli, G.

INFLUENCE OF IONS ON THE NUCLEATION PROCESSES IN LIQUIDS, I. LIQUIDS IN STABLE THERMODYNAMICAL EQUILIBRIUM, Nuovo Cimento 12, 250-9 (August 1954).

An attempt is made to study the nucleation of vapour bubbles in liquids, when the contribution of the ions is also taken into account. Some results show substantial differences from those obtained on the basis of the usual theories. The particular case of liquids in stable equilibrium is discussed in some detail. (Sci. A. 57-10132)

912. Michels, H. H.

THE MECHANISM OF MASS TRANSFER DURING BUBBLE FORMATION, Ph.D. Thesis, Univ. Dela., 141 pp. (1961).

913. Monod, Philippe.

ETUDES FAITES SUR LES BULLES, (BUBBLE STUDIES), (CEA-BIB-26)(1962), 67 p.

The literature surveyed deals mainly with studies of the factors of nucleation and the laws of growth of bubbles in a homogeneous, superheated liquid. With this in sight some more general attempts are reported dealing especially with surface tension and drops. The main results are given as figures and formulas. This survey was carried out principally to indicate methods of bubble chamber operation. A subject and author index is provided for the 86 annotated references.

914. Moore, G. R.

VAPORIZATION OF SUPERHEATED DROPS IN LIQUIDS, A.I.Ch.E. Journal 5, 458-66 (1959).

Drops suspended in a hot liquid had to be superheated to a very extreme degree in order to initiate vaporization. The results are closely related to problems of bubble formation in boiling, cavitation, and in the evolution of gases from supersatd. solns. The exptl. technique developed in this study is believed to be unique and capable of giving quite accurate data on homogeneous nucleation in superheated drops. The theory of homogeneous nucleation in pure liquids is extended to the formation of bubbles in superheated drops. The theoretical predictions are in close agreement with the exptl. results. 18 references.

915.

Novak, P. E.

DEVELOPMENT OF AN EXPERIMENTAL TECHNIQUE TO DISTINGUISH BLANKETING EFFECTS OF BUBBLES GENERATED ON A SMALL SURFACE, Master's thesis North Carolina State College, Raleigh, 1959.

916. Reed, J. C.

MASS TRANSFER FROM SINGLE BUBBLES DURING THE FORMATION PERIOD, Ph.D. Thesis, U. of Wisc., 267 pp. (1961).

917. Reiss, H.

THEORY OF THE LIQUID DROP MODEL, Industrial & Engineering Chemistry 44, 1284-88 (1952).

In this paper, a brief review of the classical theory of gas phase nucleation in its most modern form is presented and criticized. Subsequently, a brief resume of a recent, more logical theory based on statistical mechanics is given.

918. Rodebush, W. H.

SPONTANEOUS NUCLEATION OF SUPERSATURATED WATER VAPOR, Ind. Eng. Chem., 44, Pt. 1, 1289-1291 (1952).

Gibbs showed that no stable equilibrium, such as has been assumed in the derivation of the Thomson equation, can exist between the liquid drop and the vapor phase. When the drop becomes small enough, it behaves as a large molecule and below a certain critical size the translational and rotational entropies contribute a stabilizing factor which made equilibrium possible. It is assumed that the equilibrium concentrations of these aggregates or clusters are present at all times. The equilibrium concentration decreases with increasing cluster size. When the supersaturation is increased to a point where a considerable concentration of the critical size is present, condensation occurs immediately. The theory appears to agree with the reported facts for water vapor, but more reliable data are needed.

919. Semeria, R. L.

AN EXPERIMENTAL STUDY OF THE CHARACTERISTICS OF VAPOUR BUBBLES, Paper No. 7, Symposium on Two-Phase Fluid Flow, Inst. Mech. Engrs., London, England, February 7, 1962.

The present study concerns the main characteristics of bubbles generated on heating elements which are devised to make easier observations at high heat flux and under pressure. The following results were obtained: by a method using a thin wire, populations of over 10 sites per mm^2 could be counted; the departure diameter of the boiling bubbles decreases with the pressure according to the empirical formula $D_m = 1.6p^{-0.5}$ where p is in atm abs $2 < p < 20$ atm abs, and D_m is in millimeters, contrary to a formula proposed by Fritz; the time of contact of the liquid upon the site decreases with the heat flux as $\phi^{-2.5}$

At atmospheric pressure, the transition from the zone of independent bubbles to that of coalescences on the wall, according to the heat flux is studied. In saturated pool boiling, coalescences limit the birth frequency of bubbles at 100 bubbles per sec per mm^2

920. Sette, D., and Warderlingh, F.

NUCLEATION BY COSMIC RAYS IN ULTRASONIC CAVITATION, Phys, Rev., 125, 409-17 (1962).

Nucleation in ultrasonic cavitation, is due to cosmic rays. The neutron component seems sufficient to explain the experiment in water, through the creation of oxygen recoil nuclei which would act as nucleating agents; energy deposit and radiolytic effects produce small overheated and oversaturated regions in which cavities of radius larger than the critical one may originate. The microcavities would be created in the absence of a sound field and grow to visible size when an adequate sound field is applied. Enclosing the tank in which the liquid is contained with lead or paraffin screens results in threshold variations due to absorption and slowing down of primary neutrons and, probably, to nuclear reactions induced by the gamma and meson components of cosmic radiation in the screen material through the production of secondary neutrons.

921. Staniszewski, B. E.

NUCLEATE BOILING BUBBLE GROWTH AND DEPARTURE, NP 7984 (August 1959), 31 p.

The vapor bubble formation on the heating surface during pool boiling has been studied experimentally. Experiments were made at the atmospheric pressure 28 psi and 40 psi, using degassed distilled water and ethanol. The heat fluxes and heating surface temperatures have been measured simultaneously by taking high speed motion pictures of growing bubbles. The diameter time curves of the bubbles and their diameter at the departure moment were obtained in these investigations. Bubble growth rates and bubble departure sizes have been compared to existing theories. It has been found that existing growth theories do not agree very well and that the departure size of the bubble is a function of the growth velocity.

922. Sundquist, B. E., and Oriani, R. A.

HOMOGENEOUS NUCLEATION IN A MISCIBILITY GAP SYSTEM. A CRITICAL TEST OF NUCLEATION THEORY, J. Chem. Phys., (USA), vol. 36, No. 10, 2604-15 (May 1962).

A critical test of the classical nucleation theory applied to condensed phases was carried out for the liquid miscibility gap system, methylcyclohexane - perfluoromethylcyclohexane (C_7H_{14}-C_7F_{14}). The densities of, and the interfacial free energies between the co-existing liquid phases were measured as a function of temperature. The interfacial free energy was found to vary as the $\frac{3}{2}$ power of the critical temperature T_c, less the experimental temperature, and these data are used to calculate the gradient energy parameter κ in the Cahn-Hilliard theory of nucleation. The magnitudes of the relevant parameters are such that the Cahn-Hilliard theory reduces to the classical theory for the present system. These data, together with literature data on the thermodynamic properties of the bulk solutions, enable the degree of undercooling for a sensible nucleation rate to be calculated from classical theory. The experimentally determined undercoolings necessary to nucleate the C_7H_{14}-rich phase from the solution are found to be much greater than those predicted by the classical theory by factors ranging from 8.5 at 10 deg below T_c to 340 at 0.3 deg below T_c. These very large discrepancies are attributable to the breakdown of the traditional approximation in the classical nucleation theory that the number of molecules involved in the embryo population is a negligible fraction of the number of molecules in the system. When this approximation is avoided, the very complicated expression that results can be evaluated for the present case, leading to reasonable agreement between the predicted and the observed undercoolings. This is believed to constitute a satisfactory verification of the "corrected" classical theory of nucleation for condensed systems. The "embryo population" factor can be neglected in homogeneous nucleation in solidification and condensation (except near the critical temperature) and in most of the corresponding cases of heterogeneous nucleation. However, it is extremely important for nucleation in miscibility gap systems, or in any system in which the properties of the parent and daughter phases become identical at a critical temperature. (SA 62)

923. Takagi, S.

THEORY OF THE FORMATION OF BUBBLES, J. Appl. Phy. 24, 1453-62 (1953).

The perfect theory of the formation of bubbles in the case where the bubbles of vapour are nucleated spontaneously in pure liquid is presented. This is done by the systematization of the classical theory of M. Volmer (Kinetik der Phasenbildung, 1939) and the theory of D. Turnbull and J. C. Fisher [J. chem. Phys., 17, 71 (1949)] and it coincides satisfactorily with the experiment of K. L. Wismer [J. phys. Chem. 26, 301 (1922)]. Theory must be advanced further so as to afford a perfect explanation of the processes of boiling, cavitation and the critical phenomena of the movement of soil moisture. To effect this object, the author has calculated the rate of formation of bubbles at a surface. The theoretical value, however, of the negative pressure at which the liquid fractures does not coincide by any means with the atmospheric pressure in the process of boiling. This is true also in the process of cavitation and in the process of critical phenomena of the movement of soil moisture. Some other factors must be introduced in order to bring the theory to a state of practical value. (Sci. A. 57-2364)

924. Turnbull, D., and Fisher, J. C.

RATE OF NUCLEATION IN CONDENSED SYSTEMS, J. Chem. Phys. 17, 71-3 (1949).

On the basis of the nucleation theory developed by Volmer, Becker, and coworkers, and the theory of absolute reaction rates, an expression is derived for the absolute rate of nucleation in condensed systems.

925. Turnbull, D., Vonnegut, B.

NUCLEATION CATALYSIS, Ind. Eng. Chem., 44, 1292-8 (1952).

A review of the kinetics of the transformation of supersatd. vapor to liquid for which the nucleation rate is represented as a function of the supersatn. ratio, and of supercooled liquid to crystals with a detailed account of the results obtained by LaMer and P. on Sn and of Turnbull on Hg.

926. Twomey, S.

EXPERIMENTAL TEST OF THE VOLMER THEORY OF HETEROGENEOUS NUCLEATION, J. Chem. Phys., 30, 941-3 (April, 1959).

The prediction of the Volmer theory that the critical supersaturation for nucleation from the vapour phase on a flat surface depends upon $(1 - \cos\phi^2)(2 + \cos\phi)$, where ϕ is the contact angle of the condensate on the surface, has been tested experimentally. Critical supersaturations for visible fogging on test surfaces coated with various transparent plastics were found to agree within observational error with the theoretical values computed for the observed contact angles.

SIZE DISTRIBUTION

927. Bogdanov, O. S.

DETERMINATION OF THE SIZE OF AIR BUBBLES IN A FLOTATION PULP, Tsvetnye Met., 20, 23-5 (1947).

A flat glass vessel of rectangular cross section filled with a soln. of $C_{16}H_{33}(CH_3)_3NI$, acting as stabilizer for air bubbles, is lowered into a flotation cell to such a depth that the bottom of the vessel is at the level where the detn. is desired, and the vessel is fastened in a holder. A light source is turned on, and the bottom of the vessel is opened by means of a lever. The bubbles enter the vessel, and as they ascend past the light they are reflected in a mirror which transmits the reflection through a lens into a photographic camera attached to the wall of the flotation cell. The size of bubbles is then measured on the photographic film with a microscope.

928. Bohrisch, P.

ESTIMATION OF BUBBLE SIZE IN OXYGEN BATHS CONTAINING SODIUM PERBORATE (MENZEL'S METHOD), Berlin u. Munch. tierarztl. Wochschr., 12, 179-80 (1942).

A com. prepn. contg. 202.3 g $NaBO_3$ (active O 10.56%) and an unnamed catalyst of 47.4 g served as a standard in a model test bath measuring vol. production, dosage and character of O. A method previously described was used. (CA-37-4531-4)

929. Datta, R. L., and Kumar, S. R.

GAS BUBBLES IN LIQUIDS. II. FACTORS INFLUENCING BUBBLE VOLUME, Indian Chem. Engr. 3, 189-92 (1961).

A review covering orientation, geometry, submergence of orifice, chamber vol., and coalescence of bubbles. (CA-44-4290i)

930. Guyer, A., and Peterhaus, E.

THE SIZE OF GAS BUBBLES I. FORMATION BY SINGLE CAPILLARIES. II. FORMATION BY FILTER PLATES, Helv. Chim. Acta 26, 1099-1107 (1943).

The effects of capillary diam. and surface tension of the liquid on the size of bubbles formed in Et_2O, hexane, AcOH, CCl_4, C_6H_6, Ac_2O, PhCl, HCOOH, BzH, $PhNO_2$, $ClCH_2CH_2OH$, EtOH, H_2O, and a 1:9 EtOH-H_2O mixt. were detd. The diams. of the glass capillaries ranged from 0.04 to 2.6 mm. The effect of viscosity was studied on bubbles formed in PhCl, m-cresol, CS_2 acetoacetic ester, olive oil and castor oil. The results were expressed by $D = [K_1\sigma + K_2 \log \eta + A] \sqrt[3]{d}$ in which D was the diam. of the bubble, σ the surface tension in dynes/cm, η the viscosity in 10^{-3} g/cm-sec, d the diam. of the capillary in mm., and K_1, K_2 and A were empirical consts. having values of 0.012, 0.07 and 1.90, resp. For bubbles formed in CS_2 and acetoacetic ester D was almost independent of rate of formation in the range 0.2 to 10 bubbles per sec. The size of bubbles formed in castor oil increased very rapidly with increasing rate. II. Formation by filter plates. Ibid. 1107-13. Bubble sizes were detd. by a photographic method. Schott glass filter plates nos. 00, 1, 2, 3 and 4 were used. Measurements were made of bubbles formed in H_2O at rates of flow of gas between 1 and 3000 cc/min, in a 1:9 EtOH-H_2O mixt. at rates between 2 and 3000 cc/min, and in CCl_4, m-cresol, Et_2O, AcOH, C_6H_6, PhCl, BzH, $PhNO_2$, $ClCH_2CH_2OH$, CS_2 acetoacetic ester and olive oil at a rate of 250 cc/min. No satisfactory math. relation between pore size and bubble size was found. In general the bubbles from the coarser disks approached in behavior those from single capillaries. For the finer plates D passed through a min. with increasing η, increased with increasing rate of flow of gas, but was directly proportional to σ as before. (CA-38-2253-7)

931. Halberstadt, S., and Prausnitz, P. H.

ON THE SIZE OF GAS BUBBLES AND DROPLETS IN LIQUIDS, DTMB-TRANS-108 (1930), 21 p.

An apparatus is described which permits the size of gas bubbles in liquids to be measured. The size of gas bubbles which emanate from diaphragms of variable pore diameter has been studied in H_2O and ether. Variation in the size of gas bubbles produced by extrusion of gas through the same filter plate of the various liquids has been determined. The effect of pressure on the size of the gas bubbles is discussed.

932. Jenckel, E., and Hammes, H.

THE SIZE OF HYDROGEN BUBBLES FROM ALUMINUM IN HYDROCHLORIC ACID, Z. anorg. allgem. Chem. 233, 415-23 (1937).

With increasing velocity of H generation from Al in HCl, the av size and diam. of the bubbles increases, the sizes become more uniform and their no. decreases. Inhibitors to retard the velocity of soln. have no effect on the bubble size. With rapid generation, the small bubbles form large ones which cling to the Al, while with slow generation, they leave the Al quickly in great no. and uniform size. Electrolytic generation produces similar phenomena:

however the av size and diam. of the bubbles are smaller for the same amt. of H generated. Changing the surface tension between the liquid and the gas does not influence the bubble size. Surface tension is decreased up to 0.5% by inhibitors and increased up to 0.5% by diln. to 1N acid. (CA-31-8334-7)

933. Kabanow, B., Frumkin, A.

MAGNITUDES OF ELECTROLYTICALLY-PRODUCED GAS BUBBLES, Zeits. F. Phys. Chem., 165, Abt. A. 6 pp. 433-452, Aug., and 166, Abt. A. 3-4, pp. 316-17, Sept. (1933).

The interpretation by Coehn and his co-workers of the changes in size of electrolytically produced gas bubbles as due to the action of electrophoretic forces is unsatisfactory for the usual conditions of electrolysis, since this effect is infinitesimal. Another explanation is now proposed according to which the size of a bubble parting from the electrode is determined by the marginal angle at the boundary electrode-solution-bubble. This explanation is in agreement with Coehn's empirically found dependence of bubble size on the composition and concentration of the solution, as also on the direction and strength of the current. Curves are drawn for bubbles at electrodes of mercury, silver and platinum for solutions of Na_2SO_4, NaOH and H_2SO_4 at concentrations of 1 to 0.001 normal. Further, bubble-size is shown to be dependent on the potential of the electrode which is affected by its polarization. The course of the parabolic curve for diameter-potential at the mercury electrode is found to run parallel with the electro-capillarity curve for mercury. A calculation is given of the forces acting upon the bubble which show that up to the moment of rupture, the equilibrium state of the bubble is completely determined by the surface forces, the hydrostatic pressure and the internal gas pressure within the bubble. The practical importance of the theory is discussed with examples from the electrolysis of zinc.

934. Koelbel, H., Burchers, E., and Langemann, H.

SIZE DISTRIBUTION OF GAS BUBBLES IN BUBBLE COLUMNS. I. EFFECT OF LIQUID VISCOSITY AND INTERNAL COLUMN PRESSURE, Chem. Ing. Tech., 33, 668-75 (1961).

The term bubble column signifies the process of gas bubbles rising in a column of liquid. Theoretical considerations and exptl. data are presented for the effects of gas flow, column diam., pore size and spacing of gas distributor, and viscosity of the liquid. The systems air-H_2O and air-sugar soln. were used.

935. Luchsinger, W.

DISPERSE GASES. III. SIZE OF BUBBLE AND TIME OF RISING, Kolloid-Z., 81, 180-2 (1937).

The variation with their size of the time taken by bubbles of air to rise in water has been determined. The curve between volume of bubble and time of rising shows a rapid decrease in the time up to 0.004 cm^3. For bubbles larger than this there is a slight increase in the time, but above a limiting size the velocity of rising is constant. (CA-32-3229-6)

936. Quigley, C. J., Johnson, A. I., and Harris, B. L.

SIZE AND MASS TRANSFER STUDIES OF GAS BUBBLES, Chem. Eng. Prog. 51, 422 (1955).

This paper describes initial investigations of the efficiency of perforated gas absorption and distillation plates.

937. Remy, H., and Seemann, W.

DEPENDENCE OF ABSORPTION OF MISTS BY LIQUIDS ON THE BUBBLE SIZE. II. Kolloid-Z, 72, 279-91 (1935).

The effect of bubble size on the absorption of H_2SO_4 mists by water in a Drechsel wash bottle was studied by changing the width of the gas inlet tube to vary the bubble size and by changing the rate of flow. There was no simple relation between bubble size and absorption when the bubble size was varied by changing the width of the inlet tubes. With a given inlet tube, absorption decreased regularly as the bubble size was increased by raising the rate of flow. At const. rates of flow, the bubble size first decreased and then increased with increasing widths of the inlet tube. The rate of rise of the gas bubbles in the liquid had no significant effect on the absorption. The relation of the rate of bubble formation to the width of the inlet tube and to the rate of gas flow was simpler than that of the bubble size to either of these factors. For a given bubble size, the rate of bubble formation was proportional to the reciprocal rate of flow. (CA-29-7742-4)

938. Remy, H., and Seemann, W.

THE EFFECT OF BUBBLE SIZE ON THE ABSORPTION OF FOGS BY LIQUIDS, Kolloid-Z. 72, 3-12 (1935).

The bubble counter used, very accurate even at high rates of flow, consisted of a microphone placed within a resonance box on which the absorption flask stood, a powerful amplifier and a sound-recording device. The sound produced by each bubble was thus amplified and recorded. Absorption of SO_3 fogs satd. with water vapor decreases nearly linearly with increasing bubble size. For most of the absorbents used, absorption decreased almost linearly with increasing rate of flow, but glycerol and 20% KOH soln. showed anomalous behavior at low rates of flow. (CA-29-7742-2)

939. Schnurmann, R.

THE SIZE OF GAS BUBBLES IN LIQUIDS, Trans. from Z. physik. Chem. 143, No. 5 and 6, 456-74, DTMB-TRANS-110 (September 1929), 19 p.

The size of gas bubbles forced through a filter into a liquid depends on the nature of the liquid and is independent of the character of the filter. The size of the bubble as a function of viscosity of the liquid is shown for dielectric fluids, acids, bases, and salt solutions. The mechanism of macroscopic bubble formation is observed and considered. In electrolytic solutions the additional factor of the electrostatic interaction of the charged gas bubbles is added

to the effect of viscosity. This interaction permits determination of the order of magnitude of the concentrations of reversal of solutions whose viscosity does not perceptibly exceed that of water. The experimental result permits interpretation of the scatterings obtained upon determination of the pore diameters of ceramic filters for various liquids by the air pressure method. Applications for gas absorption by liquids, and flotation are discussed. (NSA-10-11786)

940. Schnurmann, R.

ON THE SIZE OF GAS BUBBLES IN LIQUIDS (Trans. from Kolloid-Z. 80, 148-51, DTMB-TRANS-111 (1937), 7 p.

By taking a water-alcohol mixture as an example, it is found that the macroscopic sizes of the gas bubbles pressed through a filter are primarily a function of the viscosity of the liquid and not of its surface tension. A minimum bubble size corresponds to a maximum on the viscosity curve. A viscosity-bubble size curve is plotted for the range of viscosity from 0.008 cgs to 0.04 cgs. The curve shows that the bubble size increases inversely with the viscosity. Experiments are discussed; the part played by the mechanism of coalescence of the sub-visible gas bubbles is shown. The pore diameter of the filter does not affect the rough qualitative effect, as long as the points of origin of the sub-visible bubbles are close enough together to permit their collision.

941. Schnurmann, R.

THE SIZE OF GAS BUBBLES IN LIQUIDS AND ITS EFFECTS ON THE RATE OF SOLUTION OF METALS IN LIQUIDS WITH HYDROGEN EVOLUTION AND ON PRIMING OF BOILER FEED WATER, J. Soc. Chem. Ind. 58, No. 5, 172-8 (1939).

The size of bubbles freely suspended in a liquid is a function of viscosity of the liquid (the greater the viscosity the smaller the bubbles) and also of the magnitude of the electrostatic charge carried by the bubbles. The gas nuclei are affected by the Brownian movement. Large pieces of Na have a greater sp. rate of soln. than small pieces. Small quantities of H_2O in EtOH cause Na to dissolve more rapidly than it does in abs. EtOH. Boiler priming is excessive during periods of heavy loads. Foaming can be prevented by addn. of bubble-forming nuclei, as certain solid matter, or blowing a jet of air or passing an elec. spark above the surface of the boiling liquid. As long as adsorbed gas is evolved from solid matter priming will not occur, but after these adsorbed molecules are no longer available as nuclei the effect is no longer noticeable. Minute amts. of castor oil act as a priming depressing agent. (CA-33-6679-8)

942. Siemes, W., and Borchers, E.

GAS DISPERSION IN LIQUIDS WITH POROUS METALLIC PLATES, Chem. Ing. Tech., 28, 283-6 (1956).

Exptl. results are reported in dispersing air in water and aq. solns. with porous filter plates in 5 different degrees of fineness. Measurements on bubble-size distribution and pressure drop as functions of throughput are presented.

943. Siemes, W., and Borchers, E.

BUBBLE SIZES IN BUBBLE COLUMNS, Chem. Eng. Sci. 12, 77-87 (1960).

Bubble sizes were investigated as a function of gas flow, distributor-plate pore size, and height above distributor. The size distribution is approx. sym. and is characterized by a peak diam. and a standard deviation. The pore size has only slight influence on the bubble size. As the gas flow increases, the bubble size also increases up to a limit. Coalescence of bubbles can be largely avoided by addn. of surface-active agents.

944. Teletov, S. G.

ON MAXIMUM SIZE OF A STEAM BUBBLE, Akad. Nauk SSSR., Energeticheskii institut. Izvestiia, 11, 41-44 (1940).

945. Weills, J. T.

STEAM BUBBLE SIZE AND RATE OF RISE THROUGH WATER AT ITS NORMAL BOILING POINT, CT-910 (1943), 5 p.

Evaporation of the moderator inside a homogeneous slurry pile and condensation of the vapor in external heat exchangers has been considered for removing heat from the system. An apparatus was erected and preliminary data were collected on the bubble size and rate of rise of steam bubbles through water at its boiling point in an attempt to evaluate the effect of vapor bubbles on bulk density and on heat removal from a boiling liquid. This experimentation was cancelled since other investigations indicated that the effect of density in power piles is too critical to permit bubble formation.

946. Widtman, Julius

CONTROL OF THE SIZE AND FREQUENCY OF GAS BUBBLES, Ger. 1,024,058, February 13, 1958 (Patent).

The size and no. of bubbles obtained by passing gases into liquids are controlled by periodically varying the pressure in the nozzle. A varying pressure is superimposed on a const. one. The system is applied to washing, dissolving, or chem. processes between gases and liquids, and for producing foams. From C.Z. 1958, 12500.

SURFACE PHENOMENA

947. Alty, T.

SOME PHENOMENA OCCURRING AT THE SURFACE OF BUBBLES IN WATER, Proc. Roy. Soc. (London) 110A, 178-90 (1926).

By means of the drop-weight method, comparison is made between the values of the surface-tension of water in contact with different gases. If the rate of flow of the gas is slow enough, the weight of a bubble is independent of the nature of the gas. If it is required to examine a new water surface, the rate of flow of the gas is increased until several bubbles emerge per second. When the necessary corrections are made, it is found that the volume of the bubble depends on the character of the gas, being relatively

great for inert gases and smaller for chemically active gases.

When flowing from the same capillary, the gases form bubbles with volumes arranged in the following order of decreasing magnitude: A, N_2, O_2, O_3, H_2, NO, CO_2, the differences being related to the adsorbabilities of the different gases. (CA-2605-5)

948. Evans, L. F.

INTERACTION BETWEEN SURFACES IN CLOSE PROXIMITY, Nature 172, 776-7 (Oct 1953).

When an air bubble is pressed against a plane glass surface under water, the disjoining water film may reach equilibrium thickness at which double layer repulsion is balanced by excess pressure of the bubble. The thickness is sensitive to the presence of surface-active impurities: for pure water and silica or glass surfaces the thickness is about 200 Å. Higher reported figures are almost certainly due to accidental contamination. (Sci. A-57-1099)

949. Hill, T. L.

CONCERNING THE DEPENDENCE OF THE SURFACE ENERGY AND SURFACE TENSION OF SPHERICAL DROPS AND BUBBLES ON RADIUS, J. Am. Chem. Soc. 72, 3923 (1950).

The approx. model used by Fowler to investigate theoretically the surface tension and energy of a plane liquid surface was extended to spherical drops and bubbles, with the additional assumption of liquid incompressibility. It was possible to derive a simple expression for the correction (to the plane surface tension) owing to curvature, which predicts that the surface tension degrees with radius. However, the magnitude of the effect is in large in this zero order approximation.

950. Jarner, F. H., and Sawyer, P. E.

SURFACE-ACTIVE EFFECTS WITHIN BUBBLES, Chemistry and Industry, 74, 192-3, (Feb. 19, 1955).

951. Komagata, S., Niskiawa, M., and Etizenya, S.

THE BOUNDARY - SURFACE POTENTIAL OF GAS BUBBLES, J. Electrochem. Assoc. Japan 7, 298-9 (1939).

The migration potential was measured on air bubbles of a few mm diam. forced through a porous glass plate. The results obtained differed from the values usually given. This is attributed to the fact that in this case the dominant factors are contact potentials. This explanation was supported by a consideration of the sign and magnitude of the potential of the reference electrode in water and in aq. solns. of KCl, soap and K xanthate. (CA-36-3083-7)

952. Morris, T. M.

MEASUREMENT OF EQUILIBRIUM FORCES BETWEEN AN AIR BUBBLE AND AN ATTACHED SOLID IN WATER, Mining Eng., Trans, 187, 91-5, 1154-5 (1950).

Forces acting between small rod, one end of which was made water repellent, adhering to much larger air bubble in water, were measured; equation is deduced which correlates these forces and influence of each force is discussed; importance of size of bubbles in flotation cell is emphasized.

UNDERWATER EXPLOSION

953. Arons, A. B., and Yennie, D. R.

ENERGY PARTITION IN UNDERWATER EXPLOSION PHENOMENA, Rev. Modern Phys., 20, 519-36 (1948).

Pressure-time curves, continuous from initial shock-wave incidence through the second bubble pulse, are examd. in the light of acoustic theory. Calcns. of impulse and reversible and irreversible energy flux are made for the various phases of the phenomenon. The energy dissipation assocd. with the propagation of the shock front has been obtained from exptl. data, and calcd. from theory, and agreement established. Impulse and energy flux assocd. with the shock wave and the bubble pulses are discussed. A tabulation of the energy partitions for the various phases of the phenomenon is made, and it is shown that, in addn. to that lost by mechanisms taken into account in the discussion, substantial quantities of energy are dissipated by turbulence induced in the H_2O surrounding the bubble, by chem. or phys. changes in the gaseous products, and by actual loss of these as small bubbles in the H_2O. (CA-45-8247i)

954. Friedman, B.

THEORY OF UNDERWATER EXPLOSION BUBBLES, Commun. Pure Appl. Math., 3, 177-99 (1950).

With the assumptions that (a) water is an ideal incompressible fluid, (b) the bubble remains spherical, and (c) the gas inside the bubble expands adiabatically, the motion of a bubble generated by an explosion is derived, taking account of the influence of the free surface and the bottom. Expressions for the period, the distance the centre moves during the first oscillation, the max. and min. radius of the bubble, the peak pressure of the wave emitted by the bubble and the energy left in the bubble after one or more oscillations are given and compared with experiment. Good agreement was obtained for the period. (Sci. A. 53-8569)

955. Gilstein, J. B.

BUBBLES PRODUCED BY SUBMERGED EXPLODING WIRES, AD 88688 (1955).

956. Herring, C.

THEORY OF THE PULSATIONS OF THE GAS BUBBLE PRODUCED BY AN UNDERWATER EXPLOSION, NDRC-Div., 6-Report C4-SR20 (1941).

957. Keller, J. B., and Kolodner, I. I.

DAMPING OF UNDERWATER EXPLOSION BUBBLE OSCILLATIONS, J. Appl. Phys. 27, 1152-61 (1956).

When an explosive detonates underwater it creates a bubble of gas which performs damped radial oscillations of large amplitude. The usual theory of these oscillations treats the water as incompressible and yields undamped oscillations of constant period. This theory has been modified by taking account of the compressibility of the water. This theory predicts

damped oscillations of diminishing period. Comparison of the predicted and observed radius - time curves for one particular case shows fairly good agreement. Radius - time curves for four representative cases have been computed with a large number of periods in each case. These can be used to describe a variety of explosions.

958. Kolodner, I. I., and Keller, J. B.

UNDERWATER EXPLOSION BUBBLES II. THE EFFECT OF GRAVITY AND THE CHANGE OF SHAPE, IMM-NYU-197 (June 1953), 28 p.

A theory is presented which describes the change of shape and the rise of underwater explosion bubbles by taking account of gravity. It is assumed that the water is unbounded, and incompressible and that the pressure is always uniform throughout the bubble and the bubble is spherical initially.

959. Soloukhin, R. I.

THE BUBBLE MECHANISM OF SHOCK-TRIGGERED COMBUSTION IN LIQUIDS, Dokl. Akad. Nauk. SSSR, 136, 311-12 (Jan. 11, 1961).

Shock waves passing through a combustible liquid may start combustion and their action is intensified by the presence of bubbles of air. For the purpose of investigating this effect the pressure in the neighbourhood of a bubble in water was measured during the time (approx. 10 μsec) in which a shock front passed by. Also the rate of compression of a bubble measured during the process of shock triggering in a acetylene-oxygen mixture. The observations do not agree quantitatively with the result of a simple hydrodynamical calculation. Further experiments with a hydrogen-oxygen mixture show that combustion starts at a temperature of 891°K. [English translation in: Soviet Physics - Doklady (USA)].

CONDENSATION

960. Aitken, John.

ON BOILING, CONDENSING, FREEZING, AND MELTING, Trans. Roy. Scottish Soc. of Arts IX, pt. III, 240 (1875).

961. Algermissen, J.

CONDENSATION OF VAPOR GAS MIXTURES: COMPUTATIONS AND EXPERIMENTAL RESULTS, Chem. Ing. Tech., 30, 502-10 (1958).

A graphical method is presented for solving simultaneous heat and mass transfer problems by the use of an enthalpy-compn. diagram. A comparison of exptl. results from literature sources with the graphical method evaluation shows that deviations up to 20% can be expected, which, however, may result in an error of as much as 100% in the final condenser design.

962. Alvarez Calvajol, J. and Duhne, C.

HEAT TRANSFER NOMOGRAPHS. X. VAPOR CONDENSATION FOR SATURATED GASES, Petrol Refiner 38, No. 7, 145-6 (1959).

2 nomographs.

963. Beatty, K. O., Jr., and Katz, D. L.

THE CORRELATION OF THE DATA ON THE TRANSFER OF HEAT FROM CONDENSING STEAM TO WATER IN A DOUBLE PIPE EXCHANGE(R), NP-1376 (1944), 23 p.

Heat transfer measurements were made with steam outside single finned tubes and with water inside, and for water flowing in an annulus outside with condensing steam inside. For water inside the tubes and steam outside, the coefficients of heat transfer for the steam film and for water film were computed. The water film coefficients increased with increased water velocity similar to the coefficients for plain tubes but the absolute values were greater due to the corrugations inside the finned tubes. A modified Dittus-Boelter equation is recommended. For water outside the tubes and steam inside, it was not possible to separate the over-all coefficient into film coefficients. The over-all coefficient of heat transfer may be estimated for all Trufin tubes by estimating the individual film coefficients and neglecting the metal resistance, except in the case of high fins at high rates of heat transfer.

964. Beck, C. B., et al.

THE FLUIDIZED CONDENSER, AECU3247 (1952), 79 p.

An apparatus using a fluidized bed of cold, recycled $ZrCl_4$ powder to condense a stream of hot $ZrCl_4$ vapor was designed and constructed. The operation of the fluidized condenser was successfully demonstrated. It was shown that caking of $ZrCl_4$ on the walls of the column was slight, with the greatest part of the condensation occurring in the fluidized phase. Because of time limitation, few runs were made. Data from future experimental runs may be used in a proposed theoretical analysis, in which several equations have been developed to allow the design of a fluidized condenser for given operating conditions. These equations predict optimum column size for the desired degree of condensation, axial temperature gradient in the bed, and over-all heat transfer and mass transfer coefficients. 36 references.

965. Becker, R., and Döring, W.

THE KINETIC TREATMENT OF GRAIN FORMATION IN SUPERSATURATED VAPORS, Ann. Physik 24, 719-752 (1935).

A theoretical discussion of grain formation, largely based upon thermodynamics, in fluids, surfaces, and crystals. The question of ohmic resistance corresponding to the p.d. between small elements in chains is dealt with, and the results obtained are used in explaining and establishing the limits of validity of Oswald's "step-rule." CA-30-1641.

966. Berman, L. D.

DISTRIBUTION OF LOCAL HEAT LOAD AND HEAT TRANSFER COEFFICIENT IN A SURFACE CONDENSER, Izvestiya Vses. Teplotekhn. Inst. (News of All-Union Heat Engineering Institute) 5, (1947).

967. Berman, L. D.

HEAT TRANSFER FROM A CONDENSING VAPOR TO A SURFACE AT LOW PRESSURES, Izvestiya Vses. Teplotekn. Inst. (News of All-Union Heat Engineering Institute) 7, 1947.

968. Berman, L. D.

THEORETICAL ANALYSIS OF EXPERIMENTAL DATA ON THE CONDENSATION OF AIR, Byulleten Tekh. Soveta (Bulletin of the Engineering Committee) 3, (1948).

969. Berman, L. D.

HEAT TRANSFER COEFFICIENT FOR A SURFACE CONDENSER, Izvestiya Vses. Teplotekn. Inst. (News of All-Union Heat Engineering Institute) 3, 1951.

970. Berman, L. D., et al.

EXPERIMENTAL DATA ON THE EFFECT OF A FLOW OF SUBSTANCE ON THE HEAT AND MASS EXCHANGE DURING CONDENSATION, Teploenergetika 4, No. 1, 49-51 (Jan. 1957).

971. Berman, L. D. and Fuks, S. N.

DESIGN OF SURFACE HEAT EXCHANGING DEVICES FOR CONDENSATION OF STEAM-WATER MIXTURE, Teploenergetika 6, 74-83 (July, 1959).

Design method based on experimental relations obtained for local coefficients of heat and mass exchange.

972. Boehm, J.

DETERMINATION OF HEAT TRANSFER OF CONDENSING STEAM, Gesundheits Ingenieur 71, 233-9 (Aug. 1950).

Temperature difference between steam and solid wall; effect of heat transfer coefficient of condensed

saturated steam on heat transfer coefficient of cooled surface; applications of formulas for calculation of vertical and horizontal heating surfaces; charts.

973. Bonilla, C. F.

BOILING AND CONDENSING OF LIQUID METALS, NYO-3150 (1952), 6 p.

Condensation data for Hg vapor on vertical low-C steel and 304 stainless steel tubes have been obtained at pressures from 2.3 to 15 lbs/in.^{2}. Dropwise condensation was always obtained. The film coefficient of heat transfer ranged from 700 to 1800 Btu/hr x ft^2 x °F, much lower than expected. Traces of inert gas may cause this effect, which is being studied further. A horizontal plate apparatus for the boiling of Na has been designed and is under construction.

974. Bonilla, C. F., and Misra, B.

BOILING AND CONDENSING OF LIQUID METALS, NYO-3152 (April 1953), 9 p.

Additional runs have been made on the condensing of Hg vapor at atmospheric pressure and 330,000 to 650,000 Btu/hr-ft^2 on carbon-steel, stainless steel, and Ni, under wetting, semi-wetting and non-wetting conditions. The highest heat-transfer coefficient observed under any conditions was 2345 Btu/hr-ft^2-°F, for completely wetted Ni, which is less than 20% of the theoretical Nusselt value. Tests run in the presence of H and of N showed that traces of inert gas were not causing the decrease in coefficient. It is believed that the decrease is due to thermal contact resistance between the Hg and the condensing surface. This hypothesis is supported by earlier work on contact resistance.

975. Bosnjakovic, F.

INTERCHANGE OF STEAM AND LIQUID OF SIMPLE SUBSTANCES, Forschung auf dem Gebiete des Ingenieurwesens 3, no. 3, 135-43 (1932).

Evasion and invasion defined; application of kinetic gas theory; heat transfer with condensing steam; between steam and liquid there is constant interchange of molecules in both directions; with condensation, molecules from steam to liquid predominate; and with evaporation, molecules from liquid to steam predominate.

976. Brin, A.

AN EXPERIMENTAL STUDY OF THE CONDENSATION OF WATER VAPOUR ON THE SURFACE OF CERTAIN ORGANIC SUBSTANCES, J. Rech. Cent. Nat. Rech. Sci., No. 35, 149-68 (June, 1956).

By means of a simple condensation chamber the part played by molecular structure on the formation of centres of condensation is determined. Irradiation by ultraviolet light favours the formation of these centres. On non-wetting substances, such as paraffin wax, water vapour is not condensed unless it is supersaturated at the temperature of the surface. The experiments are described in detail and the results discussed.

977. Bromley, L. A., Brodkey, R. S. and Fishman, N.

HEAT TRANSFER IN CONDENSATION, Ind. Eng. Chem. 44, 2962-69 (1952).

Math. analysis of the Nusselt equation for condensate heat-transfer coeff. on a tube, confirmed by expt. on BuOH, shows that, without significant error, one can assume, as in the equation, uniform temp. around the tube.

978. Carlson, J. A. Jr.

NON-ISOTHERMAL FLUID FLOW-CONDENSING STREAM: I. - EQUIPMENT CONSTRUCTION AND PERFORMANCE, University of Tulsa, M. S. Thesis, 1954, 110 p.

A literature investigation indicated that extensive data on non-isothermal fluid flow systems are required in order to substantiate existing two-phase correlations and to present an adequate basis for the design of such systems. In order to initiate a program to study non-isothermal flow systems, a 1 x $\frac{3}{8}$ inch double-pipe heat exchanger was constructed in ten 10-foot sections of straight pipe with the return bends constructed of tees, nipples and unions. At the bottom of the return bend of each section on the condensing side, a $\frac{1}{8}$ inch pipe was introduced to serve as a pressure tap. All the pressure taps were manifolded to a common pressure gage. At each return bend on the shell side were installed 24 gage copper-constantan thermocouples which terminated in a junction box.

In order to test the equipment and to note its performance steam was used as a condensing medium and water was used to condense the steam. The steam was introduced in the $\frac{3}{8}$ inch pipe, and the water was injected into the annular space countercurrently to the flow of the steam. As the two streams flowed through the exchanger, the steam side pressure and the water side temperatures were recorded and the weight rate of flow, as well as the exit qualities on both sides of the exchanger, were determined with a barrel calorimeter. The inlet steam quality was measured with a throttling calorimeter.

From a heat balance, the fluid properties at each pressure point on the steam side were calculated and from an energy balance the main friction factor for each section was computed. Upon analysis of the results of the six runs, it was concluded that the indicated trend of the friction factors agree with the meager published data; and that further work with steam and with the constructed exchanger is justified. Several recommendations for improving and refining the exchange, the experimental procedure and the calculation of the fluid properties were suggested. It was also suggested that a program be planned to systematically study the effect of the important variables such as tube diameter, condensing media, tube heated length, and the weight rate of flow on the friction factor or pressure gradient.

979. Cernuschi, F. and Segre, N.

THEORY OF CONDENSATION OF LIQUIDS OF ONE AND TWO COMPONENTS, J. chem. Phys. (USA), vol. 36, No. 2, 112-15 (Jan. 15, 1962).

Cernuschi and Eyring's (1939) theory of condensation is reconsidered, taking account of Kirkwood's (1939) criticisms, by the introduction of vibrations in the model. Variation of Einstein's frequency with temperature is considered, following some works of Raman. With these modifications results agreeing with experiment are obtained, thus overcoming Kirkwood's objections. The possibility of extending the model to the case of two components is then examined. The resulting formulae do now allow, because of their complexity, an analytic determination of the critical point. The equations can be simplified supposing that only one of the three previous interactions is different from zero. Numerical calculation is made for the case of interaction between different particles. The critical curve is found by trial and error. The calculations made for three different concentrations of one of the components (parameter in the theory) shows that the $\exp(\epsilon/kTc)-\epsilon$ interaction energy decreases with such concentration.

980. Chari, K. S., and Kulkarni, B. S.

CONDENSATION OF SATURATED VAPORS, J. Sci. Ind. Research (India) 10A, 244-9 (1951).

Nusselt's equation for the heat-transfer coeff. in condensing of satd. vapors is extended to include cases where the temp. difference is not const. over the entire length of tube. The temp. difference will be const. only for short tubes or where heat is being transferred to a boiling liquid. The derivation is made by starting with Nusselt's differential equation, but in its integration, the temp. difference is assumed to vary with tube length. After showing that in practice at $x = 0$, Δ_1 must equal zero, the following equation is derived for the mean temp. difference: $\Delta_m = (3Q/4\pi DNk)(3\mu Q/\pi De^2 g\lambda)^{1/3}$ where Q = heat transferred; D = tube diam.; e = density of condensate; λ = latent heat; μ = viscosity of condensate; k = thermal cond.; g = acceleration due to gravity; and N = tube length. Generalizations that can be made from this and other derived expressions are (a) the thickness of condensate layer varies linearly with tube length, (b) temp. drop varies as the third power of the length, (c) mean temp. drop is $\frac{1}{4}$ the value of the drop at the bottom of the condenser, (d) mean temp. drop varies inversely as tube length for const. heat flux and for const. tube length varies as $4/3$ power of heat flux. Calcn. of mean temp. difference by these methods for condensation of O and N indicates close agreement with exptl. values.

981. Chen, N. and Kellogg, M. W.

GRAPHS SPEED EVALUATION OF CONDENSING AND COEFFICIENTS OF HEAT TRANSFER, Chem. Eng. 66, 141-6 (March 9, 1959).

Graphs are presented for short-cut calcns. of boiling coeffs., and of condensing coeffs. when the condensate film is in either streamline or turbulent flow.

982. Chernobyl'skii, I. I. and Shchegolev, G. M.

AN EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER FROM CONDENSING VAPOR TO A LIQUID WITH ROTATION OF THE HEATED SURFACE, Transactions of the Institute of Heat Engineering, Academy of Sciences of the Ukranian Soviet Socialist Republic, 1 (1949).

983. Chu, Ju Chin, et. al.

HEAT-TRANSFER COEFFICIENT OF CONDENSING VAPORS, J. Applied Chem. 1, 73-80 (1951).

It has been found theoretically that the heat transfer coefficient of a condensing vapor is a function of the rate of heat only. The present study varied the rate of flow of cooling water inside the condensing tube and the over-all temp. difference to obtain the heat-transfer coeffs. at a const. rate of heat transfer. The over-all temp. drop was varied by changing the pressure in the vapor space. For the 4 compds. investigated, the value of the heat-transfer coeff. of the condensing vapor (h_0) varied with the rate of heat transfer, q. For trichloroethylene with q 2800-1900, h_0 was 298-362; bromobenzene, q 2000-1200, h_0 289-380; nitromethane, q 2700-2300, h_0 244-258; hexyl alc., q 2000-1400, h_0 151-175. The heat-transfer coeffs. predicted from Nusselt's equation agree with those detd. experimentally for trichloroethylene and bromobenzene, but for nitromethane and hexyl alc. the Nusselt predictions were about twice the observed values.

984. Colburn, A. P.

CALCULATION OF CONDENSATION WITH A PORTION OF CONDENSATE LAYER IN TURBULENT MOTION, Ind. Eng. Chem. 26, 432-4 (1934).

Point condition values of heat transfer coeff. and condensation rate; integration of total condensation and determination of average heat transfer coefficient.

985. Courtney, W. G.

KINETICS OF CONDENSATION OF WATER VAPOR, J. Chem. Phys. 36, 2018-25 (1962).

The condensation of water vapor via steady-state nucleation is examined by an exact mathematical approach which solves the kinetic equations of a computer. This approach avoids the usual assumption that nucleation abruptly stops when the parent phase becomes slightly depleted. The corrected classical theory of steady state liquid-drop homogeneous nucleation and the growth law used in the classical nucleation theory were assumed. Results gave no indication of a "critical" supersaturation for condensation and showed that condensation via classical homogeneous nucleation would be much slower than experimentally observed in cloud chambers. Condensation in 50 msec via homogeneous nucleation theoretically requires 13 particles/cc and an initial supersaturation of 5.2 at -5°C and 3.3×10^4 particle/cc and an initial supersaturation of 35 at -60°. Nucleation rates are sensitive to supersaturation but at -60° one-third of the particles are formed after a 4% decrease in supersaturation, contrary to the usual

interpretation of condensation kinetics in a cloud chamber. The rapid condensation rates experimentally observed in a cloud chamber may be due either to heterogeneous nucleation or to homogeneous nucleation with the surface energy of an 80- or 90-molecule cluster being smaller than that macroscopic value, e.g., about 3 and 30% smaller at -5 and -60°, respectively. However, the liquid-drop theory of homogeneous nucleation as classically formulated in terms of the macroscopic surface energy apparently cannot explain the experimental results in a cloud chamber and thus remains to be verified.

986. Duclaux, J.

THEORY OF GASES. XXIII. CALCULATION OF THE CONDENSATION, J. Phys. Radium, 18, 505-11 (Aug-Sept, 1957).

For previous work see Abstr. 5938 (1955). The theory of the progressive condensation of real gases previously given has been modified and agrees with the law of mass action. Its basic assumption is that the individual molecules associate to form aggregates of 2, 3, 4... single molecules, no action taking place between the aggregates. The coefficients K of the mass action law have been calculated for nitrogen between -146° and 400° and show complete agreement with experiment. The isotherms obey two laws of isocondensation, by means of which any isotherm may be deduced from any other (basic isotherm), knowing two numbers: the factor F and the translation Δ. The two laws may be somewhat at fault close to the critical point, but elsewhere they are subject to errors less than 0.05%. The comparison with the equations of state of Van der Waals and Beattie and Bridgeman shows that agreement with the experimental numbers is greatly improved. The theory extends to other gases (oxygen, argon, neon) and leads to a new conception of the corresponding states, in which the critical data play no part. The method for the calculation of the coefficients K is outlined.

987. Ebin, L. and Lincoln, R. L.

FLOW OF STEAM AND CONDENSATION AS AFFECTED BY HIGH PRESSURE, HORIZONTAL OFFSETS AND VALVES, Am. Soc. Heating & Vent. Engrs., J. 30, 475-90 (1924).

Deals with effect of high pressure on maximum velocity, valves on maximum capacity, and of horizontal offsets on maximum velocity.

988. Elton, G. A. H., Mason, B. J., and Picknett, R. G.

THE RELATIVE IMPORTANCE OF CONDENSATION AND COALESCENCE PROCESSES ON THE STABILITY OF A WATER FOG, Trans. Faraday Soc., 54, 1724-30 (1958).

A theoretical analysis of the processes which influence the stability of a water fog contained in an isothermal enclosure is presented. The changes in droplet-size distribution brought about by coalescences between droplets of different sizes, and also by the distillation of water vapour from droplets smaller than average on to those larger than average, are computed. It is shown that, for a droplet population having initially a normal droplet size distribution the evaporation-condensation process is the more important if the mean droplet radius is less than 7μ, assuming the collection efficiencies for droplets in this size range to be at least 0.1. Although the calculations have been made for a water fog, the theory is generally applicable to any similarly dispersed system. The effect of dissolved electrolytes in the droplets is to increase the stability of the fog.

989. Farkas, L.

THE VELOCITY OF NUCLEUS FORMATION IN SUPERSATURATED VAPORS, Z. Physik. Chem. 125, 236-42 (1927).

This is a mathematical paper developed on the assumption that as a result of the collisions of mols. in the vapor space, some of them will unite. The change of the no. of particles will depend on whether new mols. are caught or additional ones given off; and this in turn is a problem in probabilities. F. arrives at an expression $J = (Pr/F)ce^{-F\sigma/3kT}$ in which J is the no. of drops formed per sec., Pr is the pressure of the supersatd. vapor, F the surface of the nuclei, and σ the surface tension. According to this, the rate of formation of nuclei is const. as long as the initial conditions remain substantially the same and is proportional to the no. of the nuclei, which is in agreement with the assumptions of Volmar and Weber. CA-21-1575.

990. Friedlander, S. K.

ON THE PARTICLE SIZE SPECTRUM OF A CONDENSING VAPOR, Phys. of Fluids, 3, 693-6 (1960).

The classical theories of condensation and coagulation are considered as limiting cases of a general theory of new phase formation. By making several assumptions concerning the nature of the vapour and of the cooling process, it is shown that the equation of condensation can be written in a simplified dimensionless form. The embryo size spectrum function at the end of the condensation process is a function of a number of dimensionless groups; hence, condensation can be modeled in the sense that particle size can be controlled by varying certain scale factors. An application to condensation by mixing of a hot vapour with cool air is proposed.

991. Fuks, N.

THE SURFACE CONDENSATION OF WATER VAPOR, J. of Physical Chemistry (U.S.S.R.) 6, 4 (1935).

992. Gel'perin, N. I., and Zil'berg, V. I.

DETERMINATION OF HEAT-TRANSFER COEFFICIENTS BETWEEN CONDENSING VAPORS AND LIQUIDS, Trudy Moskov. Inst. Tonkoi Khim. Tekhnol. im. M. V. Lomondsova, No. 5, 18-26 (1955).

A method for accurate and simple detn. of a heat-transfer coeff. (I) in cal/sq. m./hr./degree, between the condensing vapors and liquids was developed. By grouping a no. of consts. from the generally accepted equation for the detn. of coeff. of heat transfer from the condensing vapors to the

heat-exchange surface, and substituting it in the general equation for the heat intensity of the heat-exchange surface, an expression for I was derived. To det. the value of I, the equation was solved graphically. Another expression was derived for the heat transfer coeff. (II) between a condensing vapor and a boiling liquid. The value of II was also computed from a graphical solution of the equation. To simplify the calcns. of I and II by their respective equations, nomographs were worked out.

993. Gibson, L. C.

RATE OF CONDENSATION OF WATER VAPOR UNDER VACUUM, Ph.D. Thesis, U. of Wisc., (Aug. 1952).

994. Gilmore, F. R.

THE KINETICS OF CONDENSATION AND VAPORIZATION, Ph.D. Thesis, Cal. Inst. Tech. (1951).

995. Gnatovskii, V. I.

EXPERIMENTAL STUDY OF HEAT TRANSFER DURING THE CONDENSATION OF STEAM IN THE CHANNELS OF A SPIRAL HEAT EXCHANGER, Izvest. Kiev. Politekh. Inst. 28, 30-3 (1959).

Heat transfer during condensation of steam moving along a spiral slit channel 6 mm. wide, in the direction from the outer periphery to the center, was studied. Cold water was passed through a channel 4 mm. wide. The dimensions of the water and steam channels, resp., were: height, 182 and 180 mm.; length, 1217 and 1058 mm.; equiv. diam., 7.83 and 11.57 mm.; radius of curvature at the origin, 45 mm.; av. radius of curvature, 61.0 and 55.5 mm. The pressure of the steam was 1.5-3.0 atm.; the velocity of the water in the channel was 24-50 m./sec. The temp. of the concave wall of the channel, on which the condensation proceeds, is noticeably lower than that of the convex wall; thus, the formation on the concave wall of a thick layer of condensate is explained. This layer is not blown away by steam, but is held to the wall by centrifugal force. Av. exptl. values of the heat transfer coeff. are 14% lower than the values calcd. from the equation for condensation of steam on vertical pipes. A graph for detn. of the coeff. during condensation of steam on a curvilinear surface in relation to the velocity of water and pressure of steam is presented. From Referat. Zhur., Khim. 1961, Abstr. No. 16148.

996. Golovinskii, G. P.

CONDENSATION OF A MIXTURE OF VAPOURS UNDER INTENSE COOLING, Zh. Tekh. Fiz., 26, 1309-1328 (1956) (In Russian) English Translation in Soviet Physics - Technical Physics 1, 1281-1290 (1957).

Discussion of results obtained in studies on liquid air. Topics dealt with are: (1) measurement of low temperatures and the determination of the saturation temperature of the condensing vapours, (2) determination of the magnitude of the heat in flow through the lagging and metal parts. Photographs of droplet condensation (1.5 atm), an intermediate regime (2 atm) and simple film type condensation (3-6 atm), and a table of the heat transfer coefficients for the condensing vapours of N_2, O_2 and A are included.

997. Gregorig, R.

OPTIMUM CONDITIONS FOR HEAT EXCHANGE IN THE CASE OF VAPORIZATION AND CONDENSATION, Intern. J. Heat Mass Transfer 5, 175-88 (1962) (In German).

The rate of irreversibility in heat exchange can be reduced if the coolant or the heating medium flows through the resp. app. in series instead of parallel flow, and no change of state occurs. This effect is shown with heat exchange setups with a number of units in which the working medium obtains heat by evapn. or gives it off by condensation. The optimum distribution of heat exchange surfaces of similar assemblies is presented. In all calcns. the sum of heat exchanging areas and necessary power is kept const. The advantage of the suggested series connection can be used with a noteworthy increase in efficiency in steam turbine-, heat pump, and refrigerating-units.

998. Gudemchuk, V. A.

HEAT TRANSFER IN A TUBE BUNDLE CONDENSER, Thermal Power Management (U.S.S.R.) 4-5 (1938).

999. Gudemchuk, V. A. and Konstantinov, V. A.

HEAT TRANSFER WITH VAPOR CONDENSATION ON A SOLID SURFACE, J. of Technical Physics (U.S.S.R.) 6, No. 9, (1936).

1000. Guth, W.

A CINEMATOGRAPH USED TO OBSERVE THE DETAILS OF THE CONDENSATION OF WATER VAPOR, Akust. Beih. 4, 1, 445-455 (1954).

As an elucidation of cavitation bubble collapse phenomena, air-free water vapor of 0.5 to 1.5 atm is ejected from nozzles of 0.3, 2.2, and 7-mm diam into cold water, and bubble condensation and rebound are photographed at rates of 42,000-65,000 pictures per sec, both directly and by schlieren method, the latter for visualization of shock-wave radiation at the implosion. The development of the camera, including its rotating mirror, lens system, stationary film, and regulated intermittent light source, is fully described, mentioning the insufficient intensity of the latter for possible higher frequencies. While author's analysis of pictures finds reasonable agreement with Rayleigh, reviewer questions suitability of experiment because of lack of bubble sphericity and widely different vapor and liquid temperatures at the start of collapse. Evidently author is not familiar with the camera, built on similar principle but with different light source and regulation, which photographs cavitation bubbles generated by sound waves at a picture rate of 10,000 per sec, improved since to 400,000 per sec (Albert Ellis, "Observations on cavitation bubble collapse," California Inst. of Technology, Hydrodynamics Rep. no. 21-12, Dec. 1952).

1002. Haire, A. M., Hays, L. G. and Collings, J. L.

RADIATOR CONDENSER FOR SPACE ENVIRONMENT, WADD TR 61-20 (AD-253791) (1960), 325 pp.

A radiator-condenser (R-C) for a Rankine cycle space power system was designed to condense and subcool superheated mercury vapor. The weight of the R-C was to be minimized at design conditions. The design incorporated curved stainless steel tubes welded to tapered stainless steel manifolds and brazed to a steel radiation fin. A test model R-C, designed to reject approximately 1 kw of heat, was tested in a closed loop laboratory system over a range of vapor inlet temperatures from 810 to 964°F. Both wet and superheated vapor conditions were used. Flow rates were adjusted over a range of values at each inlet temperature in order to move the vapor-liquid interface from a position near the R-C outlet manifold to a position near the inlet manifold. The results demonstrated that a curved tube R-C can be used to condense mercury vapor in a space power system over a relatively wide range of operating conditions. For the range covered in the present investigation, vapor-free liquid flow was obtained at the R-C outlet and relatively stable conditions occurred in the R-C. Performance of the R-C demonstrated the validity of the design method, except that measured pressure drops were considerably lower than those predicted by currently available analytical methods. All aspects of the present investigation are summarized. The design procedure is given along with fabrication and experimental details. In addition, state-of-the-art information obtained during the early phases of the investigation is included. Experience derived from operation of the experimental test loop is reported. Limitations of the data, along with problems which require further investigation, are also noted.

1003. Hampson, H., and Oezisik, N.

INVESTIGATION INTO CONDENSATION OF STEAM, Instn Mech Engrs - Proc (B) 1B, 282-94 (1952). See also Heating and Air Treatment Engr 16, 2-7, 34-40 (Jan-Feb, 1953).

Filmwise and dropwise condensation; apparatus for ascertaining heat transfer rates; effect of water velocity and mean water temperature on heat transfer with dropwise and filmwise condensation on horizontal and vertical surfaces; tests carried out on pure and impure copper of different thicknesses, 220 Btu and 125 Btu, respectively, and brass 60 Btu.

1004. Hampson, H.

CONDENSATION OF STEAM ON A TUBE WITH FILMWISE OR DROPWISE CONDENSATION AND IN THE PRESENCE OF A NON-CONDENSABLE GAS, International Developments in Heat Transfer, Part I., ASME (1961), p. 310-318.

Investigates the heat transfer during condensation of steam at atmospheric pressure on a single tube with no significant velocity of flow across the surface. The variables covered included tube diameter and inclination, heat load, mode of condensation (filmwise and dropwise), and the presence of a non-condensable gas in several concentrations. The tube heated length was 2 feet, which resulted in small temperature rise giving almost uniform heat flux along the tube. It was not possible to measure the surface temperatures of the 0.020 thick copper tubes, and the surface coefficients on the steam side were obtained indirectly. Comparisons are shown for the different steam-side conditions of filmwise or dropwise condensation with similar water-side inlet conditions and velocities. For filmwise condensation of gas-free steam, correlation with the Nusselt theory was good, and with laminar flow in the film gave steam-side coefficients for the 1" o.d. vertical tube 20-35% greater than the Nusselt theory and 2-10% greater for the 1" o.d. horizontal tube, with the lower (more normal) heat loads. With a non-condensable gas present, steam-side heat transfer coefficients depend on the mode and quantity of venting. An arbitrarily chosen "constant vent" condition was used giving 5-15% vented with dropwise condensation but 20-25% vented with film-wise condensation. There was a major effect of the location of the vent. 0-5% (by weight) of nitrogen was introduced into the entering steam as the non-condensable gas.

1005. Hazelton, R., and Baker, E. M.

CONDENSATION OF VAPORS IN IMMISCIBLE LIQUIDS, Am. Inst. Chem. Engrs. Trans. 40, 1-28 (Feb. 1944).

Condensing film heat transfer coefficients determined for mixtures of water with benzene, toluene and chlorbenzene on single 44-in. long vertical copper tubes; ranges of composition and temperature drop covered were 5 to 96%, water in condensate and 15 to 75 F; three types of condensate flow were observed; equation for vertical tubes given.

1006. Heyser, A.

HEAT AND MASS TRANSFER WITH HIGH PARTIAL PRESSURE DIFFERENCES, Chem. Ing. Tech 28, 161-4 (1956).

Exptl. results on fractional condensation are reported for H_2O-air and C_6H_6-air mixts. The data could best be correlated by assuming a fixed effective film resistance. Data of other investigators could also be correlated to a better degree in this manner than by the more complicated mechanisms employed by the respective investigators. 10 references.

1007. Hidy, G. M.

VAPOR CONDENSATION BY MIXING IN A FREE JET, Ph.D. Thesis, Johns Hopkins Univ., 169 pp. (1962).

1008. Ikeda, K.

ON THE THEORY OF CONDENSING SYSTEMS, Letter in Progr. theor. Phys., 11, 336-9 (1954).

The author's modification of Mayer's theory is presented in the form of a concise summary. Its principal contribution concerns the method of finding the term in the partition function which may asymptotically replace the whole sum. Certain inaccuracies of the older theory, the author claims, are now avoided.

1009. Ikeda, K.

CLUSTER THEORY OF CONDENSING SYSTEMS, Progr. theor. Phys., 19, 653-98 (1958).

A detailed and rigorous theory of vapour-liquid coexistence in the condensation of a system consisting of a very large number (N) of interacting molecules (in a volume Nv). Starting from the Ursell-Mayer expansion of the partition function, certain ordinary assumptions are made about the cluster integrals (b_l). First a function $l^*(N)$ is taken which satisfies certain conditions, and "small" clusters [for which $l \leq l^*(N)$] and "large" clusters [for which $l > l^*(N)$] are defined; thus all clusters in the system (for each N) are classified into "small" and "large" clusters, and the partition function (Ω_N) of the system (for each N) is expressed in terms of the factors (ϕ_N) which contain "small" clusters only and the factors (Φ_N) which contain "large" clusters only. It is then proved that an assembly of molecules divided into any number of "large" clusters may be replaced by only one "larger" cluster composed of all the molecules of the assembly with errors as small as desired if N is sufficiently large. Further, it is proved that as soon as the density of the system exceeds that of the saturated vapour, the isotherm becomes horizontal and there appears one "huge" cluster, which is defined as a cluster for which l/N is as near to some positive constant as desired if N is sufficiently large. Thus the "huge" cluster is of a macroscopic size and should be considered to represent the liquid phase coexisting with the saturated vapour. It is shown that Mayer's theory of condensation has some defects, and an improved approximate theory is proposed in which these defects are avoided. The present theory is compared with the theory of Bose-Einstein condensation, and it is noted that the present theory is quite free from the faults contained in the saddle-point method.

1010. Ikeda, K.

GENERALIZED THEORY OF CONDENSING SYSTEMS, Progr. theor. Phys. (Japan), 26, 173-220 (1961).

The theory of Abstr. 12094 of 1960, which dealt with the two-phase separation in condensing systems on the basis of the "cluster" concept and by means of a mathematically rigorous method, is generalized to the case of systems with volume-dependent cluster integrals. The cluster integrals are assumed to satisfy several mathematical conditions, which are considered to represent the essential features of the real systems. One of these conditions is concerned with the effects of the volume dependence of the cluster integrals composed of a comparatively small number of molecules. Another essential condition is that the contribution, per molecule, to a cluster integral in which the number l of the constituent molecules is infinitely large and of the same order as the volume V of the system, should be definite, finite and independent of the volume per molecule, V/l, in a certain range. By means of a function $l^*(N)$ which satisfies certain conditions, the sizes of clusters are classified into "large" [$l > l^*(N)$] and "small" [$l \leq l^*(N)$]. The "small" cluster part of the system in consideration and that of the "(0)-system" (i.e. a system with volume-independent cluster integrals) are proved to be practically equivalent. Then, after some discussions of the "large" clusters, it is proved that, in a certain range of the specific volume, the isotherm is horizontal and a "huge" cluster (i.e. a cluster of size comparable to the volume of the system) coexists with the saturated set of "small" clusters. This corresponds to the liquid-vapour coexistence range. And it is proved that, in the gas range, the system is thermodynamically equivalent to the (0)-system and has practically no "large" clusters. A comment is made on the analytical properties of the singularity representing the condensation. It is noted that the present theory applies to both the cases of "analytical" singularity and of "non-analytical" singularity. A non-rigorous treatment which leads to the same results is given in an appendix.

Abstr. 12094, 1960. See: K. Ikeda: Progr. theor. Phys., 19, 653-98 (June, 1958).

1011. Izmailova, G. I., Prokhorov, P. S. and Deryagin, B. V.

THE POSSIBILITY OF SURFACE ACTIVATION AND PASSIVATION OF NUCLEI IN THE CONDENSATION OF WATER VAPOR, Kolloid Zhur. 19, 556-61 (1957).

A stream of dry air (m_1 moles/sec., H_2O vapor pressure = p_1) was mixed with a stream of moist air (m_2 moles/sec., H_2O vapor pressure = p_2), and p_2 was varied until visible fog appeared in the mixing chamber; the supersatn. S corresponding to fog formation was calcd. as $S = (m_1p_1 + m_2p_2)/ps(m_1 + m_2)$; ps = satd. vapor pressure at the mixing temp. When NaCl crystals (obtained by vaporization of drops of dil. NaCl solns.) were introduced in the dry stream, the S was greater (0.84 to 1.33), the smaller was the approx. radius of the crystals (0.2 to 0.036μ). When CH_2O was adsorbed on the crystals before the expt., S increased by, e.g., 40%, but $(Et_3Si)_2O$, $COMe_2$, and iso-AmOH lowered S. A SiO_2 powder contg. about 2% Na_2CO_3 and 8% $CaCO_3$ was heated to 120-732° before the expt.; heating raised S up to 4-fold. The chem. or thermal treatment of the condensation nuclei changes the accommodation coeff. on them.

1012. Jakob, M.

CONDENSATION AND EVAPORATION: NEW CONCEPTIONS AND EXPERIMENTS, Z. Ver. deut. Ingr. 76, 1161 (1932).

Experimental investigation of water-film theory with particular regard to heat transfer; evaporation theory of Bosnjakovic; effect of properties of heating surface on formation of steam bubbles; factors controlling heat transfer. CA-27-789.

1013. Jones, E. A. and Loveless, L. W. J.

OVERALL HEAT FLUXES VALUES FROM CONDENSING STEAM TO BOILING LIQUIDS, Chem. Eng. Sci. 2, 32-34 (1953).

A mixt. of KOAc, Ac OH, and H_2O was subjected to evapn. in an exptl. evaporator consisting of a steam-heated stainless steel tube connected to a separator. Approx. one third of the evaporator tube was submerged. The steam pressure was varied from 68 to 123 lb/sq. in. gage with a corresponding driving force temp. change from 39° to 72°F. The overall heat transfer coeff. varied nearly linearly from 382 at 39°F mean temp. difference to 220 Btu/hr/sq ft/°F at 72°F mean temp. difference. The heat flux increased with increasing mean temp. difference to a max. at 62°F and then decreased.

1014. Jost, W., et. al.

CONDENSATION OF AIR IN ULTRASONIC FLOW, Z. Physik. Chem. 21, 125-9 (1959).

The vapor pressures of C_6H_6, toluene, PhEt, styrene, cumene, and PhBr were measured ebullioscopically (C.A. 53, 1947Se) over the pressure ranges 60-750, 60-750, 10-750, 8-750, 25-750, and 23-730 mm., resp. The consts. A, B, and C (and D for PhEt) in the equation $\log p = A + (B/T) + C \log T + (D/T^2)$ are given. The pressure ratio for cumene/PhBr is approx. const. (1.096) over the range 25-750 mm.; the pressure ratio for toluene/styrene decreases with increasing pressure.

1015. Judd, D. H.

CONDENSATION IN A REACTOR CONTAINMENT VESSEL, Nuclear Eng. 4, 431-434 (1959).

Tests were performed to determine whether the loss of heat by a contained mixture of steam and air is sufficient to cause any substantial alleviation of pressure built up in a reactor containment vessel. Steam was injected into the boiler at 120 psig and assumed to be 3% wet. The results were analyzed in terms of forced convection heat transfer (steam injection period) and free convection heat transfer. Two formulas were derived for calculating the heat loss to a containment vessel by a steam-air mixture.

1016. Kirkaldy, J. S.

THE TIME DEPENDENT DIFFUSION THEORY FOR CONDENSATION ON SPHERICAL AND PLANE SURFACES, Canad. J. Phys. 36, 446-55 (1958).

The diffusion field and the temperature distribution are calculated for the surroundings of a pure solid or liquid phase at constant temperature growing into an infinitely extended binary fluid phase of different specific volume. The solutions for spherical condensates are applicable to the condensation from air of water vapour on ice or water drops. It is demonstrated that the generally accepted quasi-stationary diffusion theory for spherical drops leads fortuitously to the correct growth law.

1017. Kirschbaum, E., et. al.

NEW DEVELOPMENTS IN HEAT TRANSFER, Chem.-Ing.-Tech. 23, 361-8 (1951).

The heating effect of flowing superheated and satd. steam was observed for film and dropwise condensation. The app. consisted of a vertical Cu tube (30 and 38 mm. diam.) with a condensing section 1.445 in. long (steam on outside). In film condensation the superheated steam gave better results at small Δt's and small vapor velocities. Both types of steam gave equiv. results when Δt (condensing temp.-tube wall temp.) was 8.5° and the entering vapor velocity 27 m./sec. In dropwise condensation better heating was obtained under all conditions with superheated steam. In film-type condensation: heat-transfer coeffs. for satd. steam were smaller at small Δt's than the values predicted by the Nusselt equation, became equal to the predicted values at $\Delta t = 5.4°$ and entering vapor velocity of 55 m./sec., and became larger than predicted at higher Δt's; all such coeffs. continued to increase with decreasing Δt. In dropwise condensation: the coeff. reached a max. and then decreased with decreasing Δt; the heat flux was about 3 times that of film condensation. Measurements on the cooling water flowing upward inside the tube gave the following results: at velocities below 0.2 m./sec. convection currents were set up; with decreasing velocity at a water temp. of 67° the heat-transfer coeff. between water and tube wall rose to a max. of 1200 kcal./$m^{-2}h°C$. Details of the equipment and many data are presented.

1018. Kruzhilin, G. N.

IMPROVING NUSSELT'S THEORY OF HEAT EXCHANGE DURING CONDENSATION, ZhTF J. of Technical Physics (U.S.S.R.) 7, Nos. 20-21 (1937).

1019. Kutaleladze, S. S.

AN EXPERIMENTAL APPLICATION OF THE THEORY OF SIMILITUDE TO HEAT TRANSFER FROM CONDENSING, SATURATED STEAM, J. of Technical Physics (U.S.S.R.) 7, No. 3 (1937).

1020. Kutaleladze, S. S.

HEAT TRANSFER IN CONDENSATION AND BOILING, 2nd ed. Translated from a publication of the State Scientific and Technical Publishers of Literature on Machinery, Moscow-Leningrad, 1952, 215 p., AEC-tr-3770 (NSA 13-21434).

Basic principles of heat exchange during a change in state and data dealing with heat transfer in condensation and boiling are presented. Various kinds of boiling are examined along with certain aspects of vapor-liquid system hydrodynamics. Thermodynamics is emphasized, and included information may be

of use to heat exchanger designers as well as engineering students.

1021. Lackey, D. L.

DIRECT CONTACT CONDENSATION WITH TWO IMMISCIBLE FLUIDS, (thesis) UCRL-10339 (June 29, 1962).

The theory, design techniques, and relative economics are presented for three basically different direct-contact condensation processes involving fluids whose condensed phases are immiscible. In the specific system developed for the study, Aroclor 1248 (Monsanto Chemical Corporation) and steam were used. The processes investigated include the injection, and the induction of steam into a high-velocity stream of Aroclor in the throat section of a Venturi. The bubbling of steam into a low-velocity stream of Aroclor, using a packed tower to artificially increase the surface of contact was also investigated. The induction, injection, pressure drop, and heat-transfer characteristics of a Venturi in direct-contact condensation service were experimentally investigated, and empirical correlations for the performance of the unit are included. The performance of a direct-injection device was also experimentally determined, and correlations obtained. A discussion is included concerning the theoretical development of relations which are used to predict the performance of packed towers in direct-contact condensation service.

1022. McAdams, W. H.

HEAT TRANSFER AND PRESSURE DROP OF AIR FLOWING IN SMALL, ROUND, TUBULAR PASSAGES AT HIGH WALL TO AIR TEMPERATURE DIFFERENCE, Second Informal Report, NEPA-678, June 18-July 18-1948, 3 p.

Tentative plans have been made for a tubular air heater unit to be heated by condensation of steam or Dowtherm vapor at 1 atmosphere. The unit is to be made of Type 347 stainless steel, and is to contain a total of 1111 tubes, each having a length of 0.625 in., an inside diameter of 0.125 in., and a wall thickness of 0.004 in. Material has been ordered.

1023. Maksimov, I. G.

GRAPHICAL METHOD FOR CALCULATING HEAT TRANSFER THROUGH METAL SHEETS BETWEEN CONDENSING VAPOR AND BOILING LIQUID, Energomashinostroenie, No. 11, 24-6 (1958).

It is assumed that the total difference between the temps. of condensing vapor and boiling liquid, Δt, is known, and the phys. consts. can be detd. The method involves graphical representation of sp. heat flows, depending on the difference between the temps. of condensing vapor and metal and between metal and boiling liquid. These are calcd. by known equations for heat transfer during vapor condensation and boiling of liquid. On Δt ordinate, heat flows to boiling liquid are plotted, and, in reverse direction, heat flows are plotted from the condensing vapor. The intersection corresponds to a point where sp. heat flows on both sides of the metal are equal, and dets. the unknown partition temp. on the side of condensing vapor and boiling liquid. A similar method of computation is valid when addnl. thermal resistance caused by surface contamination is present. From Referat. Zhur., Khim. 1959, Abstr. No. 61094.

1024. Mathewson, W. F.

EFFECTS OF SONIC PULSATION ON FORCED CONVECTIVE HEAT TRANSFER AND FILM CONDENSATION IN A VERTICAL TUBE, Ph.D. Thesis, Cornell Univ. 95 pp. (1961).

1025. Mayer, H. and Göhre, H.

THE PHENOMENON OF DELAYED CONDENSATION, Naturwissenschaften, vol. 49, No. 11, 253-4 (1962).

The condensation of Hg atoms on a quartz-glass surface was quantitatively investigated under conditions of extreme purity and cleanliness, and micro-weighed continuously to an accuracy of ±2.1 monolayers. It is found that complete condensation is only possible below a definite limiting thermodynamic temperature, above which delayed condensation occurs. The condensation coefficient (ratio of number of condensing to incident atoms) is not constant but is dependent on the structure of the condensate already present. General agreement is found with previous qualitative work.

1026. Michaels, R. W.

CONDENSATION OF SEA BREEZES, Ph.D. Thesis, U. of Wisc. (July 1953).

1027. Mirkovich, V. V. and Missen, R. W.

NON-FILMWISE CONDENSATION OF BINARY VAPORS OF MISCIBLE LIQUIDS, Canad. J. Chem. Engng. 39, 86-7 (1961).

Photographs of the phenomena are presented. CA 55:13961g.

1028. Misra, B., and Bonilla, C. F.

HEAT TRANSFER IN THE CONDENSATION OF METAL VAPORS: MERCURY AND SODIUM UP TO ATMOSPHERIC PRESSURE, Chem. Eng. Prog. Sym. Ser, 52, No. 18 (1956).

Experiments were carried out to study condensing heat transfer coefficients of metal vapors. Heat transfer coefficients were determined for mercury vapor condensing on both water- and air-cooled vertical steel, copper-plated steel, nickel, and stainless steel condensers 0.5 in. O.D. and from 0.5 to 3 in. in length. Experiments were also carried out on a 4.5-in.-long, 0.5-in. O.D. nickel-stainless-steel-composite tube condenser, in both horizontal and vertical positions. Visual observations, still photographs, and Fastax moving pictures showed filmwise condensation on copper-plated steel and nickel surfaces and dropwise condensation on stainless steel surfaces. On steel, condensation was usually dropwise near the top and filmwise near the bottom. The heat velocity varied from about 25,000 Btu/(hr.) (sq.ft.) at 0.5 lb./sq.in. abs. with air cooling to about 750,000 at 15 lb./sq.in. abs. with water cooling, and the heat transfer coefficient

ranged from about 3,000 to about 10,000 Btu/(hr./sq. ft.)(°F.) for film-type condensation and from about 4,000 to over 50,000 for dropwise condensation.

Condensing heat transfer studies for sodium vapor were also carried out on a bimetallic nickel-stainless-steel condenser. The heat velocity varied from about 60,000 Btu/(hr.)(sq. ft.) at 650°C. to about 100,000 Btu/(hr.)(sq. ft.) at 870°C., giving a heat transfer coefficient ranging from 11,000 to 13,000 Btu/(hr.)/(sq. ft.)(°F.).

The condensing heat transfer coefficients obtained for mercury and sodium are only about 5 to 15% of the Nusselt equation values for film-wise condensation.

1029. Nabavian, K.

CONDENSATION COEFFICIENT OF WATER, Ph.D. Thesis, U. of Calif., 127 pp. (1962).

1030. Nandapurkar, S. S.

CONDENSATION ON A ROTATING SURFACE, Ph.D. Thesis, North Carolina State College, 77 pp. (1958).

1031. Nishiwaki, I., and Klein, L. A.

CONDENSATION OF STEAM IN STEAM-AIR BUBBLES IMMERSED IN WATER, TID-6520 (1960), 46 p.

Numerical evaluations were made on the condensation of steam-air bubbles in a pool of water. The rate of change in bubble size, partial pressures of steam and air, partial densities, interfacial temperature, mean temperature of bubble, and heat generated by condensation at the interface were calculated for the following initial conditions: initial temperature of bubble, 280°F; bulk water temperature, 100°F; initial bubble radius, 0.25 in.; and pressure on bubble, 18 psia. The effects of initial steam-mass fraction, 0.2, 0.5, and 0.9, and heat-transfer coefficients were included. The conditions selected are applicable to current containment schemes for water-cooled reactors.

1032. Niu, K.

FLOW OF A CONDENSING VAPOUR WITH HEAT EXCHANGE, J. Phys. Soc. Japan, 15, 1108-12 (1960).

An analysis is given for the flow which passes through a pipe of constant cross-sectional area. The solutions obtained here are the extension of Chiarulli-Dressler's (Abstr. 8610 of 1958) and the general features of the phenomena are illustrated by an application to a flow with definite initial conditions. The two figures given by numerical calculations show distinctly the differences of the flow patterns between the supersonic and subsonic cases.

1033. Niu, K.

FLOW OF CONDENSING VAPOUR WITH TEMPORARY SUPERSATURATED STATE DUE TO HEAT REMOVAL EFFECT, J. Phys. Soc. Japan, 16, 798-805 (1961).

The vapour flow in a pipe of constant cross-sectional area with heat-removal effect through the pipe walls has a temporary supersaturated state in the supersonic flow by an effect of surface tension of the droplets which are born in the vapour. In case when the fluid is maintained continually in the supersaturated state, the ratio of the increase in relative humidity to the increase in Mach number or to the decrease in pressure is greater in the flow with heat-removal than in the adiabatic flow. Numerical calculations are carried out for an example of the flow with definite initial conditions and the region where the condensation shock takes place is predicted theoretically.

1034. Nusselt, W.

THE SURFACE CONDENSATION OF STEAM, Z. Ver. Deut. Ing., 60, 541-569 (1916).

1035. Otto, W.

PARTIAL CONDENSATION OF BINARY MIXTURES IN VERTICAL TUBES, Chem. Tech. 14, 228-31 (1962).

In very wide tubes of low height at low vapor velocities the condensate and vapor are in equil. and there is no further mass transfer between the reflux and vapor. A nomograph for this case is developed. An O-N mixt. was partially condensed in a 6-mm. diam., 2-m. long tube. The resistance to mass transfer was greater than predicted from diffusion. No rectification was observed. Increase of vapor velocity caused rupture of the liquid film and favored the start of rectification. CA 62 13570C.

1036. Patenter, A. R.

CONDENSATION OF STEAM, Ger. Patent 957,360, January 31, 1957.

Steam evolved in widely varying amts., e.g. in the discharge of a cellulose digester, is partially condensed in a jet condenser, and finally in a surface condenser. The rate of supply of cooling agent to the jet condenser is increased if the rate of uncondensed steam to the surface condenser exceeds a certain limit, and decreased if the rate of steam to the surface condenser falls below this limit. The rate of supply of cooling agent to the surface condenser is approx. const.

1037. Plesset, M. S.

NOTE ON THE FLOW OF VAPOR BETWEEN LIQUID SURFACES, J. Chem. Phy. 20, 790-793 (1952).

The mass flow of vapor from a liquid surface at temperature T_0 to another surface of the same liquid at temperature $T_1 (T_1 < T_0)$ may be very readily determined in the case of one-dimensional flow from the conservation relations for mass and momentum. These relations involve both the coefficient of evaporation and the coefficient of condensation. It is therefore possible to determine the condensation coefficient which has heretofore not been accessible to measurement. A new method for determining the evaporation coefficient is also made available. The temperature of the vapor between the liquid surfaces may also be found when viscous effects in the vapor flow are neglected.

1038. Portnov, I. G.

THE CALCULATION OF CONDENSATION AND VAPOUR HEAT CONDUCTION WHEN INVESTIGATING THE EXTINCTION OF A SPHERICAL BUBBLE, Vestnik Moskovsk, Univer., Matematika i Mekhanika No. 6, 84-93 (1960).

1039. Pressburg, B. S. and Todd, J. B.

HEAT TRANSFER COEFFICIENT FOR CONDENSATION OF ORGANIC VAPORS, A.I.Ch.E. Journal 3, 348-352 (1957).

The behavior of the film coefficient of heat transfer for the condensation of organic vapor mixtures was investigated experimentally to establish a satisfactory basis for applying the Nusselt equation to binary systems. Five ideal and nonideal pairs, all of which gave miscible condensates, were studied; the work was carried out under conditions of almost total condensation on a horizontal condensing surface designed to comply as rigidly as possible with the conditions for which Nusselt's equation is valid.

The same behavior was observed for all systems and all concentrations studied;the experimental coefficients fell between those for the pure components and followed the behavior pattern for pure components when the temperature difference was taken as that between the bubble point of the condensate and the surface temperature, rather than between the dew point or the measured vapor temperature and the surface temperature. Correlation of the film coeff. showed it to vary approximately linearly with composition if the coeffs. were compared at a constant value of the temp. difference, defined as above.

1040. Reitz, J. G.

ZERO GRAVITY MERCURY CONDENSING RESEARCH, Aero Space Eng., 19, No. 9, 18-23 (1960).

Analyses indicated that Rankine cycle power systems utilizing liquid metal working fluids provide high level power source, (other than propulsion), for space vehicles; mercury condenser apparatus test problems during zero g were explored by setting liquid-vapor interface in view near right end of glass condenser; conclusions from tests are applicable to three areas of space power system technology, feasibility demonstration, ground test validation, and problem identification.

1041. Shirokov, M. F., Vargaftik, N. V., and Lel'chuk, V. L.

EXPERIMENTS ON THE HEAT TRANSFER OF SATURATED STEAM AT VELOCITIES COMPARABLE TO THAT OF SOUND, ZhTF (Journal of Technical Physics, U.S.S.R.) 7, 1935.

1042. Shirokov, M. F.

RATE OF CONDENSATION AND OF HEAT TRANSFER OF SATURATED STEAM AT VELOCITIES COMPARABLE TO THAT OF SOUND, ZhTF (Journal of Technical Physics, U.S.S.R.) 6, (1935).

1043. Shumskii, K. P.

KINETICS OF THE MOTION OF A WATER VAPOR-GAS MIXTURE IN SUBLIMATION CONDENSERS, Vestsi. Akad. Navuk Belarusk. SSR, Ser. Fiz.-Tekh. Navuk No. 3, 5-10 (1958).

The condensation of water vapor to ice on the inner surface of cylindrical tubes and on flat surfaces was investigated at ≤ 4.58 mm. Hg and condensation temps. of - 196° to -20°, both in the absence of noncondensing gases and in the presence of such gases (H, He, Ar, CO_2, CH_4, CF_2- Cl_2). The effect of these gases in a static system (thermal motion of the gas mols. only) was compared with that in a dynamic system (motion of mols. because of the operation of a vacuum pump). The rate of condensation of water to ice increased with increasing partial pressures of the noncondensing admixt. Also, the temp. dropped faster, both along the axis of the cylindrical condenser tubes and along their condensing surface (inner wall) in the presence of noncondensing admixts. than in their absence. This is attributed to the fact that turbulence, which increased the rate of mass transfer, was produced by the motion of the noncondensing gas. Transportation of water-vapor mols. by the gas towards the outlet of the condenser tube is discussed on the basis of x-ray pictures of the condensed layer in the presence and absence of noncondensing gases. Differences between the interaction of noncondensing mols. with an ice surface and a water surface are given. The operation of a sublimation condenser is likened to that of a vacuum pump, the chief function of which is removal of water vapor: the crit. factor is not the rate of transfer of latent heat out of the condenser, but the rate of condensation to ice, which depends on the water vapor-pressure drop. From this standpoint, procedures for the design of high-vacuum sublimation condensers are outlined.

1044. Shumskii, K. P.

A METHOD FOR INVESTIGATING THE PROCESS OF VAPOR CONDENSATION IN THE SOLID STATE IN VACUUM, Vsesoyuz. Nauch.-Issledovatel. i Konstrukt. Inst. Khim. Mashinstroen., Sbornik Statei No. 24, 61-70 (1958).

With the use of a specially designed apparatus shown in detailed diagram the rates of condensation of water vapor to ice were measured in 52 water-air mixts. in which total pressures ranged from 0.3 to 3.3 mm. Hg. and partial pressures of air from 1.1×10^{-4} to 1.16 mm. Hg.

1045. Shumskii, K. P.

THE CONDENSATION OF STEAM INTO SOLID IN A RAREFIED MEDIUM, Zh. tekh, Fiz. (USSR) 31, 991-1000 (1961).

The results of an experimental investigation are reported and discussed on the desublimation of steam on a plane and on the inner surface of a cylinder. The tests were made in three sections: condensation

of the pure vapour without and with gaseous impurities, in an atmosphere of stationary gas, and from a flow of steam-gas mixture respectively. A method has been devised for the design of vacuum sublimation condensers based on the above data [Kholodil'naya Tekhnika, No. 2(1958)]. There are 10 references. [English translation in: Soviet Physics-Technical Physics (USA), Vol. 6, No. 8, 720-6 (Feb., 1962).]

1046. Siegert, A. J.

ON THE THEORY OF CONDENSATION, Phys. Rev. 96, 243-9 (1954).

In an attempt to understand why approximations of the van der Waals type can yield semiquantitative results in spite of being qualitatively wrong, it has been assumed that the partition function for submacroscopic volumes, as a function of the number of particles, is of the van der Waals type. As a model of a real fluid, a cubic array of submacroscopic cells with variable numbers of particles has been considered, and an interaction energy assumed between adjacent cells only. Since the van der Waals equation predicts two sharp peaks in the probability function for the occupation numbers, one has then essentially a three-dimensional Ising model. Using some of the known properties of the Ising model (and some which can be safely anticipated), with plausible assumptions about the interaction energy between cells, this model is found to exhibit condensation, and its condensation pressure, its isotherm in the stable states, and its critical temperature, to be still essentially determined by those of the individual cell.

1047. Sokolova, E.

INVESTIGATION OF HEAT TRANSFER DURING CONDENSATION OF FREON-22, Kholodil. Tekh 34, No. 3, 71-5 (1957).

Dropwise and filmwise condensation of Freon-22 on horizontal smooth and finned Cu and steel tubes are reported. On smooth tubes data are within 10% of values calcd. by Nusselt equation. Finned tubes can be correlated by same equation by using a surface area corrected coeff. based on fin geometry.

1048. Sparrow, E. M.

A THEORY OF ROTATING CONDENSATION, Am. Soc. Mech. Engrs. Trans. Sec. C. J. of Heat Transfer 81, 113-20 (1959).

An analysis is made for film condensation on a rotating disk situated in a large body of pure satd. vapor. The centrifugal field assocd. with the rotation sweeps the condensate outward along the disk surface, and gravity forces need not be involved. The problem is formulated as an exact soln. of the complete Navier-Stokes and energy equations. Numerical solns. are obtained for Prandtl nos. between 0.003 and 100 and a range of values of overall heat balance. Results are given for the heat transfer, as well as for the condensate layer thickness, torque moment, and temp. and velocity profiles.

1049. Sparrow, E. M., and Hartnett, J. P.

CONDENSATION ON A ROTATING CONE, J. Heat Transfer, C83, 101, (1961).

1050. Thomann, H.

INFLUENCE OF CONDENSATION OF WATER VAPOUR IN WIND TUNNELS ON HEAT TRANSFER AND RECOVERY TEMPERATURE, Proceedings of the 1962 Heat Transfer & Fluid Mechanics Institute, held at Univ. of Washington, Seattle, June 1962, Stanford Univ. Press, June 1962.

The influence of condensation in wind tunnels on recovery temperature and heat transfer is studied for the case of a laminar boundary layer that contains ice crystals, water vapour, & air. Two limiting cases are investigated. In one case it is assumed that none of the crystals, formed during the expansion in the nozzle, re-evaporate in the boundary layer. In this case, the increase of recovery temperature amounts to about 2.9°C per gram water per kilogram air. In the other case it is assumed that the ice crystals evaporate so quickly that the vapour concentration equals the equilibrium concentration in every point of the boundary layer in which ice crystals are present. The theoretical results are compared with experiments and it is found that the experiments agree well with the case of equilibrium flow. The experiments show further that the increase in recovery temperature is considerably smaller in the case of a turbulent boundary layer.

Heat transfer coefficients, based on the correct recovery temperatures, are increased by condensation by about 1 per cent or less per gram water per kilogram air.

Physically, these problems are also related to the problems of cooling nuclear reactors with wet steam.

1051. Tobias, M. and Stoppel, A. E.

CONDENSATION OF VAPORS OF WATER AND IMMISCIBLE ORGANIC LIQUIDS, Ind. Eng. Chem. 46, 1450-5 (1954).

The rate of heat transfer in condensation on cooled vertical tubes from mixts. of vapors of water and immiscible org. liquids was studied. Heat-transfer coeffs. calcd. were based on the use of an exptl. tube as a resistance thermometer. A schematic diagram of the app. is shown.

1052. Tsiborovskii, Ya. and Surgevich, Ya.

INVESTIGATION OF THE EFFECT OF CERTAIN FACTORS ON SUBLIMATION CONDENSATION IN THE CASE OF ADIABATIC EXPANSION, Translated from: Theses Reports and Papers at the Conference on Heat and Mass Transfer, Minsk, June 5-9, 1961, NP-tr-827 (p. 74-6).

Observations are reported on the effects of variables on the sublimation-condensation of naphthalene in mixtures with air by adiabatic expansion.

1053. Vanecek, V. and Standart, G.

ENRICHMENT IN PARTIAL CONDENSERS, Chem. Listy 52, 859-63 (1958).

The enrichment of completely miscible binary mixts. and the heat-transfer coeff. for condensation in a countercurrent partial condenser were investigated experimentally. A theoretical enrichment limit has been derived.

1054. Wakeshima, H.

SPONTANEOUS CONDENSATION IN A SUPERSONIC FLOW OF HUMID AIR, J. Phys. Soc. Japan, 10, 141-148 (1955).

The problem of the spontaneous condensation of water vapour in a supersonic flow of moist air is approximately solved on the basis of Becker-Döring's equation for the stationary rate of self-nucleation and on the law of droplet growth. Comparison of the theoretical prediction with experimental results given by Head shows good agreement and thus it is revealed that the major part of the delay in the appearance of condensation, from which some doubt has been cast over the validity of Becker's formula in such cases, can be explained plausibly without the notion of time lag in self-nucleation.

1055. Walther, H.

CONDENSATION OF MERCURY VAPOUR ON COOLED SURFACES, Z. Angew. Phys. 10, No. 6, 272-7 (1958) (In German).

The coefficient of condensation of mercury vapour on cooled nickel surfaces depends upon both their temperature and the duration of their exposure to a jet of mercury vapour. For exposure times of 10 or 15 min a plot of the coefficient of condensation as a function of the target temperature shows a minimum at -95°C, because some of the mercury atoms, which strike mercury crystals already formed on the cooled target, evaporate again before they can find a growth centre.

1056. Wuensch, G.

PARTIAL CONDENSATION OF BINARY AND MULTICOMPONENT MIXTURES, Chem. Tech. 14, 221-7 (1962).

Sepn. by partial condensation in a vertical fractionating column is improved by increased reflux ratio, increased relative volatility, and decreased total pressure. A graphical method is given for solution of a 2-component system. For multicomponent mixts. an approxn. can be obtained by differential or integral methods, either graphically or anal. Methods for calcg. the heat balance and heat transfer area of a vertical fractionating column are given.
CA 62 13570d.

1057. Yellott, J. I.

SUPERSATURATED STEAM, Trans. Am. Soc. Mech. Engrs. 56, 411-430 (1934).

Investigation of supersaturation, or failure of steam to condense when saturated condition is reached in expansion; principal objectives were location of Wilson line, which indicated condition at which condensation actually occurs, and measurement of size of drops which are formed when flowing steam condenses.

1058. Yellott, J. I. and Holland, C. K.

THE CONDENSATION IN FLOWING STEAM, A.S.M.E. Trans. 59, 171-85 (1937).

Apparatus and method for determining point of condensation in De Laval diverging nozzles; discussion restricted to nozzles with very short throats and with angles of divergence greater than 2°; condensation points and signs of steam droplets discussed for various pressure and temperature conditions before expansion for various back pressures.

1059. Zozuyla, M. V.

EFFECT OF THE CONDENSATE VISCOSITY ON THE HEAT EMISSION DURING THE CONDENSATION OF VAPOR, Dopovidi Akad. Nauk Ukr. S.S.R. 272-5 (1958).

A consideration of the relations $\gamma = f(t)$, $\lambda = f(t)$, and $\mu = f(t)$ shows that in the development of equations for detg. the coeff. of heat emission, it is of greatest importance to take into account the variation of viscosity along the film thickness, esp. during condensation of viscous substances. Application of the relation $\mu = f(t)$ permits obtaining a more exact equation for the detn. of α_1, which agrees satisfactorily with exptl. data on the condensation of the vapor of a highly viscous substance, such as glycerol.

1060. Zozulya, M. V.

STUDY METHODS AND PHYSICS OF HEAT EXCHANGE DURING VAPOR CONDENSATION, Sbornik Trudov Inst. Teploenerg., Akad. Nauk Ukr. S.S.R. No. 14, 32-42 (1958).

An app. is described for the study of heat exchange during vapor condensation in vertical tubes at atm. pressure and under a tech. vacuum. At atm. pressure, a mixed condensation occurs. The intensification of heat exchange is detd not only by the no. of drop condensation centers but also by the disturbances of the laminar flow of the condensate film, flowing periodically to these centers. The condensate film shows 2 types of flow; in the upper part of the tube the flow is laminar, but after the film had reached a certain thickness, circular waves appear, the height of which increases gradually. For glycerol flow, sep. stretched waves were observed. The transition from laminar to wave flow occurs at $Re_H = 4qH/(r\gamma v) = 25/35$, where q is the sp. heat load, H the height of the tube, r, γ, and v the latent heat of vaporization, d., and the kinematic viscosity of the liquid, resp. The process of heat exchange through the film is intensified when wave flow develops. The wave length of the flow (which is a transition between laminar and turbulent flow) covers the Re_H range from 30 to 2000-500; the heat exchange coeff., in this range can be detd from the equation: $(\alpha/\lambda)(v^2/g)^{1/3} = 1.05\ Re_H^{-2/9}$ where g is the gravity acceleration, and λ the heat cond. of the liquid.

DROPWISE CONDENSATION

1061. Baer, E. and McKelvey, J. M.

HEAT TRANSFER IN DROPWISE CONDENSATION, American Chemical Society Delaware Science Symposium, University of Delaware, Newark (1958), 24 p.

1062. Blackman, L. C. F., Dewar, M. J. S. and Hampson, H.

AN INVESTIGATION OF COMPOUNDS PROMOTING THE DROPWISE CONDENSATION OF STEAM, Journal of Applied Chemistry 7, 160-71 (1957).

Dropwise condensation(I) was induced by compds. contg. hydrophobic groups for water repellency and a chem. group which has affinity for the metallic condenser surface. Dodecyl and octadecyl hydrocarbon chains comprised the majority of water-repellent groups, and S and Se provided the chem. bonding groups for Cu-bearing condenser surfaces. A special test app. for I was designed. Perfect I was produced for at least 500 hrs. by the following: $KSSCO(CH_2)_{10}OCSSK$, $C_2H_5SSCO(CH_2)_{10}OCSSC_2H_5$, $C_{12}H_{25}SCSSC_{12}H_{25}$, $C_{12}H_{25}SCO(CH_2)_8COSC_{12}H_{25}$, $C_{12}H_{25}SCO(CH_2)_{10}SeCN$, $C_{18}H_{37}SCN$, $C_{18}H_{37}SeCN$, $CH_3CONHCSSC_{18}H_{37}$, $C_{18}H_{37}SCONH_2$, $C_{18}H_{37}SH$, $C_{12}H_{25}S(CH_2)_{10}SC_{12}H_{25}$, $(C_{12}H_{25}S)_2Si$, $(C_{12}H_{25}S)_3P$, $(C_{12}H_{25}S)_4P_2S_3$, $(C_{18}H_{37}O)_2PSSH$, $(C_{18}H_{37}O)_4P_2S_3$, $C_6H_5CH_2SCH_2C_6H_5$, $C_{18}H_{37}OCSSC_2H_5$, $C_{18}H_{37}OCSS(CH_2)_{10}SCSOC_{18}H_{37}$, $(CH_2CHCH_2)[OCO(CH_2)_{10}SCSOC_2H_5]_3$, and $C_{12}H_{25}Si(SC_2H_5)_3$.

1063. Bobco, R. P. and Gosman, A. L.

PROMOTION OF DROPWISE CONDENSATION OF SEVERAL PURE ORGANIC VAPORS, A.S.M.E. Paper No. 57-S-2 (1957), 6 pages.

Results achieved in inducing dropwise condensation of iso-octane, ethanol, carbon disulphide, and several other organic substances through use of various fluorochemicals as promoters; although no heat transfer data are avialable, question of practicability of using these promoters is discussed.

1064. Costas, L. P.

HEAT TRANSFER BY DROPWISE CONDENSATION OF STEAM ON HORIZONTAL TUBES, Ph.D. Thesis, U. of Maryland, 112 pp. (1961).

1065. Drew, T. B., Nagle, W. M., and Smith, W. Q.

THE CONDITIONS FOR DROPWISE CONDENSATION OF STEAM, American Institute of Chemical Engineers, Transactions, 31, 605-21 (1935).

Clean steam, whether or not it contains noncondensable gas, always condenses in a film on clean surfaces, rough or polished. Drop-wise condensation of steam does not occur unless the cooling surface is in some way contaminated. Although numerous substances, while actually on the surface, make it nonwettable, only those that are strongly adsorbed or otherwise firmly held are significant as drop-promoters in a condenser. Some contaminants seem to depend for their activity as promoters on the amt. of noncondensable gas present. Some contaminants are specifically effective on certain metals (e.g., mercaptans on Cu alloys); others are quite generally effective (e.g., fatty acids). Boiler steam at the Mass. Inst. of Tech. naturally contains drop-promoters which are effective on some metals but not on others. Drop-wise condensation is induced and maintained more easily on smooth surfaces than on rough.

1066. Emmons, H.

THE MECHANISM OF DROP CONDENSATION, American Institute of Chemical Engineers, Transactions. 35, 109-25 (1939).

A mol. mechanism of condensation is presented which is based upon the published studies of the behavior of mols. at surfaces. The fundamental difference between film and drop condensation is discussed and explained in terms of intermol. forces and also in terms of quantities measurable in bulk. The proposed mechanism leads to an explanation of the very high heat-transfer coeffs. obtained with drop condensation. All studies of condensation, to date, indicate that for no commercially important vapor do the necessary relations to clean tubes exist to obtain drop condensation. The mechanism of promoter action is presented to explain how the surface properties are modified by the contaminant. A table of the effectiveness of some addnl. compds. as promoters of the drop condensation of steam is included. A necessary consequence of the mechanism of promoter action is that a unimol. layer is responsible for the entire phenomenon. This is verified experimentally.

1067. Fatica, N. and Katz, D. L.

DROPWISE CONDENSATION, Chem. Eng. Progress 45, 661-74 (1949).

The mechanism of dropwise condensation was studied including the measurement of contact angles between the water droplets and the polished surface. A bare surface condenses vapor into a large no. of uniform droplets which cover about 45% of the surface. These droplets grow until a critl. size is reached at which time one drop near the top of an inclined surface will roll over the surface sweeping it bare. The crit. droplet size depends upon the angle of inclination of the surface, the difference between the advancing and the receding contact angles, the surface tension of the liquid, and the d. of the liquid. A formula for predicting dropwise condensation is presented based on the conduction of heat through the droplets and zero resistance between the vapor and the bare surface.

1068. Gelman, L. I.

HEAT TRANSFER DURING DROP CONDENSATION OF MERCURY VAPOR, Teploenergetika 5, 47-50 (March 1958).

Experimental study on condensation of mercury vapor on steel wall; formulas for heat exchange applicable in design of industrial apparatus.

1069. Morgan, P. G.

DROPWISE CONDENSATION, Eng. and Boiler House Rev. 72, 72-4 (1957).

The rates of heat transfer which can be obtained with dropwise condensation are considerably higher than those for corresponding film condensation. For dropwise condensation, the condensing surface must have a thin layer of fluid (promoter) to prevent the condensed vapor from wetting the surface. In the presence of a suitable promoter, the water vapor condenses as drops of various sizes; these grow by further condensation and coalescence until they reach a certain crit. size then the drop rolls down the condensing surface, sweeping a path of bare metal, upon which the water vapor again condenses.

1070. Nagle, W. M. and Drew, T. B.

THE DROPWISE CONDENSATION OF STEAM, Trans. Am. Inst.Chem. Eng. 30, 217-255 (1933).

Investigation undertaken to explain observations made during study of water-side coefficient of heat transfer in falling-film condenser.

1071. Nagle, W. M., et al.

HEAT-TRANSFER COEFFICIENTS DURING DROPWISE CONDENSATION OF STEAM, Trans. Am. Inst. Chem. Engrs., 31, No. 4, 593-604 (1935).

A detailed discussion of expts. which gave steam side coeff. for drop-wise condensation on Cr-plated pipe with temp. differences from 5.2 to 13.9°F. having values between 11,000 and 17,000 Btu/hr./sq. ft./°F.

1072. Osment, B. D., et al.

PROMOTERS FOR THE DROPWISE CONDENSATION OF STEAM, Trans. Inst. Chem. Engrs., 40, 152-60 (1962).

Tests of the useful life of various promoters to give dropwise condensation of steam on Cu alloy surfaces were reported for pure and industrial steam. The promoters used were octadecyl octadecylxanthate (I), decamethylene bis(octadecylxanthate) (II), didodecyl trithiocarbonate (III), octodecyl selenocyanate (IV), dioctadecyl diselenide (V), dioctadecyl disulfide (VI), tetrakis(dodecylthio)silane (VII), dodecyltris(ethylthio)silane (VIII), trioctadecyl phosphorodithioate (IX), Montan wax (X), and filming amines (mainly $C_{18}H_{37}NH_2$) (XI). Compds. I-XI were applied as 1% solns. in CCl_4. A polished brass surface immersed in a soln. of VIII for 15 min. showed crystallites of VIII scattered randomly. It had poor dropwise condensation properties during 15 min. Few crystallites remained after 15 min. and none after a 30-min. exposure to steam. The surface on reapplication of steam gave good dropwise condensation. Tests on large condensers with wet steam at high velocity showed that the promoters failed rapidly. On a small scale, with relatively pure steam, color changes were concurrent with the breakdown. Brass changed from bright yellow to reddish-brown, cupronickel from bright gray to green-grey. With ordinary industrial steam, early failure was accompanied by deposition of fouling matter. CA 62 13581e.

1073. Selin, Gunnar

CONDENSATION OF WATER VAPOR IN DROPLETS, Dechema Monograph 40, Nos. 616-641, 149-54 (1962).

Condensation of H_2O vapor on internally-cooled Cu tubes was observed for several wall, vapor, and condensate temps. Mixed droplet-film condensation was usually noted at about 50° wall and 70-5° condensate temps. for a 28.0-mm. outside diam. tube. At higher wall and condensate temps., droplets were formed; films were formed at lower temps. Heat transfer coeffs. (h_ν) are many times larger for droplet than for film formation. Thus, for a wall at 90.8° and condensate at 94.7°, h_ν was 36,000 and for a wall at 24° and condensate at 49.4°, h_ν was 1830 kcal./sq. m. hr. °C. Calcd. h_ν for film condensation are suspect due to low H_2O vapor exit concns. and condensate cooling. h_ν for droplet formation on a 42.0 mm. tube are much smaller than for the 28.0 mm. tube. h_ν are generally much lower for the larger tube. The effect of tube inclination angle is not clear.

1074. Shea, F. L., and Krase, N. W.

DROPWISE AND FILM CONDENSATION OF STEAM, A. I. Ch. E. Transactions 36, 463-90 (1940).

Steam film coeffs., for dropwise and film condensation, were measured on a vertical plate condenser 23 in. long. The improved method of obtaining plate temps. and heat throughput gave dropwise coeffs. with a max. error of about 20% and an av. deviation less than 2%. The Nusselt equation accurately predicts the change in coeff. with length for film condensation over the range studied. It gives abs. values about 10% low on very short plates and about 25% low when the length is 23 in. CA(1940) - 71706.

1075. Sugawara, S. and Michiyosi, I.

DROPWISE CONDENSATION, Memoirs of Faculty of Engineering, Kyoto University 18, 84-111 (1956).

Factors related to the mechanism of dropwise condensation are the crit. size and shape (contact angle) of a drop, the area covered by droplets on the unit area of condensing surface, and the sweeping cycle, where drops of crit. size sweep down the wall and leave a bare strip. The ratio of the area covered by droplets to the unit surface area is small at the beginning of the adhering period, increases with the lapse of time, and then becomes const. (about 0.5) at the end of the period. The sweeping cycle is reduced as the flow rate of cooling H_2O is increased, and the lower part of the condensing surface is swept more often than the upper. An equation is given for detg. crit. diam. and contact angle, and one is proposed for estg. the heat-transfer coeff. In practical applications, an effective method of inducing dropwise condensation continuously is to pour a drop promoter, e.g., oleic acid, into the steam; thus the promoters on the condensing surface are continuously replenished. This method is expected to prevent erosion of the condensing surface caused by CO_2 or O in the steam. CA(57) 6254d.

1076. Topper, L. and Baer, E.

DROPWISE CONDENSATION OF VAPORS AND HEAT TRANSFER RATES, J. Colloid Sci. 10, 225-6 (1955).

Brass coated with a layer of tetrafluoroethylene polymer 20,000 A. thick and exposed to satd. vapors exhibited dropwise condensation of H_2O, ethylene glycol, $PhNO_2$, and $PhNH_2$, but C_6H_6 condensed as a continuous film.

1077. Watson, R. G. H., Brunt, J. J., and Birt, D. C. P.

DROPWISE CONDENSATION OF STEAM, International Developments in Heat Transfer, Part II. ASME (1961), p. 296-301.

Presents some of the work carried out within the Admiralty to establish conditions for continuous operation of steam plant with dropwise condensation. Part of this work has involved a study of the mechanism of dropwise condensation and its relation to plant design.

1078. Welch, J. F.

MICROSCOPIC STUDY OF DROPWISE CONDENSATION, Ph.D. Thesis, University of Illinois (1961), 146 p.

High speed motion pictures taken through a microscope were used to study the dropwise condensation of steam on three vertical copper surfaces. The condensing areas varied from .44 in^2 to 23.6 in^2. Dropwise condensation was induced by adding .005 - .05 weight per cent cupric oleate to the feed water in the steam boiler. This promoter produced excellent dropwise condensation in a recycle system for at least 10,000 hours. It also induced perfect dropwise condensation of ethylene glycol and glycerol on copper condensing surfaces. Profile photography showed the water droplets to have an average contact angle of 70° on the cupric oleate promoted copper surface.

The surface ΔT varied from 0.4 to 47°F and the corresponding heat fluxes ranged from 5000 to 85,000 Btu/hr ft^2. The steam side heat transfer coefficients in dropwise condensation varied from 2,400 to 25,000 Btu/hr ft^2 °F and were always greater than those obtained during filmwise condensation. Heat balances indicated excellent experimental accuracy and the excellent agreement of the experimental filmwise coefficients with the theoretical coefficients calculated from the Nusselt equation further substantiated the validity of the experimental technique. The vapor velocity and inert gas concentration were accurately known for each run and the heat transfer data were readily reproducible.

Motion pictures were taken through a metallographic microscope at 4000 frames per second giving a magnification of 11.2 diameters on the negative. The motion pictures showed for the first time that when two or more droplets coalesce, a part of the metal surface previously covered by the drops is exposed. Fresh vapor rapidly condenses in a thin layer on these bare areas at a rate determined by the surface ΔT.

The following mechanism of dropwise condensation is proposed. Steam initially condenses on the bare condensing surface in a thin layer which grows to a critical thickness of from 3.9 to 10^{-4} to 6.5 x 10^{-4} mm. where it instantaneously fractures and the liquid rolls into droplets. The droplets grow primarily by collisions with one another. Each collision then exposes a new bare section where this process is repeated. An equation was derived to predict the heat transfer coefficient based on the heat transferred through these bare areas. The equation holds very well for data obtained in this and other investigations where the operating conditions were similar.

1079. Welch, J. F. and Westwater, J. W.

MICROSCOPIC STUDY OF DROPWISE CONDENSATION, International Developments in Heat Transfer, Part II. ASME (1961), p. 302-9.

Dropwise condensation of steam was studied exclusively from the microscopic view point for the first time. High speed motion pictures were taken through a microscope. Three different condensing surfaces were used. The smallest was the vertical face of a copper surface $\frac{1}{4}$ in. in dia. The largest was a vertical rectangle of copper 8 inches high and 3 inches wide. Dropwise condensation was induced by adding 0.005 weight percent cuprice oleate to the feed water in the steam-supply boiler. The useful life of this promoter in a recycle system is at least 10,000 hours. The ΔT varied from 0.4 to 47 F and the heat flux varied from about 5000 to 85,000 Btu per hr sq ft. Heat balances indicated good experimental accuracy. A set of runs in filmwise condensation showed excellent agreement with Nusselt's equation, for the large surface, and thus provided additional evidence of reliable measurements. The motion picture speeds ranged from 250 to 3000 frames per second with magnifications of about 1 to 11X on the negative. It was found that the drops grow mainly by numerous coalescences. Each coalescence results in a vibration of the new drop, sweeping up the nearby liquid film. Condensation takes place mainly on the swept areas, and only slightly on the drops. A film forms on the swept area until a critical thickness of about 0.5 micron is reached at which time the film fractures to form new drops.

1080. Westwater, J. W. and Welch, J. F.

MICROSCOPIC STUDY OF DROPWISE CONDENSATION, Motion Picture, University of Illinois, Urbana (1960).

EFFECT OF NON-CONDENSIBLES

1081. Amelin, A. G.

CORRECTIONS AND ADDITIONS TO FRANK-KAMENETSKY'S ARTICLE "THEORY OF STEAM CONDENSATION IN THE PRESENCE OF NON-CONDENSING GASES," Journal of Technical Physics (USSR) 15, No. 4-5, 287-96 (1945).

1082. Berman, L. D.

HEAT AND MASS TRANSFER IN THE CONDENSATION OF WATER VAPOR IN THE PRESENCE OF NONCONDENSABLE GASES, Ber. warmetech. Inst. 16, No. 8, 11-18 (1947) Chem. Zentr. 1947, II, 779-80.

Even the presence of a slight amount of gas produces essential modification in the conditions of condensation of steam, including a reduction in the coeff. of thermal transmission. In most mixts. the changes in the Reynolds, Grasshoff, and Prandtl nos. are slight. The applicability of the formulas of Langen and Hougen is still not clear. The formula of Colburn is based upon erroneous assumptions.

1083. Berman, L. D.

THE THEORY AND DESIGN OF CONDENSERS FOR VAPOR-NONCONDENSABLE GAS MIXTURES, Izvestiya.Vses. Teplotekn. Inst. (News of All-Union Heat Engineering Institute) 1 (1948).

1084. Berman, L. D., et al.

EFFECT OF AN AIR ADMIXTURE ON HEAT EMISSION DURING CONDENSATION OF MOVING STEAM, Izvestiya. Vses. Teplotekhn. Inst. 21 No. 11, 1-18,November (1952).

1085. Berman, L. D.

EXPERIMENTAL INVESTIGATIONS OF STEAM CONDENSATION IN PRESENCE OF UNCONDENSABLE GASES, Teploenergetika 4, 43-50 (June, 1957).

Relationships for coefficients of heat transfer and mass of steam transfer in condensation of steam from steam gas mixture. 25 refs.

1086. Berman, L. D. and Fuks, S. N.

MASS EXCHANGE IN CONDENSERS WITH HORIZONTAL TUBES WHEN THE STEAM CONTAINS AIR, Teploenergetika 8, 66-74 (1958).

A series of tests was made on the condensation of steam in the presence of air in condensers with horizontal tubes. The equipment and techniques used are described. The pressure of the steam-air mixture was varied from 0.047 to 0.91 atm. The results are given and discussed in detail. It was concluded that the mass transfer coefficient during condensation depends on the air content of the mixture and on the Reynolds and Prandtl numbers. With increasing gas content, the coefficient rises rapidly and approaches infinity as the conditions for condensation of pure steam are approached.

1087. Berman, L. D.

SIMPLIFIED EMPIRICAL RELATIONSHIPS FOR MASS EXCHANGE DURING PROCESS OF STEAM CONDENSATION FROM STEAM GAS MIXTURES, Teploenergetika 7, 74-8 (Aug., 1960).

It is shown that, when determining coefficient of mass exchange during film condensation from mixture containing less than 70-80% inert gas, it is inadmissible to determine partial pressure of steam at surface of liquid by wall temperature.

1088. Cairns, R. C.

THE CONDENSATION OF VAPOR FROM GAS-VAPOR MIXTURES, Chem. Eng. Sci. 2, 127-38 (1953).

Present methods are reviewed for the calcn. of heat transfer in condensation of vapors from gas-vapor mixts. A single-tube condenser is experimentally used to obtain data for the systems $CHCl_3$-air and steam-air.

1089. Dailey, C. E.

CONDENSATION OF VAPORS FROM AIR-VAPOR MIXTURES, Ph.D. Thesis, Carnegie, Inst. of Technology, 191 pp. (July 1954).

1090. Dmytryszyn, M.

CONDENSATION OF A CONDENSABLE VAPOR IN THE PRESENCE OF A NON-CONDENSABLE GAS, Ph.D. Thesis, 94 pp. (1957).

1091. Fastovskii, V. G. and Rovinskii, A. E.

EXPERIMENTAL INVESTIGATION OF THE CONDENSATION OF WATER VAPOR FROM A MIXTURE OF WATER VAPOR AND AIR, Izvestiya. Vses. Teplotekn. Inst. (News of the All-Union Heat Engineering Institute) 4 (1950).

1092. Frank-Kamenetskii, D. A.

THE THEORY OF THE CONDENSATION OF A VAPOR IN THE PRESENCE OF A NONCONDENSABLE GAS, ZTF (Journal of Technical Physics) 12, No. 7, 327-356 (1942).

1094. Hulden, B.

CONDENSATION OF VAPORS FROM GAS VAPOR MIXTURES, AN APPROXIMATE METHOD OF DESIGN, Chem. Eng. Sci. 7, 60-5 (1957).

A hypothetical driving force allows graphical approximation of condenser surface areas by the Colburn-Hougen method.

1095. Komarov, I. A.

HEAT TRANSFER WITH VAPOUR CONDENSATION FROM A VAPOUR GAS MIXTURE, Izv. Vyssh. Ucheb. Zav., Khimiya i Khimich, Tekh. 4, No. 2, 303-309, 1961.

In the title case, the Newton-Fourier equation is unsuitable, and the equation $Q = k' . \Delta i . F$, where Q = total amt. of heat transferred from the vapor-gas mixt. to the cooled liquid in kcal./hr., F = the surface of the dry packing in the scrubber in sq. m., Δi = the mean logarithmic difference of vol. enthalpies in kcal./cu. m., should be used. A new equation for the description of this complex process is given: $k_i' = Re_g^m . S^h_{\Delta i}$, where K_i' = a new heat criterion, Re_g = Reynolds no. for the vapor-gas mixt., and $S^h_{\Delta i}$ a new heat term representing the ratio of the mean logarithmic increase of the enthalpy to the mean logarithmic enthalpy of the vapor-gas mixt. For a sufficient irrigation d. (multijet sprinkler) the Reynolds no. of the cooling liquid does not affect the coeff. of heat and mass transfer. An equation

was detd. exptl. for the detn. of the surface necessary for heat exchange, complicated by the condensation of the vapor from a vapor-gas mixt.: $k_i' = 0.0045\ Re_g^{1.25}.S^{0.25}\Delta i$. This equation can be used for the practical calcns. of simultaneously-occurring industrial processes of heat- and mass transfer during the cooling of H_2O-vapor satd. air by H_2O in a packing scrubber.

1096. Madejski, J.

HEAT TRANSFER IN THE CONDENSATION OF VAPORS IN PRESENCE OF INERT GASES, Chem.-Ing.-Tech. 29, 801-13 (1957).

The basic theoretical principles of unidirectional mass transfer and the development of a similarity theory are given. Exptl. data from the literature are evaluated and an equation is presented for unidirectional diffusion in a tube. A method is proposed for computing condensation of vapor from vapor-gas mixts. A numerical example is shown. 29 references.

1097. Manakin, B. A., Grechanovskii, V. P. and Domentianova, Z. M.

PRECIPITATION OF WATER VAPOR FROM THE AIR WITH SYNTHETIC CONDENSATION NUCLEI, Sbornik Fiz.-Mat. Fak i Nauch.-Issledovatel. Inst. Fiz. Odessk. Univ. 5, 99-107 (1954) Referat. Zhur., Fiz. 1956. Abstr. No. 2758.

The possibility of pptg. water vapor from unsatd. air by means of synthetic condensation nuclei was studied. The expts. were made in a chamber with a vol. of 3 cu. m. for a moisture content of the air 70-79%. It was observed that the introduction of HCl vapors into the chamber followed by the spraying of powd. metals (Zn, Mg, Ca), their oxides, or carbonates into the chamber led to the formation of a fog. The droplets of the fog were solns. of the hygroscopic salts. The drops grew rapidly and fell to the bottom of the chamber within 2-3 min. If nonhygroscopic salts were formed as a result of the chem. reaction, no fog formation was observed. In the case of the sublimation of $ZnCl_2$ or the burning of P, a highly dispersed fog was formed but the droplets did not fall.

1098. Meisenburg, S. J., Boarts, R. M., and Badger, W. L.

THE INFLUENCE OF SMALL CONCENTRATIONS OF AIR IN STEAM ON THE STEAM FILM COEFFICIENT OF HEAT TRANSFER, Trans. Am. Inst. Chem. Engrs., 31, 622-38 (1935).

The effect of air in moving steam condensing as a viscous film on the outside of a vertical Cu tube of 1.00 in. outside diam. by 12 ft. long can be described by a modification of the Nusselt condensation equation,
$h_s = 0.670\ (K^3p^2gr/L\mu\Delta t)^{0.25}\ (1/C)^{0.11}$,
where h_s is the av. true steam film coeff., C is the fraction of air by wt. and all dimensions are consistent. The equation can be used for steam contg. 0.10 to 4.00% by wt. For steam without air diln. the const. of Nusselt's equation was found to be 1.440, which is 53% higher than theoretical. Steam temps. from 248° to 175°F. and temp. differences of 18° to 72°F. were used.

1099. Mikhailovskii, V. N.

DESIGN OF CONDENSERS FOR A VAPOR-NONCONDENSABLE GAS MIXTURE, Khim. prom. (Chemical Industry) 5, 1945.

1100. Mizushina, T., Hashimoto, N. and Nakajima, M.

DESIGN OF COOLER CONDENSERS FOR GAS VAPOR MIXTURES, Chem. Eng. Sci. 9, 195-204 (1959).

The graphical method for design of cooler condensers by Mizushina and Kotoo (Kagaku Kikai 13, 75(1949)) is extended to gas-vapor systems with high vapor concn. The method is applicable whether the mixt. is satd. or superheated. Examples of an air-water and air-benzene system are solved and compared with other methods.

1101. Renker, W.

HEAT TRANSFER IN THE CONDENSATION OF VAPORS WITH NONCONDENSABLE GASES PRESENT, Translated for Goodyear Atomic Corp. from Wiss. Z. tech. Hochschule (Dresden) 4, 1003-19 , GAT-Z-4060 (1954/55).

An investigation was made of the influence of gas content upon heat transfer in the condensation of vapors from vapor gas mixtures. The vapors employed were steam and isobutyl alcohol vapor, and the gases were hydrogen, air, and nitrogen. The measurements indicated that the high coefficients of the heat transfer for pure vapors drop very sharply even when minute quantities of gas are added.

1102. Ryba, M.

DESIGN OF SURFACE CONDENSERS FOR THE CONDENSATION OF STEAM IN THE PRESENCE OF NONCONDENSABLE GAS, Chem. průmysl 10, 296-300 (1960).

Cairns (CA 49, 2788f) found that surfaces calcd. by the Colburn method are 9-95% greater than actual surfaces. R. proposes the following equation of $K_D = 1/(1/k_g.L_A) + (\zeta/\alpha_0)$, for the detn. of the overall transfer coeff. based on partial pressure difference, K_D in which α_0 is the over-all coeff. of heat transfer, and L_A is the heat of evapn. of condensing matter calcd. by a special method for the temp. t_g of the main flow of gas and steam mixt. The mass transfer coeff. in the gas phase, k_g', could be calcd. according to the Chilton-Colburn correlation (cf. CA 29, 18[2]), where the logarithmic av. partial pressure p_{BM} is substituted by the approx. value p'_{BM} for partial pressure extrapolated on the cooling medium temp. (t_w). The quantity ζ is the ratio of the partial pressure difference of the condensing component at temps. t_g and t_w, Δp_A, to the difference of temps. t_g and t_w. The ratio of all heat transferred, as detd. from a heat balance, to the mixed arithmetic av. of product K_D and Δp_A for both ends of the condenser then yields the condenser

surface. By introducing these 3 simplifications, e.g., by neglecting sensible heat, by substitution of k_g for k'_z, and by introducing the quantity ζ, the method gives conservative results. For the condensation of steam from mixt. with air, N, or CO_2, and vapors of $CHCl_3$ or C_6H_6 from mixt. with air, the deviations are 10-30%.

1103. Theile, Heinz

ON THE PREVENTION OF FOGGING IN CONDENSATION OF VAPORS FROM GAS STREAMS, Translated from Erdöl u. Kohle 5, 407-12, AEC-tr-1980 (1952).

The fundamental processes involved in mist formation and demisting have been studied experimentally, using n-hexane or furfural in N_2. Nuclei production by chemical reaction, using allyl bromide; avoidance of supersaturation by matching heat and mass transfer; and demisting by a rotating strip and by superposed heat flow are discussed.

FILM CONDENSATION

1104. Baer, Eric, and McKelvey, J. M.

HEAT TRANSFER IN FILM CONDENSATION, A.I.Ch.E. Journal 4, 218-222 (1958).

A theoretical analysis of heat transfer in film condensation is presented in which the total vapor-side resistance to heat transfer is obtained by adding the resistance to conduction through the condensate film to the resistance due to the condensation process at the vapor-liquid interface. Under ordinary conditions conduction in the condensate film is controlling if the condensation coefficient is greater than 0.10; however, if the total pressure is low, under conditions of low heat flux or low condensation coefficient, the resistance of both processes must be considered.

1105. Cess, R. D.

LAMINAR-FILM CONDENSATION ON A FLAT PLATE IN THE ABSENCE OF A BODY FORCE, Z. Angew. Math. Phys. 11, No. 5, 426-33 (1960).

Laminar flow of a saturated vapour passing over a cooled flat plate was studied for the case of film condensation on the surface. It was assumed that there are no gravitational forces so that the motion of the liquid film resulted solely from the sweeping effect of the adjacent vapour. The shear stress and heat transfer at the plate surface were calculated using numerical integration methods, and results given in two diagrams. SAA (1961) 18446.

1106. Chen, M. M.

AN ANALYTICAL STUDY OF LAMINAR FILM CONDENSATION, PART I FLAT PLATES. PART II SINGLE AND MULTIPLE HORIZONTAL TUBES, ASME. Trans. Section C., J. Heat Trans 83, 55-60 (Feb. 1961).

Flat Plates: boundary layer equations of momentum and energy are written in modified integral form and solved for film condensation along vertical plate; both common liquids and liquid metals are considered. Pt. 2: Single and multiple horizontal tubes; boundary layer equations for laminar film condensation are solved for single horizontal tube, and vertical bank of horizontal tubes; for single tube case.

1107. Chung, P. M.

FILM CONDENSATION WITH AND WITHOUT BODY FORCE IN BOUNDARY LAYER FLOW OF VAPOR OVER A FLAT PLATE, NASA-TN-D-790 (1961) 35 p.

Laminar film condensation on a flat plate under the influence of the gas-liquid interface shear and the body force (g force) has been analyzed. The major governing parameters in the condensation of a pure vapor are the ratio of d. x viscosity of the gas to that of the liquid, $(\rho_v \mu_v / \rho \mu)^{1/2}$, the ratio of the temp. potential to the heat of condensation, $(1/Pr)[c_p(T_0 - T_w)/h^0]$, and the Froude no. $u^2_{v,\infty}/gx$. When the gas phase is a mixt. of a condensable vapor and a noncondensable gas, the gas-phase diffusion potential also becomes an important parameter. The heat transfer, the condensing rate, and the liquid-film thickness were calcd. for the case of a condensing pure vapor. The results show that the condensing rate increases slowly with the d. viscosity ratio, $\rho v \mu v / \rho \mu$, and rapidly with the ratio of temp. potential to heat of condensation $(1/Pr)[c_p(T_0 - T_w)/h^0]$. The Nusselt no. also increases with the d. viscosity ratio, but the rate of increase becomes smaller as the ratio of driving temp. potential to heat of condensation increases. As the condensation proceeds, it creates a suction velocity at the interface for the gas-phase boundary-layer which results in an increased interface shear stress. The increased shear increases the condensation rate by increasing the liquid velocity. The increased condensing rate, in turn, increases the interface shear stress imposed by the gas-phase boundary layer. Because of the complementary interaction between the gas and liquid, the film condensation in a boundary-layer flow occurs at a high rate. The ratio of temp. potential to heat of condensation had a large effect on the magnitude of the body force which can be supported by the liquid film before the characteristics of the film are altered substantially.

1108. Hassan, K.

LAMINAR FILM CONDENSATION OF PURE SATURATED VAPORS AT REST ON NONISOTHERMAL SURFACES, ASME Paper No. 58-A-232 for meeting Nov. 30-Dec. 5 (1958), 29 p.

Nusselt theory of laminar film condensation extended to include condensation on nonisothermal surfaces; cases of condensation on inclined flat plates and cylinders with any known temperature distribution treated analytically; results compared with those calculated assuming surface is isothermal at its integrated mean temperature; condensations on inclined flat plates and horizontal cooled by fluid streams are similarly treated.

1109. Koh, J. C. Y., Sparrow, E. M., and Hartnett, J. P.

THE TWO PHASE BOUNDARY LAYER IN LAMINAR FILM CONDENSATION, Int. J. Heat Mass Transfer 2, 69-82 (1961).

Consideration is given to the two-phase flow problem in laminar film condensation which arises when induced motions of the vapor are included. The shear forces at the liquid-vapor interface, heretofore neglected, have been fully taken into account. It is shown that the problem can be formulated as an exact boundary layer solution. From numerical solutions of the governing equations, it is found that the effects of the interfacial shear on heat transfer are negligible for Prandtl numbers of ten or greater and are quite small even for a Prandtl number of one. For the liquid metal range, the interfacial shear was found to cause substantial reductions in heat transfer.

1110. Labuntsov, D. A.

HEAT TRANSFER FOR FILM CONDENSATION OF PURE VAPOURS ON VERTICAL SURFACES AND HORIZONTAL PIPES, Teploenergetika 4, No. 7 72-80 (1957).

Relationships of improved accuracy are presented for calculating heat transfer on the condensation of vapor films in the zone of laminar and turbulent flow of the condensate. These were obtained from the analysis and development of existing theories concerning the mechanism of the process, and were confirmed by generalizing a large quantity of experimental data.

1111. Mabuchi, Ikuo

HEAT TRANSFER BY FILM CONDENSATION - AN APPROXIMATE THEORY OF LAMINAR FILM CONDENSATION ON A VERTICAL WALL, Trans. Japan Soc. of Mech Engrs, 26, 1134-38 (1960).

1112. Prabhudesai, R. K. and Rytchkov, A. I.

INFLUENCE OF PHYSICOCHEMICAL PROPERTIES OF SUBSTANCES ON HEAT TRANSFER DURING FILM-WISE CONDENSATION OF SINGLE SATURATED VAPORS, Bombay Technologist 8, 46-54 (1957).

A crit. review with 18 references.

1113. Rohsenow, W. M., Webber, J. H. and Ling, A. T.

EFFECT OF VAPOR VELOCITY ON LAMINAR AND TURBULENT-FILM CONDENSATION, Am. Soc. Mech. Engrs. - Trans 78, 1637-43 (1956).

Study relating to heat transfer; effect on rates of condensation of vapor shear stress at liquid-vapor interface; both laminar and turbulent films are considered and are combined to give analytical results for case of laminar flow on upper portion of plate and turbulent flow on lower portion.

1114. Rohsenow, W. M.

HEAT TRANSFER AND TEMPERATURE DISTRIBUTION IN LAMINAR-FILM CONDENSATION, Am. Soc. Mech. Engrs. Trans 78, 1645-8 (1956).

Most of the analyses of laminar-film condensation since Nusselt's pioneer paper have assumed a linear-temperature distribution within the film. Bromley performed an analysis allowing for a nonlinear temperature distribution but omitting the effect of cross flow within the film. His result is in variance with the result obtained here.

1115. Rychkov, A. I.

EFFECT OF PHYSICOCHEMICAL PROPERTIES OF HEAT TRANSFER DURING FILM CONDENSATION OF VAPOR, Trudy Moskov. Inst. Khim. Mashinostroeniya 15, 55-64 (1958).

Empirical relations were sought to improve calcn. of heat-transfer coeffs. in film condensation of pure satd. vapors on horizontal tubes, since the coeffs., αNu, calcd. from the Nusselt equation $\alpha\text{Nu} = 0.72 (r\gamma^2\lambda^3/\mu H\Delta t)^{0.25}$ are not accurate enough. By selecting a best straight line on a logarithmic plot of M, the mol. wt. of the vapor, and α/αNu, where α is the exptl. heat-transfer coeff., the equation $\alpha/\alpha\text{Nu} = 2.24M^{-0.21}$ was obtained. A still better relationship was sought by relating α/αNu to T/E, which should reflect the influence of internal pressure of the liquid (T = condensation temp.; E = ebullioscopic const.). A best straight line resulted in the equation $\alpha/\alpha\text{Nu} = 0.75 + 0.000725$ (T/E). Literature data for H_2O, NH_3, and org. compds. were used in the correlations.

1116. Seban, R. A.

REMARKS ON FILM CONDENSATION WITH TURBULENT FLOW, Transactions of the American Society of Mechanical Engineers 76: 299-303 (1954).

Analogy calculations of Prandtl-Karman type applied to film condensation of pure substance on vertical wall under such conditions that flow in condensate layer is turbulent; results extended to condensates of low Prandtl number, such as molten metals; contribution of turbulence is found to be small until high Reynolds numbers are attained; heat transfer effects.

1117. Sparrow, E. M.

BOUNDARY LAYER TREATMENT OF LAMINAR FILM CONDENSATION, J. Heat Transfer 81, 13-23 (1959).

The problem of laminar-film condensation on a vertical plate is attacked by using the math. techniques of boundary-layer theory. Starting with the boundary-layer (partial differential) equations, a similarity transformation is found which reduces them to ordinary differential equations. Energy-convection and fluid-acceleration terms are

accounted for. Solns. are obtained for values of the parameter $C_p\Delta T/\lambda$, where C_p is the sp. heat at const. pressure, ΔT is the temp. difference between the satd. vapor and the wall, and λ is the latent heat of condensation, between 0 and 2 for Prandtl nos. between 1 and 100. The Prandtl-no. effect, which arises from retention of the acceleration terms, is very small for Prandtl nos. greater than 1.0. Low Prandtl no. (0.003-0.03) heat-transfer results are given, and a greater effect of the acceleration terms is displayed.

1118. Sparrow, E. M. and Siegel, R.

TRANSIENT FILM CONDENSATION, J. of Applied Mechanics, 26, 120-21 (1959).

Analytical solution for transient laminar film condensation on vertical plate obtained using method of characteristics; analysis considers situation where plate temperature, initially same as that of saturated vapor, is suddenly dropped; results obtained for transient heat transfer coefficients.

1119. Yang, S. M.

HEAT TRANSFER THEORY OF FILM CONDENSATION OF SATURATED VAPOR AT REST, Chi Hsien Kung Ch'eng Hsüeh Pao 5 No. 1, 41-53 (1957) (English Summary).

The limitation of Nusselt's formula is discussed. Math. treatment of heat transfer of film-type condensation of satd. vapor at rest led to Kruzhilin's formula; introduction of a correction factor η gave the same result as Nusselt's equation. $\eta = 1/\{[1/(1 - (5/8K))] + 2/3(1/PrK)\ [1/(1 - (5/8K))]^2\}^{1/4}$, where Pr = the Prandtl no., and K = enthalpy ratio. For $Pr > 1$ and $K > 5$, as in the case of condensation of steam under ordinary conditions, η is very close to 1. For $Pr < 1$ or $K < 5$, as in the case of condensation of metals, however, the correction factor is significant.

1120. Yang, S. M.

FILM CONDENSATION HEAT TRANSFER FROM QUIESCENT SATURATED VAPOR, INCLUDING LOW PRANDTL NUMBER VALUES, I., II. Chiao Tung Ta Hsueh Hsueh Pao, No. 1, 17-32, No. 2 13-15 (1958).

Boundary layer theory was applied to treat the heat transfer problem of film condensation from quiescent satd. vapor. Film condensation heat transfer involves 4 factors, Nu or Re, Ga, Pr, and K. K is the ratio of the thermal cond. of the liquid film to the thermal cond. of the liquid-vapor interface. When steam is quiescent and the condensing liquid film is in laminar flow, the velocity distribution of the condensing liquid film is parabolic and its temp. distribution is linear. The basic differential equations of film condensation heat transfer were transformed to integral equations of motion and heat. When $Pr > 1$ and $K > 5$, e.g., vapor condenses under normal pressure, the theoretical result is the same as Nusselt's equation. But when $Pr < 1$ and $K < 5$, e.g., condensation of metal vapors, the correction factor in Nusselt's equation cannot be neglected. Correction factors for Nusselt's equation are given for various Pr and K values. II. Ibid. No. 2, 15-13. - The theory was extended to the turbulent flow region. Theoretical analysis and exptl. results agree as for the laminar flow region of Nusselt's equation. The following equation may be adopted for calcg. Re, $Re = 0.025\ (Ga^{1/3}/PrK)^{1.41}$.

ON THE INSIDE OF HORIZONTAL & VERTICAL SURFACES

1121. Akers, W. W., Deans, H. A., and Crosser, O. K.

CONDENSING HEAT TRANSFER WITHIN HORIZONTAL TUBES, Chemical Engineering Progress 54, No. 10, 89 (1958).

Studied the effect of vapor velocity, liquid loading, and physical properties of the fluid on the condensing coefficient of a vapor inside a horizontal tube.

1122. Akers, W. W. and Rosson, H. F.

CONDENSATION INSIDE A HORIZONTAL TUBE, Chem. Engr. Progress Symposium Series 56, No. 30, 145-149 (1960).

Heat transfer data were taken for methanol and Freon-12 condensing inside a horizontal tube over considerable ranges of pressure, temperature driving force, liquid loading, and vapor velocity. For condensation in a horizontal tube three primary regions of flow are postulated: semistratified flow (annular condensation and run down superimposed on stratified flow), laminar annular flow, and turbulent annular flow. A semitheoretical equation is developed and shown to be applicable to both semistratified and laminar annular flow. Other equations must be used for turbulent annular flow.

1123. Altman, M., Staub, F. W. and Norris, R. H.

LOCAL HEAT TRANSFER AND PRESSURE DROP FOR REFRIGERANT-22 CONDENSING IN HORIZONTAL TUBES, Chemical Engineering Progress Symposium Series 56, No. 30, 151-159 (1960).

Local heat transfer coefficients and pressure drop were determined for refrigerant-22 condensing in an 8-ft. long, 0.343-in. I. D. horizontal tube. The method of Carpenter and Colburn was used to correlate the data, and an empirical correction factor was derived that enabled the data in the desuperheating region also to be correlated by this simplified method. The analyses of Seban and Rohsenow were modified to include the effect of high vapor shear in horizontal tubes. This theoretical approach is well supported by the experimental data when the method of Martinelli-Nelson is employed to compute the shear stress at the tube wall.

1124. Ananiev, E. P., Boyko L. D. and Kruzhilin, G. N.

HEAT TRANSFER IN THE PRESENCE OF STEAM CONDENSATION IN A HORIZONTAL TUBE, International Developments in Heat Transfer, Part II. ASME (1961), p. 290-5.

Deals with an application of the analogy between heat transfer and hydraulic resistance according to Reynolds pertinent to the condensation of vapor in a tube. From this point of view the local values of the heat transfer coefficient in the analyzed case are determined by $h'' = h\sqrt{(p/p_m)}$ while the mean values are given by: $h = h/2\ (1 + \sqrt{p/p_v})$. The results of computations using these formulas agree satisfactorily with experiment.

1125. Carpenter, F. G.

HEAT TRANSFER & PRESSURE DROP FOR CONDENSING PURE VAPORS INSIDE VERTICAL TUBES AT HIGH VAPOR VELOCITIES, University of Delaware, Ph.D. Thesis (1948), 90 p.

The effect of high vapor velocities on the heat transfer coefficients for pure vapors condensing on the inside of a long vertical tube are measured. A general correlation of the effect of vapor velocity on heat transfer coefficients is developed.

1126. Carpenter, F. G. and Colburn, A.

EFFECT OF VAPOUR VELOCITY ON CONDENSATION INSIDE TUBES, General Discussion on Heat Transfer - London Conference, Sept. 11 to 13, 1951. Instn Mech Engrs., London and Am Soc Mech Engrs., New York, 1951, 217 p.

1127. Cohn, P. D.

HEAT TRANSFER COEFFICIENTS FOR CONDENSATION OF LIQUID METAL VAPORS INSIDE A VERTICAL TUBE, M. S. Thesis, Oregon State College (1960).

Includes a study of mercury, mercury with 0.3% sodium, mercury with 1.0% sodium, and cadmium. Water was used to determine if the apparatus operated correctly.

1128. Cronauer, D. C.

CONDENSATION OF MIXED VAPOR IN A VERTICAL TUBE, Ph.D. Thesis, Carnegie Inst. of Tech. 141 pp. (1961).

1129. Crosser, O. K.

CONDENSATION HEAT TRANSFER INSIDE HORIZONTAL TUBES, Ph.D. Thesis, Rice Inst., 93 pp. (May 1955).

1130. Dunn, R. J., and Stuhbarg, H.

THE PRESSURE DROP OF CONDENSING STEAM IN HORIZONTAL PIPES, A. S. M. E. Paper, 58-TH-2 (1958).

New equation presented for computing pressure drop and experimental data supporting it; table gives observed pressure drop vs. calculated value; pipe could be in form of tank coil of heat exchanger.

1131. Gorodinskaya, S. A.

GENERALIZATION OF EXPERIMENTAL RESULTS FOR HEAT TRANSFER DURING THE CONDENSATION OF VAPORS INSIDE OF HORIZONTAL PIPES, Izvest. Kiev. Politekh. Inst. 18, 362-72 (1955); Referat. Zhur., Khim. 1956. Abstr. No. 56921.

The exptl. results of various authors for the condensation of NH_3, water, benzene, and toluene vapors in horizontal pipes are generalized with respect to the dimensional correlation proposed by Kichigin (Trudy Kiev. Politekh. Inst. 8 (1939)). The exptl. results cover the range of heat fluxes from 2000 to 125,000 kcal./sq. in. hr., of pressures from 1 to 14 atm., and values of L/D from 48 to 225. It was found that all results are satisfactorily correlated by the equation: $Nu = C\ Re^{0.5}\ \Pi_\sigma^{0.3}\ \Pi_\gamma^{0.3}\ (L/D)^{0.35}$, where $\Pi_\sigma = \sigma/(\gamma D^2)$; $\Pi_\gamma = \gamma/\gamma''$; σ is the surface tension of the condensate; γ,γ'' are the ds. of the liquid and of the vapor. The coeff. C has the following values: for the condensation of NH_3 and H_2O vapors, 1.26, and for the condensation of benzene and toluene, 0.89.

1132. Hartmann, H.

HEAT TRANSFER IN CONDENSATION OF SATURATED VAPORS FLOWING IN VERTICAL TUBES, Chem. - Ingr.-Tech 33, 343-8 (1961).

A theoretical discussion of a generalized case of parallel flow of vapor and condensate.

1133. Konsetov, V. V.

HEAT TRANSFER RATES FOR THE CONDENSATION OF STEAM IN HORIZONTAL PIPES, Inzhener.-Fiz. Zhur., Akad. Nauk Belorus, S.S.R. 3 No. 6, 9-16 (1960).

An approx. soln. is presented for the detn. of the heat-transfer coeff. for the condensation of a pure satd. vapor flowing inside horizontal and slightly inclined tubes. The calcd. results are compared with published exptl. data.

1134. Mizushina, T., et. al.

HEAT AND MASS TRANSFER IN A SINGLE-TUBE COOLER CONDENSER, Chem. Eng. (Japan) 17, 152-4 (1953).

The coeffs. of heat transfer, h, and that of mass transfer, k', were measured in a vertical single-tube condenser, where the mixts. of air and water vapor and such org. vapors as toluene, EtOH, and MeOH were cooled and condensed. In turbulent region the data were correlated by the following dimensionless and similar equations: $(Sh) = 0.0235(Re)^{0.8}\text{-}(Sc)^{1/2}$ and $(Nu) = 0.0235(Re)^{0.8}\ (Pr)^{1/2}$. These relations and the value of h/k' derived from them were identical with the results of their previous papers (C.A. 45, 5465c; 46, 10697e, 10703a).

1135. Van Es, J. P., and Heertjes, P. M.

CONDENSATION OF A VAPOR OF A BINARY MIXTURE IN A VERTICAL TUBE, Chem. Eng. Sci. 5, 217-25 (1956).

The condensation of a binary mixt. on the wall of a vertical tube is treated theoretically. The considerations of this treatment were examd. experimentally. The vertical tube was 88 mm. in diam. and 1080 mm. long. Its wall was cooled with circulating oil. The condensate formed, its compn., and mass flow through the tube were measured.

ON THE OUTSIDE OF HORIZONTAL AND VERTICAL TUBES

1136. Amelin, A. G.

FORMATION OF SUPERSATURATED STEAM DURING CONDENSATION ON A SURFACE, J. Tech. Phys. (U.S.S.R.) 16, 1409-26 (1946) (In Russian).

An expression was developed for calcn. of the pressure of the steam which is condensing in the gaseous film and of the pressure of the steam in the main stream of the gaseous mixt. during condensation. An equation was proposed for calcn. of the max. degree of supersatn. of steam during condensation on a surface. Methods were worked out for calcn. of the pressure of steam and its degree of supersatn. on condensation of steam in a tower which is being sprayed with liquid. The use of a nozzle in a tube being cooled from the outside considerably reduced the degree of supersatn. An equation was developed for the condensation process of steam in a tube with a nozzle. Equations were developed for the process of condensation of steam in a tube having at its center a supplementary heating element.

1137. Baker, E. M., Kazmark, E. W., and Stroebe, G. W.

STEAM FILM HEAT TRANSFER COEFFICIENTS FOR VERTICAL TUBES, Ind. Eng. Chem. 31, 214-222 (1939).

Steam film coefficients for a 2-inch o.d., 20-foot long vertical tube are correlated by means of the coordinates, $h_s(\mu^2/k^3\rho^2 g)^{1/3}$ and $k\Delta t_s/\mu\lambda$. Other data for tubes 8 feet and 12 feet long are also correlated on the same basis and found to deviate from those for the 20-foot tube by a factor of $L^{1/2}$. No apparent break in the curve, indicating viscous and turbulent flow, could be observed, though it is believed that turbulence must occur over at least part of the tube. Therefore, turbulence in the steam condensate film apparently does not control the rate of heat transfer, within the range of these experiments.

1138. Baker, E. M. and Tsao, U.

CONDENSATION OF VAPORS ON A HORIZONTAL TUBE, Industrial and Engineering Chemistry 32, 1115 (1940).

Coefficients of heat transfer from vapor to a horizontal tube were determined for the condensation of mixed vapors of water and nonmiscible organic liquids. This work is an extension of the research previously published by Baker and Mueller. In the present work a much wider range of vapor compositions was studied for systems of water vapor mixed with vapors of benzene, toluene, chlorobenzene, trichloroethylene, or tetrachloroethylene. The data were correlated into the following relatively simple equations:

$$\frac{h_t}{1 - \frac{0.0167}{D}} = \frac{500}{1 - 0.0085\ v/o\ H_2O} + 80$$

$$h_t = \frac{366\sqrt[4]{\frac{1}{D}}\left(1 - \frac{0.0284}{D}\right)}{1 - 0.0085\ v/o\ H_2O} + \frac{1.67}{D}$$

Where D = outside diameter of tube, ft.

h_t = coefficient of heat transfer, based upon ΔTcalculated from saturation temp. of mixed vapor, Btu/(hr.)(°F.)(sq. ft.)

The value of h_t given by either of these equations is independent of ΔT.

1139. Furman, T., and Hampson, H.

AN EXPERIMENTAL INVESTIGATION INTO THE EFFECTS OF CROSS-FLOW WITH CONDENSATION OF STEAM AND STEAM-GAS MIXTURES ON A VERTICAL TUBE, Proceedings of the Institution of Mechanical Engineers, 173, no. 5, 147-69 (1959).

As part of a programme of comparison of filmwise and dropwise condensation of steam, it was required to know the effect of a cross flow of steam, with some non-condensable gas present, over the condenser tube. A 'steam tunnel' was developed in order to produce the required steam velocity with a limited steam supply at atmospheric pressure. Details of the apparatus are given together with the results of tests on a vertical tube.

1140. Gudemchuk, V. A.

HEAT TRANSFER WITH VAPOR CONDENSATION ON AN INCLINED TUBE, Izvestiya Vses. Teplotekn Inst. (News of All-Union Heat Engineering Institute) 12 (1935).

1141. Gudemchuk, V. A.

HEAT EXCHANGE WITH VAPOR CONDENSATION ON A VERTICAL TUBE, Izvestiya Vses. Teplotekn. Inst. (News of All-Union Heat Engineering Institute) 6, (1946).

1142. Hassan K. E., and Jakob, M.

LAMINAR FILM CONDENSATION OF PURE SATURATED VAPORS ON INCLINED CIRCULAR CYLINDERS, Trans. Am. Soc. Mech. Engrs. 80, 887-94 (1958).

Laminar film condensation of pure satd. vapors on inclined circular cylinders is treated analytically under the same assumptions as Nusselt's theory of film condensation. Expts. were performed to check the analytical results. The problem is expressed in terms of dimensionless groups and the solution gives, in these terms, the local film thickness at any point on the surface of a cylinder. The local film coeff. can be obtained from the results of

the analysis, and hence a mean film coeff. for the entire surface of any cylinder at any inclination. Every tube has an optimum inclination at which the rate of condensation on the entire tube is a max. The expts. were made by condensing steam on the inside surface of a thick Cu tube $1\frac{1}{4}$ in. in diam. and about $8\frac{1}{8}$ in. long. The actual film coeffs. obtained during the expts. were 28-100% higher than those predicted by the theoretical analysis. The deviation from theory increased with the inclination of the tube and the temp. difference between the tube surface and the steam.

1143. Kirkbride, C. G.

HEAT TRANSFER BY CONDENSING VAPOR ON VERTICAL TUBES, Industrial and Engineering Chemistry 26, 425-28 (1934).

Data are presented on liquid films flowing down vertical walls. Films thicknesses for isothermal flow are measured and correlated with the dimensionless groups $2m^3,\rho^2g/C^2$, and $4C/\mu$. Data available in the literature on heat transfer by condensing vapor on vertical surfaces were correlated by the coordinates $h_m(\mu^2/k^3\rho^2g)^{1/3}$ and $(W/\mu D)_b$ which are suggested by the Nusselt equation for viscous flow of condensate films. While the data of certain investigators appear to check with the Nusselt theoretical equation for values of $4C/\mu$ less than 2,500, above this value the data in the literature on condensation indicate that it is probably no longer valid but instead gives results that are too low.

1144. Kirschbaum, Emil and Wetjen, K. A.

HEAT TRANSFER IN FILM TYPE CONDENSATION OF AIR CONTAINING STEAM PASSING OVER A VERTICAL PIPE, Chem. Ing. Tech 25, 565-8 (1953).

A summary of expts. in condensing air-steam mixts. on a vertical Cu pipe 30/38 mm. diam. and heated length of 1455 mm. Equations are presented for calcg. the heat-transfer coeffs. for various ranges of vapor velocities as a function of the mean air content of the entering and leaving mixts. Steam losses occur as the air leaving the condenser is satd. Data are summarized in graphs.

1145. Labuntsov, D. A.

HEAT TRANSFER DURING CONDENSATION OF STEAM ON A VERTICAL SURFACE FOR TURBULENT FLOW CONDITIONS OF THE CONDENSATE FILM, Inzhener.-Fiz. Zhur., Akad. Nauk Belorus. S.S.R. 3, No. 8, 3-12 (1960).

The theoretical solution given previously (Teploenergetika 4, 72 (1957))being incomplete, a new solution is presented. Two different approaches were used, based on the semiempirical treatments of turbulence proposed by Schlinger, et al. and Lin. The following relations were derived (1) $(\alpha/\lambda)(\nu^2/g)^{1/3} = 0.023\sqrt[4]{RePr^2}$ and (2) $Re = [253 + 0.069\ Pr^{1/2}\ (Z-2300)]^{4/3}$, where Z is a criterion characterizing the relative extent of the condensation surface. The values calcd. by means of (1) and (2), the relations for the crit. values $Re_{cr} = 1600$ and $Z_{cr} = 2300$, and the relation $Re = 3.8Z^{0.78}$, for $Z<2300$ (laminar region) are in excellent agreement with the available exptl. data, which confirms the validity of the proposed solution. Finally, a nomogram is given for the detn. of the heat transfer coeff. for the condensation of water vapor on a vertical surface.

1146. Levin, B. I.

HEAT TRANSFER BY CONDENSATION OF SATURATED STEAM ON VERTICAL TUBE BUNDLES, Teploenergetika 7, No. 5, 73-5 (1960).

Exptl. results indicate that the coeffs. of heat transfer (α) calcd. by Nusselt's formula are too low. More realistic values of α (in kcal./sq.m.hr.°) are $0.95Z_f^{0.78}r\gamma_f\nu_f/L\Delta t$ for laminar flow and $0.25r\gamma_f\nu_f[253 + 0.069(p_f/p_{St})^{0.25} \times P_f^{0.5}(Z_f - 2300)]^{4/3}/L\Delta t$ for turbulent flow of the condensate. The crit. values of Reynolds no. and Z_f differentiating between laminar and turbulent flow are 1600 and 2300. resp. $Z_f = (g/\nu_f)^{1/3}L\lambda_f\Delta t/r\gamma_f\nu_f$; L is the effective length of the condenser tubes, r the latent heat of evapn., γ_f, ν_f, and λ_t are d., kinematic viscosity, and thermal cond. of the condensate, resp.

1147. Peck, R. E., and Reddie, W. A.

HEAT TRANSFER COEFFICIENTS FOR VAPORS CONDENSING ON HORIZONTAL TUBES, Ind. Eng. Chem. 43, 2926-31 (1951).

Theoretical modifications of Nusselt equations show little effect of nonuniform temp. around the tube. Consideration of acceleration effects in condensate led to a semiempirical relation which was obtained from new data on 6 org. vapors and literature data from 16 investigators.

1148. Popov, V. D.

HEAT TRANSFER DURING VAPOR CONDENSATION ON A HORIZONTAL SURFACE, Trudy KTIPP im A. I. Mikoyana, No. 11 (1951).

1149. Selin, G.

HEAT TRANSFER BY CONDENSING PURE VAPOURS OUTSIDE INCLINED TUBES, International Developments in Heat Transfer, Part II. ASME (1961) p. 279-289.

Presents an experimental investigation on the influence of tube angle on heat transfer by condensing pure saturated vapours outside inclined tubes. Vapours of three alcohols (methanol, 2-propanol and 1-butanol) have been condensed outside copper tubes, 2m in length and with three different diameters, 3/4, 1, and $1\frac{1}{2}$ inches.

1150. Slepyan, E. E.

INVESTIGATION OF HEAT TRANSFER IN CONDENSING STEAM ON HORIZONTAL, SMOOTH, FINNED TUBES, Khodol, Tekhn (Refrigeration Technology) 1 (1952).

Condensation of Freon-12 on horizontal and on three types of finned tubes was studied at 20-50°. Math. relationships are derived for the heat transfer.

1151. White, R. E.

CONDENSATION OF REFRIGERANT VAPORS - APPARATUS AND FILM COEFFICIENTS FOR FREON-12, American Society of Mechanical Engineers 70, 689-93 (1948).

Description of apparatus for direct determination of condensing vapor heat transfer film coefficients in which precision measuring methods are employed; data on condensation of saturated Freon-12 under ideal conditions on plain horizontal tube. EI (47) 991.

EVAPORATION

1152. Abbott, M. D., et al

HEAT TRANSFER COEFFICIENTS FOR A HORIZONTAL TUBE EVAPORATOR, MS Thesis, M.I.T. (1938).

1153. Aganesova, L. N.

PRESENT DAY EQUIPMENT FOR EVAPORATION OF HEAT SENSITIVE LIQUIDS, Trudy, Tsentral. Nauch.-Issledovatel. Inst. Spirt. i Likero-Vodoch. Prom., No. 11, 285-93 (1961).

Descriptions are given of various types of evaporators found on present day markets, or used in the industry of the U.S.S.R. The majority are of the vertical type with liquid films either carried upwards by formation of steam, or distributed by revolving rotor-plates, or flowing down circular pipes through slots formed by the insertion of pipes of smaller diam. which carry away the vapors. Horizontal types include one with a revolving rotor. A plate-type evaporator is also described. All evaporators described can function under pressure or vacuum.

1154. Akin, G. A.

HEAT TRANSFER TO SUBMERGED EVAPORATORS, Thesis, M.I.T. (1942).

1155. Albertson, M. L.

ON THE APPLICATION OF THE REYNOLDS ANALOGY TO EVAPORATION, C. R. Acad. (Paris) Sci. 239, (6) 474-6 (1954).

1156. Armstrong, C., Bell, N. R., and Murray, H. D.

EVAPORATORS FOR THE FINE CHEMICAL INDUSTRY, Mfg. Chemist. 28, 263-8 (1957).

The authors discuss the basic aspects of the problem of heat transfer to boiling liquids, and the recent developments in the design of evaporators for fine chemicals, in which low temps. are involved without any noticeable loss in quality. Suggestions for calcg. the heat transfer rates are given. 14 refs. (CA-13481-a)

1157. Ashley, C. M.

HEAT TRANSFER OF EVAPORATING FREON-12, Refrigeration Engineering 43, 89-95 (Feb. 1942).

Results of test carried out by Carrier Corp. in order to determine proper values of heat transfer coefficient of Freon-12; flowing in horizontal copper tube of 0.575 in. ID; load, flash gas, suction temperature and excess liquid were varied; values found vary widely from accepted values; tables for coefficient in relation to load are given; tested refrigerant was substantially oil free.

1158. Badger, W. L.

HOW LONG-TUBE EVAPORATOR WORKS, Chem. and Met. Engrg., 46 640 (1939).

Practical correlation and interpretation from performance viewpoint of recent researches on underlying theory of this evaporator shows probable mechanism of what happens in its operation.

1159. Bauer, E. and Zlotnick, M.

EVAPORATION INTO A BOUNDARY LAYER, Phys. of Fluids, 1, No. 4, 355-6 (1958).

The evaporation rate of a solid or liquid into a stream of gas flowing across its surface is considered as a function of surface temperature and of material and gas properties, neglecting chemical reactions. One of the boundary conditions to be used at the interface between the gas and the solid (or liquid) is derived.

1160. Bennewitz, K.

THE PROCESS OF VAPORIZATION, Ann. Physik. 59, 193-224 (1919).

The rates of vaporization into a vacuum of Cd and Hg are detd. and found to have values varying, with exptl. conditions, up to the value of the rate of absorption of vapor, and therefore of evapn. into a satd. space. The correct value of the ratio of rates into a vacuum and into a satd. space is therefore taken to be 1, that is, there is no reflection of the impinging gas mols. II. A mathematical theory of evapn. is derived, where one new underlying assumption is that the effective vol. of the mol. is the solid projection of its path in space, with the mol. treated as a point. This results in an interesting series of speculations. (CA-14-878)

1161. Berman, L. D.

EVAPORATIVE COOLING OF RECIRCULATED WATER, Gosenergoizdat (State Power Engineering Publishing House) 1949.

1162. Berman, L. D.

THE RATE OF EVAPORATION OF DROPS OF WATER, Zhur. Tekh. Fiz. 23, 1886-9 (1953).

A discussion with references.

1163. Berman, L. D.

EFFECT OF THERMAL RESISTANCE OF A LIQUID IN SOME CASES OF EVAPORATION OF A LIQUID AND CONDENSATION OF A VAPOUR FROM VAPOUR-GAS MIXTURES IN FILM APPARATUS, Zh. tekh. Fiz., 24, 1022-34 (1954) In Russian.

It has been claimed by McAdams (Chemical Engineering Progress, 45, No. 4, 241 (1949)) that it is not justified to assume that, when heat and mass transfer occurs between liquids and saturated vapours at low rates of heat flux, the effect exerted by the thermal resistance of the liquid on the rate of evaporation or of condensation can be neglected. This paper contains a critique of the bases on which McAdams drew this conclusion, which is shown to be unfounded, from an analysis of the author's own, and other published work on the subject. The exact nature of the effect cannot be deduced from McAdams' own experiments, and requires further study.

1164. Borishanskii, V. M. and Kutateladze, S. S.

DATA ON THE EVAPORATION OF LIQUID FROM A SPHEROIDAL STATE, J. of Tech. Physics (USSR) 18 No. 8 (1947).

1165. Bosnjakovic, F.

VERDAMPFUNG AND FLUSSIGKEITSUBERHITZUNG, Tech. Mech. u. Thermodynam. 1, 358 (1930).

1166. Bressler, Reinhard

HEAT TRANSFER IN A THIN-FILM VAPORIZER, Forschungsber. Landes Nordrhein-Westfalen No. 770 (1960), 50 p.

The flow of H_2O on vertical, heated plates with and without vaporization is described and illustrated. The plates were completely wetted when cold, but under even moderate heating dry areas were observed. When the temp. was high enough for bubble formation, the film coeff. approached the value for nucleate boiling. Tests with H_2O are reported for a Sambay thin-film vaporizer (Schneider, CA 49, 10678b) 50 mm in diam. with both rigid and hinged, rotating wiper blades. The ranges of the variables were 0-2600 r.p.m., 6-30 kg/hr flow rate, and 125-200° surface temp. The amt. vaporized increased with increasing feed rate and reached a max. when 50-75% of the feed was vaporized.

1167. Cessna, O. C. and Badger, W. L.

MAXIMUM LIQUID TEMPERATURE IN LONG-TUBE VERTICAL EVAPORATOR, Am. Inst. Chem. Engrs.-Trans. 37 No. 2 and 5, Apr. 25, 311-31 and Oct. 25, 725-6 (1941).

Data derived from study of performance using $\frac{3}{4}$ in. tube, 18 ft 6 in. long, presented; equations resulting from correlation of data from investigations in which water and 30%, 40% and 50% sucrose solutions were fed to $\frac{3}{4}$ in., $1\frac{1}{4}$ in. and 2 in. tubes at various rates and evaporated at 150 and 200 F boiling points, given. Bibliography.

1168. Clark, R. L. and Bromley, L. A.

SALINE WATER CONVERSION BY MULTIPLE-EFFECT ROTATING EVAPORATOR, Chem. Engng. Progr. 57, 64-70 (Jan. 1961).

Predict steam economy and production rates of rotary evaporators by linearized solution methods. Preliminary tests prove validity of performance predictions.

1169. Coulson, J. M. and Mehta, R. R.

HEAT TRANSFER COEFFICIENTS IN A CLIMBING FILM EVAPORATOR, Trans. Inst. Chem. Engrs. (London) 31, 208-28 (1953).

Results are presented for evapg. H_2O aq. sucrose solns., and iso-PrOH by using a $5\frac{1}{4}$ ft. long and $\frac{1}{2}$ in. outside diam. stainless steel tube with hot H_2O in the annulus as the heating medium. The liquid, at its b.p., was fed to the bottom of the tube, and the temps. within the tube were read with a thermocouple probe. The overall heat-transfer coeffs. are based on the temp. difference between the av. temp. of the heating H_2O and the av. temp. of the boiling liquid. The film coeffs. are detd. with an adaptation of Wilson's graphical method. The coeffs. are influenced by the temp. difference and feed rate, and by the viscosity of the liquid. A comparison of the results with those obtained in submerged boiling shows that the climbing film unit is efficient when the temp. difference are small.

1170. Daskin, Walter

EVAPORATION FROM SPRAYS, Purdue Univ. Eng. Bull., Research Bull. No. 128, 329-41 (1955).

The evapn. history of a spray is treated theoretically in terms of the statistical description of the spray at its inception and the fundamental evapn. data of individual droplets. Methods of calcg. the initial drop size of the equiv. uniform spray are given.

1171. de Haas van Dorsser, A. H., Leniger, H. A. and van Meel, D. A.

THE INFLUENCE OF THE DEGREE OF AIR TURBULENCE ON THE RATE OF EVAPORATION FROM A FREE WATER SURFACE INTO AN AIR STREAM, Ingenieur(Utrecht) 61, No. 40, Ch 25-30 (1949).

In a small wind tunnel a piece of blotting paper kept wet was subjected to air velocities of 3-20 m/sec and turbulence degrees of 1.7; 2.0; 3.5; 7.0, and 13%. The max. increase in evapn. was at a turbulence degree of 5% and amounting to 50%.

1172. Dieter, Karl

PERFORMANCE AND PARTIAL-TRANSFER DATA OF FILM EVAPORATORS, Dechema Monograph 32, 160-82 (1959).

Heat-transfer measurements were conducted on the evapn. of liquids and solns. and on the sepn. of binary mixts. through partial evapn. in a Sambay-type film evaporator having a 100-mm-wide evapg. tube of 970 mm heated length. The liquid flow was found to be laminar. The thickness of the evapg. layer was a function of the wiper adjustments of the app. and the compn. of the liquid only. If the heated surface was completely wetted, the evapn. did not affect the heat transfer. Formation of foam in the course of the evapn. (as in the case of azeotropic EtOH or sugar solns.) improved the heat transfer. Owing to the fact that material transfer in the liquid proceeds practically without resistance, the equations covering the distn. of a binary mixt. such as EtOH-H_2O are also applicable to the partial film evapn. of the mixt. A major portion of the flow energy of the vapors will be released at the liquid precipitators. The pressure loss in the vapor is a function of the amt. of vapor and of vapor d. only. The energy requirements of the sweeping rotator depended on the r.p.m. of the rotator only (180-380 w. for 150-600 r.p.m. in the app. used).

1173. Dlouhy, J. and Gauvin, W. H.

EVAPORATION RATES IN SPRAY DRYING, Can. J. Chem. Eng. 38, 113-20 (1960).

Heat- and mass-transfer coeffs. during evapn. of water sprays produced by pneumatic atomizing nozzles in a vertical, concurrent spray dryer were essentially the same as for single, stationary droplets evapg. in still air for droplet diams. from 11.5 to 38.5μ.

1174. Doll-Steinberg, A.

THE PERFORMANCE OF A CLIMBING FILM EVAPORATOR, Brit. Chem. Eng. 3, 536-9 (1958).

An experimentally based analysis of the heat-transfer behavior of the climbing film evaporator shows that

at least 3 correlations are required to describe quantitatively its heat-transfer performance over a wide range of values of temp. driving force. There are 4 regions; 1 and 2 are the gradual increase of the bubble population in the body of the liquid; 3 is the region of linear fall-off; while 4 is the region of const. value.

1175. Duffield, W. G.

THE REACTION CONSEQUENT UPON THE EVAPORATION OF A LIQUID AND UPON THE EMISSION OF VAPORS FROM SMALL ORIFICES, Phil. Mag. 45, 641-88 (1923).

Expts. with the elec. arc showed that the poles behave as though a mech. pressure were acting to force them apart. The most likely explanation appeared to be the evapn. of C atoms from the hot poles. To det. whether the evapn. of ordinary liquid is accompanied by such a pressure, the present expts. were undertaken. The results show that when a liquid is made to boil or evap. rapidly on one arm of a balance into air, no such counter pressure as predicted is to be observed; but when the evapn. takes place into a vacuum a large counter pressure is observed; of about the calcd. magnitude. An explanation of the observation in air is sought in an interference process between the vapor mols. issuing from the liquid and the opposing air mols. A theory is advanced that the vapor mols. upwardly directed stop an equal no. of air mols. coming in the opposite direction and prevent their exerting a pressure upon the liquid which is just equal to that which the vapor mols. exerted on leaving the surface and hence there is no unbalanced pressure produced, as in vacuo. Direct evidence of such an interference was found by a torsion method of discharging a rapid stream of vapor through variable-sized small orifices into water. The phenomena of boiling and evapn. are also dealt with. In boiling far more mols. are projected into the vapor phase through interchange at the bubble wall than by actual bursting of bubbles. (CA-17-2070-7)

1176. Dukhin, S. S. and Deryagin, B. V.

THEORY OF THE LARGE DISTANCE INTERACTION BETWEEN EVAPORATING OR GROWING DROPS, Dokl. Akad. Nauk SSSR, 112, 407-11 (1957) (In Russian).

In a previous paper (Deryagin and Dukhin, Dokl. Akad. Nauk SSSR, Vol. 106, No. 5, 851, 1956) the authors evaluated the forces of attraction or repulsion, acting between the fog droplets or between a drop and a continuous liquid surface and affecting considerably the motion of the drops in relation to the medium. In the first approximation, however, the forces of diffusion were found to be compensated by the effect of Stefan's flux. In the present paper the authors introduce the factor of heat transfer which, as a rule, disturbs this compensation; the diffusion forces are shown to be able to influence substantially the precipitation and coagulation of the aerosols.

1177. Feder, A.

CHART PREDICTS EVAPORATION RATES, Chem. Eng. 66, No. 19, 159-60, 162 (1959).

Four-quadrant nomograph facilitates finding evaporation rate for any fluid in moving air streams; applicable to design of jet engine, spray dryer, cooling towers; based on empirical data and assumption of average droplet diameter of 45μ, four sections of chart determine fraction of liquid evaporated under equilibrium conditions as function of liquid boiling point, air velocity, pressure and temperature.

1178. Fedoseev, V. A. and Polishchuk, D. I.

EVAPORATION OF DROPS OF COMBUSTIBLE LIQUIDS, Zh. Tekh, Fiz., 26, 1509-1518 (1956), In Russian. English Translation in: Soviet Physics-Technical Physics, 1, 1470-1478, (1957).

Evaporating liquid drops are observed under the microscope and the rate of change of their diameter is converted to the rate of vaporization. Experiments are made with drops of benzene, toluene, xylene and alcohol surrounded by an atmosphere of air which is flowing at a steady rate or is at rest; in the latter case some vapor of the vaporizing substance is admixed to the atmosphere. Results corresponding to various temperatures, rates of flow and concentrations of vapor are shown in the form of graphs and tables.

1179. Fledderman, R. G. and Hurwicz, H.

ANALYSIS OF TRANSIENT ABLATION AND HEAT CONDUCTION PHENOMENA AT A VAPORIZING SURFACE, Chem. Eng. Prog. Symp. Series No. 32, 57, 24-34 (1961).

An exact analysis of heat and mass transfer in an ablating three-phase system (reduced to vapor-liquid) is made. Account is also taken of internal heat radiation and of the results of steady-state ablation theory. An approximate method based on effective heat of ablation and constant surface temperature is also developed.

1180. Foust, A. S., et al.

LIQUID VELOCITY AND COEFFICIENTS OF HEAT TRANSFER IN A NATURAL CIRCULATION EVAPORATOR, Ind. Eng. Chem. 31, 206 (1939).

Experimental data for basket type evaporator of semi-commercial size when evaporating water; results submitted in form of equations which relate each of these quantities with three important operating variables investigated, either directly or through fundamental variables dependent on them.

1181. Fritz, W. and Ende, W.

THE VAPORIZATION PROCESS ACCORDING TO CINEMATOGRAPHIC PICTURES OF VAPOR BUBBLES, Physik. Z. 37, 391-401 (1936).

Previous studies (Jakob and Fritz, CA 26, 1679) are extended by means of a camera taking 600 pictures per sec. The vol. of the bubbles leaving the surface agrees with the max. vol. calcd. by the theory of capillary forces. The following were also detd.: Increase of bubble from the moment of its formation,

its velocity of rise in water, the no. of bubbles formed in a given spot per sec. The heat transfer by the bubbles was calcd.

1182. Haidlen, E.

SULFUR DIOXIDE EVAPORATION. EBULLITION LAG AND BUBBLE FORMATION, Ice and Cold Storage 41, No. 485, 136 (1938).

The superheat of a liquid in ebullition, according to the temp. of the vapor given off, depends on the wt. of the vapor passing through the surface. The superheat increases until it reaches its highest value in the case of ebullition lag, this value itself being dependent on the evapn. temp. In the case of vaporization with the formation of bubbles, the superheat decreases with the increase in the rate of evapn. Measurements of temp. at different depths show that superheat remains const. at distances below 5 mm under the evapn. surface and progressively decreases from here to the surface until it becomes a temp. jump between liquid and vapor. For SO_2 and probably for other refrigerants evapn. with ebullition lag and evapn. with formation of bubbles are not clearly delimitated. Between 45 and 60 kg/sq m hr both kinds of evapn. are possible. The greater the amt. evapd. the easier it is to disturb evapn. with a lag in ebullition and convert it into evapn. with the formation of bubbles. (CA-33-6091-1)

1183. Hardy, J. K.

EVAPORATION OF DROPS OF LIQUID, PB-110923 (1947), 9 p.

Includes heat transference theory, and effect of atmospheric pressure on evaporation rate.

1184. Haüssler, W.

TEMPERATURE PROFILES ON EACH SIDE OF AN EVAPORATING WATER SURFACE, Technik (Berlin) 12, 3-6 (1957).

In considering the simultaneous heat and mass transfer occurring in cooling by the adiabatic humidification of air, it is concluded that the data of Merkel and those of this work agree with Lewis' rule which states that the quotient of the heat transfer coeff. divided by the mass transfer coeff. in this process is equal to the product of the specific heat and a dimensional const. The measurements upon which these conclusions were based were obtained with a specially designed resistance thermometer.

1185. Heckel, V. K. and King, E. C.

TESTS OF A FILLING PROCEDURE FOR THIRD FLUID SYSTEM OF COMBUSTION ENGINEERING EVAPORATOR, NP 6087 (1956), 13 p.

During preparation for installing the Combustion Engineering evaporator, it was discovered that the third fluid passages of many of the tubes were restricted to such an extent that it was questionable that they could be completely filled with NaK. Tests were devised to determine a method of filling the third fluid passages and determine the voids remaining after filling. The relative degree of restriction and volume of each of the 10 third fluid passages were successfully filled and the tests indicate that it should be possible to fill the evaporator by this method even though some of the third fluid passages are partially plugged. (NSA-10-10135)

1186. Hedlin, C. P. and Hooper, F. C.

INFLUENCE OF PRESENCE OF VAPOR DIFFUSION FROM WETTED NON-ADIABATIC BOUNDARY UPON SENSIBLE HEAT TRANSFER BETWEEN BOUNDARY WALL AND GAS STREAM, Can. J. Chem. Eng. 37, n 6, 208-211 (1959).

Experimental equipment was devised to measure sensible heat transfer coefficients at inside surface of porous ceramic tube from which water was being evaporated; results indicate sensible heat transfer coefficients did not depart significantly from those predicted by generally accepted relationships for dry wall case.

1187. Heertjes, P. M. and Ringens, W.

THE j_H (HEAT TRANSFER) AND THE j_D (MASS TRANSFER) FACTOR FOR AIR DRYING, Chem. Eng. Sci. 5, 226-31 (1956).

For C_6H_6, CCl_4, EtOH, and H_2O during evapn. at const. rate in a current of air j_H was substantially equal to j_D. The moist body was suspended from a balance arm and fed liquid via a microburet. Amt. of liquid evapd. was weighed as a function of time.

1188. Heitmann, G. and Knacke, O.

VELOCITY OF EVAPORATION OF LIQUID POTASSIUM AMALGAM, Z. Physik. Chem. 7, 225-35 (1956).

By aid of the Knudsen dropping method the evaporation coefficient of Hg in liquid K amalgam at room temperature was determined; it is $\alpha = 1$. It is shown theoretically that this result can be generalized, the evaporation coefficient being approximately 1 for the evaporation of most mixed phases. The connection between diffusion and phase transition is discussed theoretically by aid of the heat conductivity equation.

1189. Hickman, K. C. D. and Trevoy, D. J.

STUDIES IN HIGH VACUUM EVAPORATION. THE FALLING-STREAM TENSIMETER, Ind. Eng. Chem. 44, 1882-8 (1952).

A falling-stream mol. still is described for detg. evapn. coeffs. from pristine liquid surfaces. Evapn. occurs from a falling column of liquid and condensation occurs on the inner surface of an air-cooled glass jacket. Distn. rates were detd. for Et hexyl phthalate (I) and Et hexyl sebacate (II) and a mixt. of 29.4 mole % of I and II. I and II do evap. with a coeff. of unity from clean, new surfaces. Relative volatilities of the mixt. increase greatly with reduction of temp. and distn. rate. (CA-47-6707a)

1190. Hoffman, T. W. and Gauvin, W. H.

EVAPORATION OF STATIONARY DROPLETS IN HIGH-TEMPERATURE SURROUNDINGS, Can. J. Chem. Engr. 38, 129-37 (1960).

The evapn. rate of stationary droplets in high-temp surroundings does not appear to be governed by the rate of heat transfer by natural convection. The

evapn. rates appear to be predicted by the expression $[(dm/d\theta)(Cp)/(\pi Dk_f)](Pr)^{-1/3} = 3.2\ B^{0.97}$ over a range $0.03 < B < 1.0$, where m = mass, g.; θ = time, sec.; Cp = heat capacity of gas, cal/g-degree; D = droplet diam., cm; k_f = thermal cond. of gas at av. film temp., cal/sec-cm-degree; Pr = Prandtl no.; and B = transfer no.

1191. Hoffman, T. W. and Gauvin, W. H.

ANALYSIS OF SPRAY EVAPORATION IN A HIGH-TEMPERATURE ENVIRONMENT, Can. J. Chem. Engr. 39, 179-88 (1961).

The difficulties inherent in the calcn. of the absorption of thermal radiation by clouds of particles suspended in an absorbing gas medium are discussed. Approxns. are made to permit the calcn. of the absorption strength of spray from operating conditions and the properties of the atomized liquid.

1192. Hoffman, T. W. and Gauvin, W. H.

ANALYSIS OF THE RADIANT HEAT ABSORPTION IN THE BOUNDARY LAYER SURROUNDING AN EVAPORATING DROP, Can. J. Chem. Eng. 39, 252-9 (1961).

An analysis based on a spherically sym. boundary layer model and neglecting any convection effects is presented for an evapg. drop in high temp. surroundings. At atm. pressure, the absorption of radiant energy in the boundary layer is very small and hence does not affect the temp. gradient or the rate of heat transfer at the droplet surface.

1193. Hoffman, T. W. and Gauvin, W. H.

ANALYSIS OF SPRAY EVAPORATION IN A HIGH-TEMPERATURE ENVIRONMENT. II. CALCULATION OF THE EVAPORATIVE LOAD DISTRIBUTION, Can. J. Chem. Eng., 40, 110-18 (1962).

The calcn. of the evaporative load distribution in a spray of droplets suspended in an absorbing gas medium contained in a cylindrical column after a temp. profile for the gas has been assumed, takes into account the phys. characteristics of the spray, such as initial drop-size and distribution, drop velocities, and spray angle. (CA-62-14906h)

1194. Hofmann, E.

HEAT TRANSFER COEFFICIENTS OF EVAPORATING REFRIGERANTS, Kaeltetechnik, 9, Heft 1, 7-12 (1957).

1195. Holland, L.

USE OF CARBON CRUCIBLES IN MEASUREMENTS OF THE RATE OF EVAPORATION OF LIQUID METALS IN VACUUM, Brit. J. Appl. Phys. 5, 411-12 (1954).

Bubble formation in liquid metals is discussed and it is concluded that bubbles can form only when heat is supplied at a very rapid rate; this gives rise to uneven temp. Possible surface disruption from expansion of absorbed gases is mentioned, as is the possibility of bubble formation at the surface of a liquid that is covered by an oxide. Reply. J. Yarwood (Polytech., London). Ibid. - Bubble formation in liquid metals is discussed, and it is concluded that bubble formation is likely at small depths at a uniform temp.

1196. Ingebo, R. D.

PRESSURE EFFECTS ON VAPORIZATION RATE OF DROPS IN GAS STREAMS, Natl. Advisory Comm. Aeronaut. Tech. Notes, No. 2850, 1-36 (1953).

The rate of evapn. of 4 liquids into an air stream at pressures varying from 450 to 1500 mm Hg was detd. by noting the loss of wt. of porous spheres. For the case of isolated drops and low-approach stream turbulence, the following expression was derived: the vaporization rate, $dm/d\theta = (k_g \Delta t/H_v)\ 2\pi d\ [1 + 1.29 \times 10^6\ (ReScgl/\bar{c}^2)^{0.6}(k_g/k_v)^{0.5}]$, where k_g and k_v are thermal conds. of gas and vapor, resp., d is drop diam., Re and Sc are Reynolds' and Schmidt nos., resp., g is acceleration due to gravity, l the gas mean free path, $\bar{c}$ root-mean-square velocity of the gas mol., H_v latent heat of vaporization, and Δt the temp. difference between gas temp. and surface temp. of drop. The investigation indicated that pressure does not directly affect heat-transfer coeff., but the vaporization rate, in its effect on droplet surface temp. It was also established that the relative humidity of the air stream had little effect on vaporization rate; rate of vaporization of octane was not changed as air relative humidity varied from 16% to 48%. Other tests were made with CCl_4, C_6H_6, CH_3COCH_3 evapg. into air and CH_3OH into He, A, and CO_2. (NACA-TN-2850)

1197. Ingebo, R. D.

VAPORIZATION RATES AND DRAG COEFFICIENTS FOR ISOOCTANE SPRAYS IN TURBULENT AIR STREAMS, (1954) 39 p.

Includes heat-transfer theory. (NACA-TN-3265) 55) (PB-115513)

1198. Isachenko, V. P., Vzorov, V. V., and Vertogradskii, V. A.

HEAT TRANSFER BY EVAPORATION OF WATER FROM A POROUS WALL WITH AN AIR CURRENT, Teploenergetika 8, No. 1, 65-72 (1961).

Heat transfer, by evaporation of H_2O from a porous wall with an air current, was studied in a specially constructed app. The velocity and temp. of the air were varied between 9 and 115 m/sec and 12 and 140°. The Reynolds no. varied between 131×10^3 and 165×10^3. The heat transfer depended on the heat and mass transfer and was proportional to the 0.8 power of the Reynolds no. Equations are given for estg. the heat transfer with turbulent flow.

1199. Ismailov, M. I.

THE THEORY OF CONVECTION HEAT TRANSFER IN THE CASE OF EVAPORATION, Theses Reports and Papers at the Conference on Heat and Mass Transfer. Minsk, NP-tr-827 (p. 62-4) June 5-9 (1961) (Translation).

Evaporating particles lead to the appearance of turbulent motion in the boundary layer of the fluid flow at Reynolds' numbers substantially below the critical. The effect of evaporation on the mixing length is discussed. Precise solutions are derived for heat

transfer and fluid flow under these conditions. Comparison of the theoretical results with experimental data shows good agreement.

1200. Jakob, M. and Fritz, W.

EVAPORATION HEAT OF WATER AND SPECIFIC VOLUME OF SATURATED STEAM IN RANGE TO 310 CENTIGRADES (100.7 at.), Wissenschaftliche Abhandlungen der Physikalisch-Technischen Reichsanstalt 14, No. 1, 175-90 (1930).

Bases for experiments and their utilization; auxiliary and principal experiments, test results and their comparison with English and American values.

1201. Jakob, M. and Fritz, W.

INVESTIGATION OF THE PROCESS OF VAPORIZATION, Wissenschaftliche Abhandlungen der Physikalisch-Technischen Reichsanstalt 15, No. 2, 269-81 (1932).

Experimental investigation of evaporation process of water over horizontal heating surface by direct observation of evaporation, measurement of temperature difference between liquid and steam and by determination of heat transfer from heating surface to boiling water.

1202. Jakob, M.

PROCESS OF EVAPORATION, Chemische Apparatur 19, No. 11/12, 109-11 (1932).

Review of recent investigations; results of evaporation tests of Jacob and W. Fritz and comparison with results of tests obtained by Heidrich; remarkable agreement in mechanism of heat transmission was found in spite of entirely different method of steam generation.

1203. Jakob, M. and Linke, W.

HEAT TRANSMISSION IN THE EVAPORATION OF LIQUIDS AT VERTICAL AND HORIZONTAL SURFACES, Physik. Z. 36, 267-80 (1935).

Results of experiments on heat transfer of boiling liquid, such as water, carbon tetrachloride, etc.

1204. Jakob, M.

HEAT TRANSFER IN EVAPORATION AND CONDENSATION I, Mech. Eng., 58, 643-660, 729-39, correction p. 845 (1936).

Paper comprises six lectures delivered in United States in April 1936, based chiefly on contents of several papers published during last decade by authors and his former co-workers; first three lectures devoted to evaporation and last three to condensation.

1205. Jakob, M.

THE INFLUENCE OF PRESSURE ON HEAT TRANSFER IN EVAPORATION, Proceedings of the Fifth International Congress Applied Mechanics, 1938, p. 561. Reprinted in Techn. Bull. Armour Inst. Tech., Vol. 2, No. 1 (1939).

1206. Jakob, M.

LOCAL TEMPERATURE DIFFERENCES AS OCCURRING IN EVAPORATION, CONDENSATION AND CATALYTIC REACTION, Temperature, Its Measurement and Control in Science and Industry, pp. 834, Reinhold, New York, Vol. 1, 1941.

1207. Jarman, R. T.

THE EVAPORATION OF SPRAYS, Brit. J. Appl. Phys., 9, No. 4, 153-4 (1958).

The rate of evaporation of an aircraft spray of kerosene droplets in the atmosphere was measured, and found to approximate to the theoretical estimates.

1208. Jarvis, N. L. and Kagarise, R. E.

DETERMINATION OF THE SURFACE TEMPERATURE OF WATER DURING EVAPORATION STUDIES. A COMPARISON OF THERMISTOR WITH INFRARED RADIOMETER MEASUREMENTS, J. Colloid Sci. (USA), vol. 17, No. 6, 501-11 (Aug. 1962).

In this investigation the temperature of a water surface was measured by two techniques, one utilizing a commercial infrared radiometer and the other, thermistor probes. Both methods were shown to be satisfactory for following changes in surface temperature during evaporation studies; however, the radiometer used was less sensitive to changes in temperature than the thermistors, being limited to changes in temperature of 0.1 deg C or greater. The radiometer does have the advantage of measuring the temperature of a much thinner layer of water than the thermistor, 0.1 mm as compared to 2 or 3 mm. It also responds more rapidly to changes in water temperature than the thermistor and can be operated at some distance from the water surface. It was shown that the presence of a monomolecular film will not significantly alter the emissivity of a water surface, within the limit of sensitivity of the radiometer. Any change in apparent temperature detected by the radiometer when a monolayer is spread at the interface must, therefore, be due to changes in the real temperature of the water surface. Such changes could result from the monolayer's influence on the rate of evaporation or on movement of surface water.

1209. Johnson, J. C.

MEASUREMENT OF SURFACE TEMPERATURE OF EVAPORATING WATER DROPS, J. Applied Physics 21, n. 1, 22-23 (1950).

Results of temperature determinations made that have been found to be in agreement with requirements of theory enunciated by N. Fuchs which state that temperature is determined by difference between ambient and saturated vapor density of drop; pertinence to meteorology and study of liquids.

1210. Kazanskii, V. M.

THE DETERMINATION OF HEAT OF EVAPORATION OF MOISTURE CONTAINED IN A POROUS BODY, Inzhen.-fiz. Zh. (USSR), 4, No. 8, 36-42 (1961).

A recording electrocalorimeter is described and instructions given for its application in the determination of heat of evaporation of moisture from a porous

body for various moisture contents. Experiments on the drying of silica gel show that heat of evaporation of moisture absorbed by a porous body, for all moisture contents is larger than the heat of phase transition of free water into vapour.

1211. Kichigin, M. A.

METHODOLOGY OF THE DETERMINATION OF THE COEFFICIENTS OF HEAT TRANSFERENCE OF EVAPORATORS, Sakhar 17, No. 2, 19-24 (1939); Chem. Zentr. 1939, II, 4292.

Formulas are given for calcg. the coeffs. of heat transference from the walls to the boiling liquid, from the vapor to the walls, etc.

1212. Kimura, H.

IMPROVEMENT OF HEAT TRANSFER IN EVAPORATORS, Japan 2421, 1959, April 14 (Patent).

Ultrasonic waves of 200-500 kc are applied to prevent scaling, bumping, and foaming at the heating surface of evaporators. (CA-985f)

1213. King, P. J.

EVAPORATION, Chem. Process. Eng. 43, 69-73 (1962).

A review with 30 references.

1214. Kirschbaum, Emil and Dieter, Karl

HEAT TRANSFER AND PARTIAL DISTILLATION IN THIN-FILM EVAPORATORS, Chem. Ing. Tech. 30, 715-20 (1958).

Heat-transfer data and distn. performance of binary mixts. are reported for a Sambay thin-film evaporator (cf. Schneider, CA 49, 10678b). The evaporator tube had an inside diam. of 10 cm and a height of 97 cm. Liquid loading and rotation of internal wipers were varied over the capacity range of the unit. The data for evapn. of H_2O,95% EtOH, toluene, and a 10% sugar soln., and for partial distn. of EtOH-H_2O mixts. are presented in graphical form.

1215. Kirschbaum, E.

EVAPORATION IN A VERTICAL TUBE WITH AUTOMATIC RECYCLING, Dechema Monograph 40, Nos. 616-641, 121-47 (1962).

Vertical, glass and steel evaporator tubes (2-4 m height, 33 or 37 mm diam.) were used to evap. H_2O and aq. sugar solns. Wall and liquid temps. and pressures were detd. at several tube heights. The origin and subsequent disappearance of vapor bubbles in the lower part of the tubes is shown by a series of photographs. The wall temp. is $>$ the b.p. and the liquid temp. is $<$ the b.p. in this zone. Up to 80% of the total heat transfer occurs in the lower zone.

1216. Knacke, O. and Stranski, I. N.

THE MECHANISM OF EVAPORATION, Progress in Metal Physics 6, 181-235 (1956).

A review. Discusses experimental methods for determining the condensation coefficient, using either evaporation into a high vacuum, at higher pressures or condensation. The theory of evaporation is discussed, including consideration of statistical calculations, the mechanism of step-wise evaporation and application of transition-state theory. 100 references.

1217. Knudsen, M.

THE MAXIMUM SPEED OF VAPORIZATION OF MERCURY, Ann. Physik 47, 697-708 (1915).

The author first obtains a formula for the velocity of evaporation, assuming that the molecules which leave the surface of the liquid do not return again to it. The formula is $G = 43.75 \times 10^{-6} \sqrt{(Mp/\theta)}$ where M is the molecular weight, θ the temperature, and p the vapour pressure in dynes/cm^2. The calculated value for mercury is 7.81 mgm., the observed value is 7.48 mgm.

1218. Knuth, E. L.

EVAPORATION FROM LIQUID WALL FILMS INTO A TURBULENT GAS STREAM. Heat Transfer and Fluid Mechanics Institute. Univ. of Southern Calif. Los Angeles, 1953. Stanford Univ. Press, Stanford, Calif., 1953. p. 173-192.

Although thin (several thousandths of an inch thick) liquid wall films in the presence of high-velocity (several hundred feet per second) turbulent gas streams occur frequently in engineering, e.g., in condensing, evaporating, and film-cooling processes, relatively little basic knowledge is available concerning this type of flow. Hence an investigation was undertaken for the purpose of obtaining (a) design data for the attachment of a thin liquid film to a solid wall in the presence of a high-velocity gas stream (particularly applicable to film cooling), (b) a criterion for the inception of instability for a liquid wall film, and (c) a means for predicting the mass-transfer rate from a film surface for given flow parameters and fluid properties. Theoretical analyses were made of the film stability and of the mass-transfer problems. The analysis of the first problem (based on the assumption that turbulence in the gas stream produces small disturbances in the film surface) indicated that the inception of unstable long-wavelength disturbances depends on the relation of the equivalent sand roughness of the film surface to the thickness of the laminar sublayer of the gas stream. In the mass-transport analysis, the heat transport into the liquid film was first calculated and then equated to the heat required to evaporate the material which leaves the liquid surface. Experimental data were obtained for the optimum injection velocity for a radial-hole injector (which injector appears to be satisfactory for the attachment of a liquid film in many film-cooling applications) and were correlated in a dimensionless plot. Sufficient conditions for the stability of a liquid wall film were experimentally found to be a function of the Reynolds number of the liquid film and the ratio of the viscosity of the gas-vapor mixture to that of the liquid, where the viscosities were evaluated at the liquid-film surface temperature. Still further experiments substantiated the theory advanced for the mass-transfer rates. The design procedure for a film-cooling application is included.

1219. Konstas, A. S.

EVAPORATION BY TRICKLING OVER HEATED HORIZONTAL TUBES, Genie Chim. 79, 179-85, (1958).

K. shows good agreement between exptl. and calcd. values of heat-transfer coeffs. for a liquid flowing under viscous flow conditions over the hot outside surface of horizontal tubes when evapn. occurs without boiling or formation of bubbles. Two types of com. evaporators are described, 1 for concg. grape sirup and the other for evapg. benzene-acetone solvent in an installation for paraffin removal from lubricating oils.

1220. Kramers, H., Capelle, A. E. F. van, and Schraaf, E. V. van der

HEAT TRANSFER IN FILM EVAPORATOR. Ingenieur 67, No. 8, Ch. 9-15 (1955). See also English abstract in Engrs' Digest 16, No. 4, 159-62 (1955).

Various types, their advantages and disadvantages described; experimental results presented on rate of evaporation of various liquids in Mueller evaporator.

1221. Kucherov, R. Ya. and Rikenglaz, L. E.

ON HYDRODYNAMIC BOUNDARY CONDITIONS FOR EVAPORATION AND CONDENSATION, J. Exptl. Theoret. Phys. (USSR) 37, 125-6 (1959), English Transl. in: Soviet Phys. JETP 37 (10), 88-9 (1960).

The boundary conditions have been found for hydrodynamic equations in the presence of evaporation and condensation. For small evaporation rates the temperature jump and the deviation of the vapor pressure from the equilibrium value are shown to be of the order of the ratio between the speed of the vapor flow v and the mean speed of heat transfer c. It is shown that the expressions commonly used in the literature for the flow of materials and heat in the presence of evaporation and condensation contain an error.

1222. Langstroth, G. O., Diehl, C. H. H., and Winhold, E. J.

THE EVAPORATION OF DROPLETS IN STILL AIR, Can. J. Research 28A, 580-95 (1950).

The evapn. of droplets of 1 to 2 mm in diam. into still air was studied with the following 9 liquids forming a series of graded volatility: toluene, PrOH, glacial AcOH, ethylbenzene, o-chlorotoluene, AmOH, aniline, water, and BuOH. The exptl. results agreed with calcns. based on diffusion and heat-transfer theory, The surface temp. of the more volatile drops was found to be significantly lower than the bulk temp.

1223. Leniger, H. A. and Veldstra, J.

HEAT TRANSFER IN A THIN-FILM EVAPORATOR, Chem. Ing. Tech. 31, 493-7 (1959).

Expts. are reported for evapn. of water in a Luwa film evaporator. The variation of the heat transfer coeff. was detd. as a function of boiling temp., temp. difference between vapor and b. temp., liquid flow rate, and r.p.m. of the rotor.

1224. Lienerth, A.

DETERMINATION OF HEAT TRANSFER VALUE BY BUBBLE EVAPORATION IN ENAMEL APPARATUS, Periodica Polytech 3, No. 1, 51-64 (1959).

A 250-l. reduced-scale enamel app. was used to det. heat-transfer values for H_2O and molasses solns.

1225. Linden, C. M. and Montillon, G. H.

HEAT TRANSMISSION IN AN EXPERIMENTAL INCLINED TUBE EVAPORATOR, Trans. Am. Inst. Che. Eng. 24, 120-141 (1930).

Work was carried out on small evaporator constructed so that velocity of flow of liquid in downtake pipe could be measured; runs were made with distilled water boiling at 180,195, and 210 deg. fahr.; by means of suitable thermocouples vapor and pipe temperatures were measured at temperature differences varying from 8 to 28 deg. for each temperature of evaporation.

1226. Lukavsky, J. and Novotny, J.

HEAT TRANSFER IN A FILM EVAPORATOR, Chem. prumysl, 10, 410-14 (1960).

The tests were conducted on a lab. film evaporator (Luwa L 020 type). The inner diam. of the evaporator was 80 mm, the length of the heating surface was 480 mm, and the max. distance between the rotor and the evaporator tube 1 mm. The rotor was operated at 1000-2000 r.p.m. The estd. evapg. output was 20 kg H_2O/hr. Distd. H_2O was used as the test liquid. The coeff. of heat transfer k was calcd. from the equation $Q = k F \Delta t$, where Q is the heat transfer rate calcd. from the energy balance, F is the heating surface, and Δt is the temp. drop between the steam temp., t_p and the b.p. of liquid t_v. The dependence of k on Δt and t_v at a liquid feed rate of 60 kg per hr. and a rotor speed of 1000 r.p.m. and the dependence of k on the heat flux q at various t_v were detd. In both these cases, k increases with Δt, and with q only slightly up to $t_v = 70°$ and more rapidly for t_v over 80°. At $\Delta t = 40°$, $t_v = 80°$, and 1000-2000 r.p.m., k increases with the liquid feed rate, but the optimum output of the evaporator is reached between 40 and 50 kg/hr. By increasing from 1000 to 2000 r.p.m., k is increased ~15%. Deviations of k at various feed temps. and with other parameters const. were $\leq 3\%$. Comparison of the results with values reported by Bressler [V.D.I. Zeitschrift 100, 630 (1958)] and Schneider (CA 49, 10678b) for an evaporator with movable blades, shows that fixed blades are advantageous at high wall temps.

1227. Lustenader, E. L., Richter, R. and Neugebauer, F. J.

THE USE OF THIN FILMS FOR INCREASING EVAPORATION AND CONDENSATION RATES IN PROCESS EQUIPMENT, J. Heat Transfer 81, 297-307 (1959).

An investigation was made of an evaporating and condensing test app. in which over-all heat transfer coeffs. as high as 8000 Btu/(hr)(sq ft)(°F) were obtained with water by utilizing thin films both in evaporation and condensation (much higher than for dropwise condensation). The films were obtained by

wiping the evaporating surface and utilizing surface tension effects on the condensing surface. The phenomena on both the evaporating and the condensing surfaces are amenable to theory. Investigations were made as to the best surface and wiper design. The results are applicable to the design of compact and economically operating process equipment. Sea-water tests have shown that the slowly rotating wiper retards the formation of scale on the evaporating surface. The absence of bubbling in the thin film minimizes brine carry-over and as a result a high purity condensate is produced.

1228. Lype, E. F.

KINETIC THEORY OF EVAPORATION RATES OF LIQUIDS, Trans. Am. Soc. Mech. Engrs. 77, 211-19 (discussion) 219-23 (1955).

Study of low rates of evaporation of water found in numerous experiments; evaporation of liquid calculated from Polanyi-Wigner theory of escape of molecules from surface of solid body; evaporation of "pseudo-crystalline" fluid is obtained from Volner's extension of this theory; condensation on surface of "pseudo-crystalline" fluid is obtained from kinetic theory; comparison with results of other workers.

1229. Madden, A. J. and Halfen, F. J.

TEMPERATURE DEPRESSIONS FOR EVAPORATING SPHERES AT LOW PRESSURES, A. I. Ch. E. Journal, 7, 160-2 (1961).

The evapn. of naphthalene spheres into air in the pressure range may be accompanied by an appreciable surface temp. depression. The magnitude of the effect depends on the geometry of the exptl. system and the pressure level. Such effects are of interest in the studies aimed at detg. evapn. coeffs. (CA-56-5785b)

1230. Maisel, D. S. and Sherwood, T. K.

EFFECT OF AIR TURBULENCE ON RATE OF EVAPORATION OF WATER, Chem. Eng. Prog. 46, 172-5 (April, 1950).

Study of effect of both intensity and scale of turbulence on rate of vaporization of water into air from small spheres and cylinders; these were supported in 10.2 cm ID high velocity air duct and measurements made of turbulence using hot wire anemometer; results of measurements; effect of turbulence on mass transfer.

1231. Maisel, D. S. and Sherwood, T. K.

EVAPORATION OF LIQUIDS INTO TURBULENT GAS STREAMS, Chem. Eng. Progress 46, 131-138 (Mar. 1950).

Data on evaporation of liquids into gas streams; tests made using wetted plane surfaces, cylinders, spheres, and disks; water was evaporated into air from each of several shapes; evaporation data for water into carbon dioxide and into helium from cylinders, benzene and carbon tetrachloride into air from cylinders, and benzene into air from spheres.

1232. Marek, Jan and Rod, Vladimir

HEAT TRANSFER DURING EVAPORATION IN JACKETED VESSELS, Chem. Listy 49, 1-9 (1955).

Dimensionless relations are derived for computing the evapn. in jacketed vessels with various types of bottoms. Plots of these relations are given to facilitate calcns. at const. and variable temp.

1233. Monchick, Louis and Reiss, H.

STUDIES OF EVAPORATION OF SMALL DROPS, J. Chem. Phys., 22, 831-6 (1954).

The rates of evapn. of small droplets of diamyl sebacate (av. radius $R \sim 10^{-4}$ cm) were measured in a Millikan oil-drop chamber, and observed to obey a law of the form $dR/dT = a/(1 + bR)$ that was predicted by the theory of N. Fuchs [Physik Z. Sowjetunion 6, 225 (1934)] and Frisch and Collins (CA-47-4167i). By use of a nonequil. distribution function of the velocities, the relation was derived in a more rigorous fashion. An empirical form of the Stokes-Cunningham law for the limiting velocity of fall in a dil. medium was obtained for dioctyl sebacate in air.

1234. Moore, F. D. and Mesler, R. B.

MICRO-LAYER VAPORIZATION, Presented at AIChE Meeting, Cleveland, 1961; also Univ. of Kansas, December, 1960.

1235. Murgatroyd, W.

SOME ASPECTS OF THE HIGH PRESSURE WETTED WALL EVAPORATOR, AERE X/M 124 (1954) 27 p.

Pressure losses and evaporation rates have been evaluated for the evaporation of water into superheated steam at pressures up to 1500 psia. In order to do this some drastic assumption as to the flow conditions were necessary. It is shown that some of these assumptions, though reasonable in the wetted-wall columns used in the Chemical Engineering Industry, are probably invalid when working at high pressures and high vapor velocities. A hypothesis is put forward which, if confirmed, would simplify the complicated two-phase flow problem at high pressures and velocities. Experimental work is urgently needed on this problem, since no relevant data are available for a designer.

1236. Nesterenko, A. V.

HEAT- AND MASS-EXCHANGE DURING THE EVAPORATION OF A LIQUID, Teplo-i Massoobmen v Protses. Ispareniya, Akad. Nauk S.S.S.R., Energet. Inst. 24-9 (1958).

The surface temp. of an evaporating liquid was detd. The expts. were set up so that the heat flow occurred from the liquid into the surrounding medium either under free or forced air flow. Distilled H_2O was used. The dependence of the surface temp. on the hygrothermal and hydrodynamic conds. of the process was detd. The relations, $\psi = 0.0135\ K^{-1.5}(ArPr)^{0.06}$(free air flow) and $\psi = 0.00615\ K^{-0.96}Re^{0.34}$ can be used for detg. the surface temp. of an evaporating liquid under any hydrodynamic or hygrothermic conditions.

1237. Nusselt, W.

HEAT TRANSFER, DIFFUSION, AND EVAPORATION, Translated from: Zeitschrift für angewandte Mathematik und Mechanik, 10, 105-21 (NACA-TM-1367) (Apr. 1930).

The general similarity of heat and mass transfer (diffusion) processes is discussed, with particular reference to the lack of complete identity of the relations governing the two phenomena. It is indicated that, for example, the boundary conditions in the two cases at the surface of a body will not be the same. The correct equation of diffusion is given for various simple cases. Generalized relations for combined heat and mass transfer are then evolved for particular situations, comparisons being made among several different approaches to the problem. Finally, the effect of a buoyancy force field on the generalized relations is considered, with special reference to the evaporation of water.

1238. Panchev, S.

EVAPORATION OF SPHERICAL DROPS OF WATER FALLING FREELY THROUGH THE ATMOSPHERE, C. R. Acad. Bulg, Sci., 10, No. 5, 355-8, (1957) (In Russian).

The equation of motion of drops is formulated and solved. It is found that the velocity of the drops is proportional to the square root of their radius.

1239. Parker, R. O. and Treybal, R. E.

THE HEAT, MASS TRANSFER CHARACTERISTICS OF EVAPORATIVE COOLERS, Chem. Eng. Prog. Symp. Series No. 32, 57, 138-149 (1961).

A new mathematical model for evaporative coolers has been devised in which the performance is described in terms of two transfer coefficients, U and K, U is a heat transfer coefficient accounting for the transfer of heat from the tube fluid to the spray water; K is a mass-transfer coefficient accounting for enthalpy transfer from spray water to the air stream. The differential equations have been integrated to yield results useful in the design and testing of these exchanges.

From the experiments performed, film coefficients for heat and mass transfer were deduced for the following: (1) air flow over dry tubes, (2) tubes to spray water for sensible heat transfer to the water only, (3) adiabatic evaporation of water into air, and (4) bulk spray water to the air-water interface. It is from these that U and K may be synthesized.

1240. Patten, T. D.

A REVIEW OF HEAT TRANSFER DATA ON THE EVAPORATION OF LIQUIDS AT SUB ATMOSPHERIC PRESSURES, Gt. Brit. Royal Aircraft Establishment, Farnborough, Harts. England. Tech Note Mech. Eng. No. 216 (1956).

1241. Peisakhov, I. L.

EVAPORATION OF SOLUTIONS BY UTILIZATION OF A LOW TEMPERATURE HEAT CARRIER, Tsvetnye Metally 30, No. 12, 41-4 (1957).

When vacuum is not used, bubbling of air through a salt soln. speeds up its evapn. and considerably decreases its temp., thus permitting the use of low-temp. heat sources, such as low pressure steam and hot water. The air is introduced at a shallow depth, 50-100 mm, by means of a ventilating fan. Calcns. are given.

1242. Penner, S. S.

KINETICS OF EVAPORATION, J. Phys. Chem. 56, 475-479 (1952).

The kinetics of evapn. of liquids is reconsidered from the point of view of classical reaction kinetics and also by application of the theory of abs. reaction rates. Evapn. treated as a unimol. rate process, with a rate proportional to the surface concn. of energetic mols., leads to the Knudsen equation for spherical mols., provided 6 square terms contribute to the energy of activation. The theory of abs. reaction rates, after correction for lack of equil. between normal mols., and the activated complex, leads to the Knudsen equation for spherically symmetric mols. if reasonable assumptions are made concerning the nature of the activated complex. Evidence is presented in support of the idea that the equil. theory of abs. reaction rates is not consistent with the model of the liquid used to det. evapn. rates. The theoretical treatment is next extended to polar liquids with restricted rotation, and it is shown that the evapn. coeff. should be identified with the free-angle ratio. (CA-46-8479a)

1243. Pepper, D.

DESIGN OF CLIMBING FILM EVAPORATORS, Ind. Chemist 34, 191-4 (1958).

Important factors in the design of climbing film evaporators are discussed, including heat transfer, tube dimensions, max, evapn. factor, entrainment, and corrosion.

1244. Petrazhitskii, G. B.

EVAPORATION OF DROPS AT HIGH TEMPERATURES AND PRESSURES, Trudy Odessk. Gosudarst. Univ. im I. I. Mechnikova 150 Ser. Fiz. Nauk No. 7, 125-36 (1960).

A study of the heat- and mass-transfer between liquid drops and a flowing gas was performed in a specially constructed app. The evapn. of drops of H_2O, 96% EtOH, and kerosene was investigated in in various air flows at 10-60 atm. and 90-500°. In another app., the evapn. of H_2O from the surface of a porous sphere at 1 atm. and 2800° was studied.

1245. Petrazhitskii, G. B.

TREATMENT AND GENERALIZATION OF THE RESULTS OF AN EXPERIMENTAL INVESTIGATION OF THE EVAPORATION OF DROPS, Trudy Odessk. Gosudarst. Univ. im I. I. Mechnikova 150, Ser. Fiz. Nauk No. 7, 161-86 (1960).

The processes taking place during evapn. of a liquid drop are discussed. Equations for detn. of the temp., evapn. time, etc., are given, and the results of the theoretical calcns. are compared with the exptl. data obtained by various authors. An attempt is made to generalize the individual results.

1246. Pigott, R. J. S.

VAPOR LOCK OR DUMB ENGINEERING, J. of the Society of Automotive Engineers, 52, 310-317 (1944).

Properties of automobile and aviation gasoline are given that bear on the problem of vapor lock. Factors which can be controlled, other than gasoline type, to help prevent vapor lock are given. Air solubility is discussed. Curves and formulas for the effect of pipings of different kinds are given and explained. Types of flow, pump losses, vapor traps, effect of carburetor, calculations for systems, are explained. Conclusions: (1) The vaporization characteristics of any gasoline can be determined. The hydraulic system must be designed specifically to meet these characteristics. (2) The pipe and fitting resistances are quite fully known, including that for flow of mixtures of gas and liquid. (3) The ratio of pump volume rate of delivery to required maximum volume rate of liquid gasoline determines the limiting V/L for successful operation without vapor lock from the fuel system. (4) From the foregoing, the critical vapor lock tank temperature and maximum altitude can be determined. (5) Vapor-lock beyond the fuel pump is chiefly a matter of elimination of vapor or gas at measuring point, and no heat addition before the metering operation.

1247. Pleteneva, N. A. and Rebinder, P. A.

EFFECT OF SURFACE-ACTIVE SUBSTANCES ON THE EVAPORATION OF A DROP OF WATER IN THE SPHEROIDAL STATE, J. of Physical Chemistry (USSR) 20, No. 9 (1946).

1248. Pleteneva, N. A. and Rebinder, P. A.

MECHANISM OF THE EVAPORATION OF A DROP OF LIQUID IN THE SPHEROIDAL STATE, J. of Physical Chemistry (USSR) 20, No. 9 (1946).

1249. Radusch, R.

THE VELOCITY OF EVAPORATION OF DROPS OF WATER, Chem. Ing. Tech. 28, 275-7 (1956).

A discussion of the effect of drop size on speed of evapn. and heat-transfer coeff. A drop diam. of 0.35 mm represents an optimum value for heat transfer when water spray is used for fire-fighting. Some data and 8 references are given.

1250. Ranz, W. E. and Marshall, W. R., Jr.

EVAPORATION FROM DROPS, I. Chem. Eng. Progress 48, 141-46 (1952).

The factors affecting the rate of evapn. of pure liquid drops and the rate of evapn. of water drops contg. dissolved and suspended solids were studied. The study was restricted to a Reynolds-no. range of 0 to 200, the range usually encountered in spray-drying operations. Independent correlations of heat- and mass-transfer rates were obtained from drop temps. measured with 0.5-mil-thermocouples. Drop diams. ranged from 0.06 to 0.11 cm, and air temps. up to 200°. Results of studies on pure liquid drops confirmed the analogy between heat and mass transfer at low Reynolds nos., and verified the simple expression for the Nusselt no. at zero Reynolds no. A general correlation of existing data on spherical particles showed the results of this study could be extrapolated with remarkable accuracy 5 times beyond the exptl. range of Reynolds nos.

1251. Ranz, W. E. and Marshall, W. R., Jr.

EVAPORATION FROM DROPS. II., Chem. Eng. Progress 48, 173-80 (1952).

Exptl. results for pure liquid drops, discussion of results on evapn. from pure liquid drops, evapn. from drops contg. solids in soln. and suspension, drying drops in still dry air with heat of crystn. and supersatn. effects, and estn. of drying time.

1252. Ranz, W. E.

EVAPORATION OF A DROP OF VOLATILE LIQUID IN HIGH-TEMPERATURE SURROUNDINGS, Trans. Am. Soc. Mech. Engrs. 78, 909-13 (1956).

The evapn. of a drop of volatile liquid in high-temp. surroundings is analyzed in terms of the rate of heat transfer. Transfer of heat by mass transfer and by radiation as well as by conduction is taken into account for a pseudostationary and steady state without convection. The flow of cold vapor to the surroundings during evapn. requires that a considerable amt. of heat conducted inward be used to warm vapor moving outward. This waylaying of heat energy results in a significant decrease in the apparent rate of heat transfer as measured by the rate of evapn. Applications of the theoretical results to evapn. and combustion are discussed, and an empirical treatment for cases of free and forced convection is indicated.

1253. Rodebush, W. H.

NUCLEI IN EVAPORATION AND CONDENSATION, Chem. Revs. 44, 269-76 (1949).

The condition of dissolved non-polar gases in water soln. is entirely a matter of speculation. There is evidence that bubbles small enough to escape observation are very persistent and noticeably affect the properties of water. The supersatn. of vapors in the absence of nuclei is subject to thermodynamic treatment. The Thomson equation is no longer valid when the single drop ceases to det. a liquid phase, as occurs when the no. of mols. becomes small enough so that the share of each in the colligative entropy of the drop becomes considerable. The drop then becomes a mol. aggregate in a homogeneous equil. and a definite limit to supersatn. is established. Exptl. data are in general agreement with the conclusions of this theory. (CA-43-6046i)

1254. Rodenacker, Wolf

FILM EVAPORATOR, March 21, 1957, German Patent, 1,004,590 (Cl. 12a).

The evapg. surface is a cylinder inside the evaporator which forms, with at least 1 protruding body, a small slot into which the fluid is introduced under pressure.

1255. Rohsenow, W. M.

HEAT TRANSFER WITH EVAPORATION, p. 101 in: Heat transfer . . . a symposium held at the University of Michigan during the summer of 1952. Ann Arbor, Engineering Research Institute, 1953.

1256. Ronco, J. J.

CALCULATION METHODS IN DIFFUSIONAL OPERATIONS. I. FUNDAMENTAL THEORY, II. DIFFUSIONAL EVAPORATION. Lab. ensayo materiales e invest. technol., Prov. Buenos Aires (La Plata, Arg.) Sec. II, No. 49, 5-48 (1952).

A general discussion of continuous and discontinuous diffusion in terms of material, energy, and enthalpy balance, equil. conditions, and kinetics. A complete list of symbols is given, and equations are derived for homogeneous and heterogeneous cases of fluids in motion and heat and material transfer. II. Diffusional evaporation. Ibid. 29-48 - Specific equations are derived for discontinuous evapn. of water. The app. is described, and tables of the apparent coeff. for heat and material transfer are given for 22 test conditions. Another app. used to study continuous operations is described. Heat- and material-transfer coeffs. are given for 12 trials.

1257. Rounthwaite, C. and Clouston, M.

HEAT TRANSFER DURING EVAPORATION OF HIGH QUALITY WATER-STEAM MIXTURES FLOWING IN HORIZONTAL TUBES, p. 200-11 of International Developments in Heat Transfer. Part I., New York, ASME, 1961.

A high-pressure steam rig was built to study the evaporation of wet steam in a horizontal hair-pin type of tube, 1.6 in. bore, for a wide variety of flow rates, steam pressure, and quality conditions, but at relatively low heat-fluxes. The internal heat transfer coefficients were measured during the transition from high "boiling" values to low superheated values, which occurs at high steam qualities. Under all test-conditions the fall in coefficient was fairly rapid, and generally occurred at steam qualities between 94 and 98%. The value of the coefficient before "transition" showed a direct dependence on flow-rate, though under some conditions the onset of transition was very much affected by heat flux. Local coefficient measurements made around the circumference of the tube showed that at low steam velocities a stratified flow condition existed at inlet to the test-section. Furthermore, under all test conditions the actual transition did not occur in a uniform manner around the tube-section. The fall in coefficient first occurred at the top of the tube-section and then gradually spread around the sides to the bottom. This phenomenon was qualitatively explained with reference to possible water-steam flow patterns in the tube during transition.

1258. Ruckenstein, E.

VAPORIZATION OF A THIN FILM OF LIQUID IN HIGH VACUUM, Stud. Cercetari Fiz., (Roumania), 8, No. 1, 25-39 (Jan.-Mar. 1957).

A theoretical study of the evaporation from a thin film of liquid containing several constituents, flowing over a vertical surface. Equations for the dependence of the rate of flow of each constituent on the distance from the point of entry are set up and solved. The case of undulating flow is also discussed. (SA-61-5377)

1259. Sarukhanian, G.

HEAT TRANSFER IN EVAPORATION, Chem.-Ing.-Tech. 25, 477-80 (1953).

Review of heat transmission of boiling liquids and establishment of general equation according to recent Russian literature. 14 references.

1260. Scala, S. M.

VAPORIZATION OF A REFRACTORY OXIDE DURING HYPERSONIC FLIGHT, p. 181-92 of 1959 Heat Transfer and Fluid Mechanics Institute, Stanford, Calif., Stanford Univ. Press, 1959. 250 p.

During flight through a hypersonic environment, the heat transfer to a vaporizing surface depends critically upon the aerothermochemical processes which occur in the boundary layer. The pertinent conservation equations on heat and mass transfer effects are presented and are employed in an analysis of the processes of diffusion, convection, and thermal exchange during the vaporization of a refractory material which reaches extremely high surface temperatures, such that re-radiation must be considered at the surface. It is shown that the quantity Q*, called the "effective heat of vaporization," which includes all heat absorbing or heat blocking effects, is an increasing function of stagnation enthalpy and a decreasing function of stagnation pressure, independent of body size, except where $\alpha\sqrt{R_B}$ and $\epsilon_w\sqrt{R_B}$ effects appear. The effects of vaporization rate-controlled mass loss applicable to high altitude flight are investigated and the relationship between the interphase mass transfer and the vaporization coefficient is established. The effects of non-equilibrium vaporization into a hypersonic laminar boundary layer are treated.

1261. Schlegel, Richard

EVAPORATION OF DISSOLVED GAS FROM WATER IN A HEAT EXCHANGER, CP-3062 (1945), 15 p.

The equations given in report CP-2701 (TID-3305, Ref. 81) for heat-exchanger performance are adapted for the calculation of dissolved gas removal in falling-water film exchangers. The transfer of O_2, H_2, and Xe to a gas stream (He) which sweeps up through the exchanger is considered. It is assumed that transfer occurs with no bubble formation. Concentrations to be expected for a given removal rate are estimated on the basis of assumed transfer coefficients.

1262. Sergeev, G. T.

AN INVESTIGATION OF EXTERNAL HEAT AND MASS TRANSFER WITH LIQUID EVAPORATION BY A CAPILLARY POROUS BODY, Inzh. Fiz. Zh. (USSR) 4, No. 5, 33-s37 (1961).

1263. Sergeev, G. T.

HEAT AND MASS TRANSFER DURING EVAPORATION OF A LIQUID INTO A GAS IN FORCED FLOW, Inzhener. - Fiz. Zhur., Akad. Nauk. Belorus. S.S.R. 4, No. 2, 77-81 (1961).

H_2O, acetone, C_6H_6, and BuOH were evapd. into air in the app. The heat transfer of a dry body was measured. The air had Reynolds Nos. 2-15 x 10^4,

temps. (t) 20-200°, relative humidity (ϕ) 15-80%. The coeff. of heat transfer (h) increases with the evapn. rate. With increasing t the h during evapn. increases more rapidly than the h of a dry body. Nusselt nos. for heat and mass transfer (Nu_q and Nu_m, resp.) increase with a decrease in ϕ for evapn. of H_2O. For all liquids $Nu_m > Nu_q$.

1264. Severson, E., Madden, A. J. and Piret, E. L.

EVAPORATION RATES OF LIQUIDS TO FLOWING GAS STREAMS, A.I.Che.E. Journal 5, 413-18 (1959).

The effect of high concn. gradients and high evaporative velocities on rates of mass transfer was studied by evapg. liquids into low-speed inert-gas streams at pressures approaching the vapor pressure of the liquids. Inert gas concn. in some expts. changed nearly 5-fold across the boundary layer. The velocity normal to the surface (owing to evapn.), usually neglected in comparison with main-stream velocity, was 0.038-19 times the main-stream velocity. The data for air-H_2O, air-CCl_4, air-C_6H_5Cl, and He-C_6H_5Cl systems were represented within exptl. error over the Graetz no. range 0.1-1800 by the flat-duct equations of Butler and Plewes (CA-48, 9118h) and also by the usual dimensionless plots.

1265. Sherwood, T. K. and Phillips, O.

THE EVAPORATION OF WATER AT HIGH HUMIDITIES, Part III of Final Report, NP-6333 (1957), 233 p.

The factors by which changes in concentration of the diffusing compound affect the rates of mass transfer between a gas and a wet surface are discussed. The study included evaporation from a wetted-wall tower, and the evaporation of water from a porous wet cylinder. In all runs turbulent conditions were maintained in the gas phase. A theoretical discussion is included of diffusion in the evaporation process.

1266. Shpil'rayn, E. E., Asinovskiy, E. I.

CALCULATION OF THE LATENT EVAPORATION HEAT OF ALKALI METALS, Inzhenero-fizicheskiy zhurnal, 5, No. 4, 1962, 35-40.

Evaporation of liquid alkali metals proceeds in two stages. First, atomic vapor is formed, subsequently, dimerization takes place to a certain percentage. Thus, the vapor pressure decreases and the liquid metal evaporates until equilibrium sets in. The vapor phase can be regarded as a single-component system irrespective of its real structure. For isobaric reactions the authors prove that the Clausius-Clapeyron equation from which the molar evaporation heat can be calculated holds also for this complex evaporation process. To determine the specific evaporation heat the molecular weight must be measured separately, e.g., by measuring the volume elasticity of vapor. The specific evaporation heat of alkali metals cannot be determined by pressure measurements only, but the degree of vapor dimerization has to be taken into account. The authors demonstrate that in a number of papers the numerical data on the specific evaporation heat of alkalies are incorrect because dimerization has not been taken into account. For lithium, sodium, and potassium, the following correct values are given:

	Atomic weight	Molar evaporation heat, kcal/mole	Specific evaporation heat, kcal/kg
Li	6,940	36,3	4636
Na	22,991	24,1	926
K	39,100	19,5	473

These values hold for the boiling point of the individual metals. There are 1 table and 16 references: 5 Soviet and 11 non-Soviet. The four most recent references to English-language publications read as follows: K. K. Kelley, Bur. of Mines., Bull. 383, Washington, 1935; L. Quill, The chemistry and metallurgy of miscellaneous materials, 1950; R. Lyon, Handbook on Liquid Metals Suppl., Washington, 1950; W. H. Evans et al., J. Res. Nat. Bur. Stand., 55, 83, 1955.

1267. Shuleikin, V. V.

KINETIC THEORY OF EVAPORATION, J. of the Russian Physicochemical Society, Physical Section 3 (1926).

1268. Shumskaya, L. S.

THE EFFECT OF CIRCULATION OF LIQUID AND VAPOR ON THE CHANGE IN PRESSURE, AND IN LEVEL IN A DRUM EVAPORATOR AT UNSTEADY STATE, Transactions of the Central Scientific Research Institute for Boilers and Turbines. 19 (1951).

1269. Simpson, T. B. and Winding, C. C.

PROPERTIES OF EVAPORATED METAL FILMS RELATED TO THEIR USE FOR SURFACE-TEMPERATURE MEASUREMENTS, A.I.Ch.E. Journal, 2, 113-117 (1956).

Extension of the understanding of properties of films of metals produced on glass surfaces by vacuum evaporation has permitted the fabrication of film-resistance thermometers that with simple instrumentation accurately measure surface or average surface temperatures without altering the geography of that surface. Formerly unknown and unstable related properties of such films have been classified and may be anticipated or eliminated by recommended experimental procedures. Films of several of the most chemically inert and refractory metals 300 to 3,000 A. thick have been shown to attain accuracies as high as 0.01 C. for practical periods of time. Their use, which is described, is developing satisfactorily, and the technique and equipment for their preparation are relatively simple.

1270. Spangenberg, W. G. and Rowland, W. R.

CONVECTIVE CIRCULATION IN WATER INDUCED BY EVAPORATIVE COOLING, Phys. of Fluids (USA), 4, 743-50 (1961).

Schlieren photographs taken simultaneously from the top and side of a tank of water were used to study convection currents induced by evaporative cooling. It is found that water from the cooled surface layer collects along lines producing thickened regions which become unstable and plunge in vertical sheets. Surface water then continues to flow downward through the sheets, reducing the cooled surface layer

to a thin film. In top schlieren views the plunging regions sometimes appear straight, sometimes curved, and branched or terminated with no fixed pattern. The number of lines per unit area is a function of the cooling rate rather than the depth of the container. Reticulated surface patterns were observed only at particular cooling rates and columnar plunging occurred only on rare occasions. No distinctly different combination of conditions to differentiate between the causes of these different modes was evident. Numerical integration of the nonlinear temperature distribution in the cooled layer showed a critical Rayleigh number of 1193 when convective circulation started, and a Rayleigh number of 102 for maintaining an established uniform circulation.

1271. Stenzel, W. and Schultze, G. R.

EVAPORATIVE COOLING. I. METHOD FOR NONSTATIONARY MEASUREMENT OF HEAT TRANSFER, Chem. Ing. Tech. 30, 643-7 (1958).

The cooling behavior of a heated measuring element, which is located in the liquid to be cooled, is followed with a thermoelement and recorded on a cathode ray oscillograph as a differential equation. The distortions of the curve, resulting from relaxation phenomena in the liquid and from temp. gradients in the temp. probe, are discussed. The temp. gradient effect can be analyzed mathematically by a system of solutions of polynomials of the heat-transfer equation. Details are presented for the construction of the temp. probe and the recording equipment.

1272. Stenzel, W. and Schultze, G. R.

EVAPORATIVE COOLING. II. THEORY OF EVAPORATIVE COOLING AND MEASUREMENT OF HEAT TRANSFER IN QUENCHING OILS AND SALT SOLUTIONS, Chem. Ing. Tech. 30, 720-8 (1958).

A generalized theory is presented on the basis of 2 existing heat-transfer mechanisms, the boiling phase and the film phase. Some exptl. data and their theoretical interpretation are given.

1273. Stewart, F. C. and Hechler, F. G.

FILM HEAT TRANSFER COEFFICIENTS FOR SO_2 IN VERTICAL EVAPORATOR, Refrig. Eng. 31, No. 2, 107-11 (1936).

Preliminary values for film heat transfer coefficients for simple vertical evaporator operated flooded.

1274. Styrikovich, M. A.

DETAILS OF INTERNAL EVAPORATOR PROCESSES AT HIGH STEAM PRESSURE, Izvestiya AN SSSR, OTN. (News of the Academy of Sciences of the USSR, Division of Technical Sciences) 8 (1950).

1275. Tanasawa, Yasushi and Kobayashi, K.

THE EVAPORATION VELOCITY OF A LIQUID DROPLET IN A HIGH TEMPERATURE GAS, Technol. Repts. Tohoku Univ. 14, 55-67 (1950).

The problem is of importance in combustion in Diesel engines, gas turbines, and gasoline engines. The evapn. velocity of a droplet with radius a is represented by $da/dt = -(k/2E_2)(1/a)$ under the assumptions that the temp. of the gas is not altered by evapn. of the droplet and that convection in the liquid is negligible. The time τ required from the injection to the disappearance of the droplet is given by $\tau = a_0^2/k(E_1 + E_2)$, where a_0 is the initial radius of the droplet, k is the thermal diffusivity of the liquid, and E_1 and E_2 are dimensionless coeffs. Data are given for the rate of evapn. of water, CH_3OH, C_6H_6, octane, and hexane injected at 20° with an initial diam. of 50 μ into air at 500° and 1 atm. Similar data are given for air at 1000°. The rates of evapn. of water droplets 200, 150, 100, and 50 μ injected into air at 500° and 1 atm. are compared.

1276. Thomson, Sir W.

ON THE EQUILIBRIUM OF VAPOR AT A CURVED SURFACE OF LIQUID, Proc. Roy Soc. (Edinburgh) A7, 63 (1870).

1277. Timofeev, M. P.

EVAPORATION FROM A WATER SURFACE IN A TURBULENT ATMOSPHERE, Uchenye Zapiski Leningrad Gosudarst Univ. in A.A. Zhdanova No. 120, Ser. Fiz. Nauk No. 7, 202-40 (1949).

Equations are given for evapn. from a water surface over which there is a turbulent flow of air. The local rate of evapn. E at a fixed height of the order of 1 m above the surface is given by $E = Bq_0v^{p}k^{(1-p)}/X^{p}$, where q_0 is the limiting value of the vol. concn. of steam at the surface, v = av. air flow rate, k = coeff. of turbulence at the fixed height, p - H_2O vapor pressure, B = complex function of p, and X = function of the fixed height, the scale of the turbulence, v, and k. From this math. treatment, it is possible to calc. q_z, the vol. concn. of steam at the fixed height Z, as a function of q_0 and Z for various assumed conditions, such as different turbulent conditions or temps. of stratified air. Comparisons are made for large surfaces of evapn. with dimensions of the order of 1000 km. For low coeffs. of turbulent diffusion, the satd. concns. characteristic of laminar substrates are obtained to a first approx. The theoretical distribution of the concn. of vapor on the surface is obtained for the case of well-developed turbulence of the air. The treatment is extended to surfaces other than water, in particular ice, Hg, and MeOH, for which literature data on evapn. are available.

1278. Toei, R.

DRYING RATE IN THE SURFACE EVAPORATION PERIOD - CONSIDERATION ON THE ACKERMANN EFFECT, Chem. Engng. Japan, 25, 65 (1961).

1279. Tovbin, M. V. and Savinova, E. V.

KINETICS OF THE NONSTEADY STATE OF A PROCESS AT A LIQUID-GAS INTERFACE. I. KINETICS OF THE NONSTEADY STATE OF THE EVAPORATION WATER. II. THE EFFECTS OF ADSORPTION LAYERS ON THE NONSTEADY-STATE EVAPORATION OF WATER, Zhur. Fiz. Khim. 31, 2445-52 (I) 2117-19 (II) (1957).

A method was developed to measure the rate of evapn. of water from a stream moving at a regulated rate through thermostatically controlled dry air with a very short contact with the air. The evapn. rate increased at first with longer contact, passed

through a max., and then dropped to a steady value that was characteristic of the steady state. At lower contact time of the phases the temp. coeff. of the evapn. rate increased, and the apparent activation energy increased to a value close to the latent heat of evapn. An intermediate self-absorbing layer was assumed to form on the freshly-formed liquid surface, and the evapn. process proceeded by the desorption of the substance from this layer. The formation of this layer required 3.3×10^{-9}g. mols./sq cm H_2O at 25°. II. The effects of adsorption layers on the nonsteady-state evaporation of water. Ibid. 2717-19 - The evapn. of H_2O from the surface of a stream of an aq.-soln. of surface-active substances (iso-AmOH, octanol, butyric acid, and isobutyric acid) at 25° with an air velocity past the stream of 200 ml/min. was investigated. The effects of the adsorption layer on kinetics of the nonsteady-state evapn. of water was a function of the time of contact of the air with the water, and when the time of contact (τ) was <0.002 sec, the adsorption rate was greatly increased; at higher τ values the evapn. rate was reduced, and the inhibiting effect decreased further as the process approached the steady-state conditions. The nonsteady nature of the evapn. H_2O at very low surfactant concn. was attributed to the surfactant being present in such low concns. in the soln.-air interface that it had no effect on the H_2O concn. in it, or on the evapn. rate.

1280. Tschudin, K.

RATE OF EVAPORATION OF ICE, Helv. Phys. Acta 19, 91-102 (1946).

The evapn. coeff. is independent of temp. between -60° and -85°, its value being 0.94. This is compared with the max. theoretical value of unity and the value of 0.04 obtained by evapn. from the liquid phase. (Sci. A. 40-3671-7)

1281. Tverskaya, N. P.

EVAPORATION OF A FALLING DROP, Uchenye Zapiski, Leningrad. Gosudarst. Univ. in A. A. Zhdanova No. 120. Ser. Fiz. Nauk No. 7, 241-66 (1949).

The change in size of drops of water or ice in streams of air flowing at various rates was measured over the temp. range from -20° to +25°. The drop size was of the order of 500μ, and the relative humidity of the air varied from 40 to 80%. In static air, the function $X = dD^2/dt$, where D = drop diam. and t = time, was independent of drop size at const. relative humidity and temp. The function F (equal to the ratio of X in moving air to X in static air) is related to R, the Reynolds no., by the equation $F = a(1 + kR^n)$. Above R = 350, the equation can be satisfied by a = 1, k = 0.23, but the equation is more complex below R = 350. The evapn. rate of supercooled water drops is almost comparable to the rate for ice drops, but the rate for the liquid is always somewhat greater, showing its max. difference at -12°.

1282. Tverskaya, N. P.

TEMPERATURE OF EVAPORATION OF DROPLETS, Izvest. Akad. Nauk USSR, Ser. Geog. Geophys. 15, 74-81 (1951).

The temp. of evapn. of droplets of water constitutes an important part of the problem of the study of the thermodynamics of the atm. The following equation was used for calcg. the rate of evapn. of a droplet: $dm/dt = (4\pi\Delta M/RT)(E_k - e)rf$ where m is the mass of the evapg. droplet, Δ is the coeff. of diffusion, M is the mol. wt., R is the gas const., T is the abs. temp., r is the radius of the droplet, f is the wind factor, E_k is the vapor pressure above the surface of the droplet, e is the vapor pressure in the surrounding air at a large distance from the droplet. This equation combined with the well-known psychometric formula was used as the basis for calcns. made. The results are summarized in the form of a monogram whose ordinates represent vapor pressure of water in the air some distance from the evapg. droplet. The abscissa is in degrees abs.

1283. Uchida, S., Nishikawa, S. and Shinkawa, T.

HEAT TRANSFER COEFFICIENT IN THE CLIMBING-FILM TYPE EVAPORATOR, Chem. Eng. (Japan) 15, 305-11 (1951).

Exptl. investigations were made on a vertical climbing-film type evaporator (diam. 11.9, 18.6 and 25.5 mm, length 2.5 m) with water and MeOH-water mixts. Vapor and liquid were sepd. in a cyclone, and their rates of formation were measured. The overall coeff. was 1000-3000 kcal/sq m hr°C. Vapor and liquid were in equil. at the exit end of the evaporator tube. The correlation of the overall coeff., U, with other variables is expressed by the equation $U/\lambda = 30.4\,(4\Gamma/\mu)^{0.56}(V/F)^{0.37}(Pr)^{2/3}$, where F, V, Γ, λ, and μ refer to feed rate, vapor rate, mass rate of liquid per unit length of periphery of the tube, liquid viscosity, and thermal cond. of the liquid, resp. The accuracy of the relation is about ±15%.

1284. Ueda, M.

RATE OF EVAPORATION OF WATER BY FORCED CONVECTION, J. Appl. Phys., Japan, 29, 443 (1960).

1285. Vedrilla, Stephen

EVAPORATION OF A LIQUID INTO A GAS PASSED THROUGH IT, Mitt. Chem. Forsch. Inst. Ind. Österr. 5, 85-8 (1951).

When a gas is passed through a liquid the gas either (1) will be charged with the vapor of the liquid or (2) will dissolve in the liquid. The theory and equations are developed for the evapn. of the liquid into the gas.

1286. Veldstra, J.

HEAT TRANSFER IN EVAPORATORS, Intern. Fruchtsaft Ber. Wiss. Tech. Komm, No. 3, 117-25 (1961).

Heat transfer studies in evaporators are reviewed.

1287. Veron, Marcel

ON THE SEMI-GRAPHICAL CALCULATION OF EVAPORATION-EXCHANGERS, C. R. Acad. Sci. 244 No. 7, 862-5 (1957)(In French).

Curves of the humidity of the air as a function of the water and air temperatures, and of the enthalpy of the air as a function of the humidity are used to assist in the solution.

1288. Veron, M.

REPEATED CALCULATIONS FOR EXCHANGERS INVOLVING EVAPORATION, C. R. Acad. Sci., 244, No. 6, 728-9 (1957)(In French).

A flexible method of calcn. for heat exchangers is proposed for those cases where there is a flow of water exchanging with a coolant or a condensing fluid, such as NH_3. At the same time the water is evapg. in an air stream, thus being warmed and humidifying the air.

1289. Volmer, M. and Esterman, L.

THE VAPORIZATION COEFFICIENTS OF SOLID AND LIQUID MERCURY, Z. Physik 7, 1-12 (1921).

When a vapour at constant pressure is deposited on a cold surface, the temperature of which is so low that er-evaporation can be neglected, the max. velocity of deposition G (in gm per sec per cm^2) is equal to the number of molecules falling on the surface. Hence $G = \frac{1}{4}ncm = \sqrt{(M_p/T)}/\sqrt{(2\pi R)}$, where m denotes the mass of a molecule, p = pressure of vapour ($dynes/cm^2$) m = molar weight, T and R respectively the absolute temperature and gas constant. If a fraction α of the impinging molecules only is condensed and the remainder are reflected, we have $G = \alpha\sqrt{(M_p/T)}/\sqrt{(2\pi R)}$. If the condensate is at a temperature corresponding to the vapour pressure p, we have equilibrium, i.e., the velocity of evaporation is equal to the velocity of condensation. Hence for vaporisation in a vacuum we have $G = \alpha\sqrt{(M_p/T)}/\sqrt{(2\pi R)}$. These are Langmuir's expressions. Experiments made by Marcelin, Knudsen, and Bennewitz to determine α have not led to completely satisfactory results. Knudsen and Bennewitz concluded that $\alpha = 1$ in all cases, but researches of Grosse and Volmer on the formation of crystals show that for solids α must be less than unity. The author's experiments were designed to obtain further results covering a wide range of temperature, with the hope of settling the value of α. The remainder of the paper contains a full description with tables of results of two methods used to find the values of α. In one method the velocity of evaporation was deduced from the rate of diminution of radius of the drop, and in another set of results (applicable to temperatures below 0°) the amount of deposited mercury is obtained from its electrical resistance. In the other method the condensation and reflection at a solid mercury surface were determined by the help of an improved form of Knudsen's apparatus for the same purpose. The authors conclude that for liquid mercury α is unity and independent of the temperature, while for solid mercury α is less than unity, but the dependence on temperature is uncertain. Another paper on sulphur, phosphorus, etc., is promised, these having small values of α, besides being suited for determining the temperature effect. The experiments showed a close connection between the values of α and the degree of under-cooling.

1290. Walters, R. J.

SODIUM TRANSFER-HELIUM FLOW CIRCUIT NAA-SR-Memo-7393 (May 15, 1962).

Vaporization rates of sodium into the helium stream were estimated using the analogy between heat and mass transfer. Because of the high helium velocities existing in the fuel handling cask, essentially all of the sodium vaporized from the fuel element surfaces will be carried into the external circuit unless an entrainment separator is provided. Approximately one pound of sodium will be carried as mist and vapor from the cask during the initial 15 to 30 minutes of the fuel handling operation. The gas has a saturation capacity of 0.11 lb/hr of sodium. In the external heat exchanger, 0.11 lb/hr of mist will be formed. This sodium should not deposit on the tubes because of the high flow velocity. To protect the heat exchanger and the blower, cyclone separators or wire mesh demisters are recommended. (NSA-62-33122)

1291. Witzig, W. F., et al.

HEAT-TRANSFER RATES TO EVAPORATING FREON 12 IN A HORIZONTAL-TUBE EVAPORATOR, Refrig. Eng. 56, 153-7 (1948).

Effects of Freon-12 mass flow rate, progressive evaporation, evaporation temperature, and oil contamination in horizontal 0.305 in.ID copper tube, studied; data treated statistically and correlation coefficient obtained; data show large variation in heat transfer rate with temperature difference, evaporation temperature, and progressive evaporation, little variation found with mass flow rate and oil contamination.

1292. Wyllie, G.

EVAPORATION AND SURFACE STRUCTURE OF LIQUIDS, Proc. Roy. Soc. (London), Series A, 197, 383-395 (1949).

The condensation coefficient (c.c.) of a liquid is defined as the ratio of the observed rate of evaporation under given conditions to the "expected" rate calculated from the known saturation vapour pressure, for the same conditions. Values of the c.c. < 1 have been reported in the past, but the accuracy of the experiments has been criticized on various grounds. Experimental work is described which establishes that the c.c. of glycerol at 18°C is 0.052 ± 0.005. Previous experimental determinations are reviewed in the light of this result, and it is found that for various liquids the c.c. ~ the free-angle ratio defined by Kincaid and Eyring., on the basis of a simple model of liquid structure. This equality is not found for chloroform. The theory of evaporation is discussed on a model of the liquid surface consisting of a compact ordered layer with a mobile adsorbed layer of molecules above it. On the assumption that evaporating and condensing molecules pass through the adsorbed condition, it is shown that the c.c. is determined by the rates of exchange between substrate and adsorbed layer, and adsorbed layer and vapour, respectively. In particular, a c.c. near unity results if the rate of exchange between substrate and mobile

layer is ≫ than that between mobile layer and vapour. The above assumption does not give a satisfactory explanation of the equality of c.c. and free-angle ratio for alcohol molecules. It is shown that for polar molecules which form an oriented surface layer in the liquid state it is to be expected that evaporation will take place mainly by direct exchange of molecules between the ordered layer and the vapour, although an adsorbed layer will be present. In this case an argument given by Herzfeld shows the condition for equality of c.c. and free-angle ratio to be that there should be no exchange of energy between rotational and translational coordinates in the process of evaporation. It is further concluded from a rather qualitative discussion that a major contribution to c.c. and free-angle ratio for the simple alcohols arises from restriction of rotation of the OH group about the C-O bond.

1293. Young, Gale

EVAPORATION OF DISSOLVED GAS FROM A LIQUID, MUC-GY-28 (1945).

The analogy between heat and momentum transfer is employed.

1294. Zivojinov, J. M.

RELATION BETWEEN TEMPERATURE AND EVAPORATION PRESSURE, J. Phys. Radium (France) 23, Suppl. No. 3, 7A-12A (1962)(In French).

An equation which determines the relationship between the evaporation temperature and the corresponding pressure is established. Temperatures from this equation are determined. The temperature prediction from the equations in the thesis corresponds more closely to the experimental results than Van der Waal's equation.

1295. Zwick, S. A.

NOTE ON EVAPORATION, J. of Appl. Physics, 31, 1735-1741 (1960).

A simple kinetic model is employed to investigate nonequilibrium evaporation from a liquid. Molecules are assumed to evaporate into a (one-sided) Maxwellian velocity distribution at the liquid surface. Molecules reaching the surface from the vapor are assumed to form part of an ellipsoidal velocity distribution. Of the molecules approaching the liquid at the interface only the fraction α condenses there; the remainder is taken to undergo specular reflection back into the vapor. By equating physical conditions at the surface with conditions in the vapor, one can relate the vapor pressure to that which would prevail at equilibrium, as a function of the surface accommodation coefficient α and the mean velocity u of the vapor relative to the interface.

1296. Hua Hsueh Shih Chieh

CONTINUOUS-FLOW THIN-FILM EVAPORATOR, Shanghai Pharmaceutical Industrial Research Institute, 231-7 (1959).

Expts. were conducted in concg. streptomycin soln. The effects of temp. difference, flow rate, boiling temp., and viscosity on the coeff. of heat transfer of the sample layer were studied. Temp. difference gave the greatest effect. The exptl. data agree with those obtained by Coulson and Mehta (CA-48, 6751i). The boiling temp. also has a large effect. Beside streptomycin, protein solns., such as egg albumin, were studied to demonstrate this effect. There was a greater effect of viscosity on the coeff. of heat transfer than that observed by Coulson and McNelly (CA-51,7775i).

EQUATIONS OF STATE

1297. Bird, R. B., et al.

THEORETICAL CALCULATION OF THE EQUATION OF STATE AND TRANSPORT PROPERTIES OF GASES AND LIQUIDS, Trans. A.S.T.M. 76, 1011-1033, 1954.

Further data on viscosity and other properties of gases and gas mixtures; determination of equation of state of moderately dense gases, very dense gases and liquids, and coefficients of diffusion, viscosity and thermal conductivity of dilute gases, dense gases, and liquids, value for engineering design and chemical process studies.

1298. Widom, B. and Rice, O. K.

CRITICAL ISOTHERM AND THE EQUATION OF STATE OF LIQUID VAPOR SYSTEMS, J. Chem. Phys. 23, 1250-55 (1955).

Pressure-volume-temperature data on xenon, carbon dioxide, and hydrogen are analysed. Special attention is paid to the regions fairly close to, but not in the immediate neighbourhood of, the critical point. It is shown that in each case the critical isotherm is of the fourth degree, one degree higher than that of the coexistence curve, as is required by the theorem of Rice. However, the relation between the critical isotherm and the co-existence curve is determined by the almost constant value of $\partial^2 P/\partial T \partial \rho$ in the PVT region considered, and this is different from its value at the critical point. The critical isobar is also considered and it is shown that it is of the fourth degree near the critical point, but of lower degree further away. A general equation of state is deduced for the PVT region under discussion, and the implications of this equation of state with respect to the coexistence curve and the critical isotherm are considered.

INTERFACIAL CHARACTERISTICS

1299. Allred, J. C., Blount, G. H. and Miller, J. H.

EXPERIMENTAL STUDIES OF TAYLOR INSTABILITY, LA-1600 (1953) 72 p.

Experimental observations of Taylor instability have been made on interfaces of fluids under uniform and under impulsive accelerations. The theoretical results of Pennington and Bellman and of Birkhoff and Ingraham concerning the effects of surface tension and viscosity on the growth by surface tension is found to be in essential agreement with the theory. The growth coefficients, $\alpha(\eta = \eta_0 \cosh \alpha t)$, were measured to be less than those predicted by the linear theory in cases where growth of a wave was observed. The discrepancy is perhaps due to effects connected with the necessarily finite amplitude of the wave when measurements can be made. A new mechanism leading to the restraint of growth is proposed, that of the existence of a density gradient of finite width at an interface, as opposed to a true discontinuity of density. The importance of Helmholtz instability in the development of the shape of the interface is demonstrated. Turbulent mixing of the fluids at sufficiently great Reynolds number is observed. The mixing, producing a region of density gradient, provides a final inhibitory effect on the growth. The wavelength of most rapid growth at an interface has been observed in experiments with impulsive acceleration, again in agreement with theory. Some experimental refinements for future observations of impulsive accelerations are suggested.

1300. Bellman, R. and Pennington, R. H.

EFFECTS OF SURFACE TENSION AND VISCOSITY ON TAYLOR INSTABILITY, Quarterly of App. Math. 12, 151-153 (1954).

The model used is that of two fluids of infinite depth, with the interface initially in the form of a sine wave with amplitude small compared to wave length. The fluids are considered incompressible, and only the linear terms in the equations of hydrodynamics are used. The first four sections discuss the effects of surface tension and viscosity. The fifth gives a few numerical results to illustrate the main points of the preceding sections.

1301. Birkhoff, G.

NOTE ON TAYLOR INSTABILITY, Quart. Appl. Math. 12, 3, 306-309 (October 1954).

G. I. Taylor has discussed the stability under normal acceleration of a plane interface separating two fluids of different density. His main conclusion is the interface is unstable when the light fluid is accelerated towards the dense fluid and (presumably) stable when the reverse holds. This conclusion has applications to gas-filled underwater explosion bubbles. Its applicability to small vapor-filled (i.e. constant pressure) cavities is, however, less clear. The purpose of this note is to show that, in spite of the fact that the denser liquid is being accelerated towards the lighter vapor, collapsing bubbles are unstable, and that this result is unaffected by surface tension (though it may be affected by viscosity or thermodynamic considerations). The proof of this fact depends on a study of the stability near $t = 0$ of differential equations of the form $t^n x^{(n)} + a_1 t^{n-1} x^{(n-1)} + \ldots + a_n x = 0$; $x^{(k)} = \frac{d^k x}{dt^k}$. Since $t = 0$ is a regular singular point of this equation, the type of instability arising is algebraic and not of the exponential kind usually considered. (AMR-8-1409)

1302. Birkhoff, G.

TAYLOR INSTABILITY AND LAMINAR MIXING, LA-1862 (1954) 76 p.

Taylor instability involves 5 successive stages of mixing: infinitesimal amplitude, finite amplitude, Taylor's "asymptotic" interpenetration by spikes and round-ended columns, breakup of these spikes, and turbulent mixing. The existing theory of Taylor instability is critically reviewed and extended. This theory covers the first 3 stages in the growth of periodic disturbances of the interface separating 2 nonviscous incompressible fluids. (Using Fourier analysis, the first stage can be treated without assuming periodicity.) The analysis is based on classical hydrodynamics, supplimented by modern numerical methods. It is indicated how the fourth stage can be treated similarly. The fifth stage must be treated by statistical methods. (NSA-9-6245)

1303. Chiarulli, P. and Dressler, R. F.

CONDENSATION INTERFACES IN TWO-PHASE FLOWS, Journal of Applied Physics, 28, 990-997 (September 1957).

The condensation zone of a condensing vapor flowing in a channel is idealized as an interface separating vapor and liquid phases of the fluid with a concentrated friction, heat removal, and cold-liquid injector mechanism at the interface. Rankine-Hugoniot relations are obtained including effects of the mass, momentum, and energy sources at the interface. For a stationary interface, an explicit approximate solution is obtained giving the final liquid state in terms of the other parameters. In addition, a rapidly converging iterative procedure is presented with this solution as a first approximation and utilizing directly thermodynamic tables of the vapor and liquid. Examples corresponding to steam flow in a pipe and to an underwater stream jet are considered and their Hugoniot curves are computed and compared to similar curves obtained in detonation theory. The thermodynamic requirements of the existence of a steam-water interface limit these curves in extent and result in upper and lower bounds on the values of the cooling parameters.

1304. Davies, R. O.

A DISCUSSION ON THE FIRST AND SECOND VISCOSITIES OF FLUIDS: A NOTE ON SIR GEOFFREY TAYLOR'S PAPER, Proc. Roy Soc. (London) A226, 39 (1954).

Incompressible fluids possess only one coefficient of viscosity because, by definition, no changes in volume can occur. If such a fluid contains air bubbles it becomes compressible, and any changes in volume involve a contraction or expansion of the bubbles which is resisted by the ordinary viscosity of the surrounding fluid. The resulting second coefficient of viscosity is found to be $4\mu/3\nu$, where μ is the viscosity of

the incompressible fluid and ν the (small) proportion of the total volume which is occupied by the bubbles.

The effect of compressibility in the fluid is discussed in Notes by Taylor and Davies. In the second of these it is shown that a relaxation time must exist and in the first the volume viscosity of water containing air bubbles is calculated. This is found to reach a maximum value of 6700 times the viscosity of water when $\nu = 5 \times 10^{-5}$. (Sci.A.-58-85)

1305. Davies, R. O.

THE TWO COEFFICIENTS OF VISCOSITY FOR AN INCOMPRESSIBLE FLUID CONTAINING AIR BUBBLES, Proc. Roy Soc. London, A226, 40-2 (1954).

By allowance for the compressibility of the liquid Taylor's model can be modified so as to exhibit relaxation.

1306. Gilbert, H. W. and Shaw, P. E.

ELECTRICAL CHARGES ARISING AT A LIQUID-GAS INTERFACE, Proc. Phys. Soc. (London) 37, 195-214 (1925).

The various methods of studying the potential differences and electric charges which arise at the liquid-gas interface are reviewed and discussed under the following headings:

I. The determination of P.D. at the interface of liquid-gas when one or both of these is at rest.

II. Cataphoresis of gas bubbles.

III. Passage of gas over a liquid, without rupture of the latter, or of a gas over a wet solid with the same proviso.

IV. The fall of a liquid in an unbroken column through a gas.

V. Liquid jets.

VI. Waterfall electricity.

VII. Electrification produced by bubbling gases through liquids.

VIII. Electrification produced by shattering drops in an air stream.

IX. Electrification produced by spraying a liquid.

An attempt is made to co-ordinate the material obtained from this vast area of research. Many of the results may be explained in terms of the modern theory of orientation and polarisation at the liquid-gas interface, but there are other facts which do not appear to come within the scope of any established principles. Suggestions are made as to possible developments in future research. (CA-19-2772-9)

1307. Gleim, V. G. and Shelomov, I. K.

ON THE PHENOMENA AT THE INTERFACE BETWEEN TWO PHASES IN BOILING MIXTURES, Shur. Priklad. Khim., 30, 32-8 (1957).

Peculiarities of the phase interface of solutions during boiling. V. G. Gleim and I. K. Shelomov (Inst. Railroad Transportation Engrs., Rostov-on-Don). Zhur. Priklad. Khim. 30, 32-8(1957); cf. C.A. 49, 10014b. The surface tension σ of 1 and of 2 mole % solns. of NaCl, NaOH, Na_2SO_4, Na_2CO_3, and $MgSO_4$ was detd. in the range of 20-90 $\pm$0.05°. The difference in σ of these solns. was slight. Hence, the desorption of these salts from the surface of their solns. could not be selective, i.e. the relative proportions of these salts at the surface and in the bulk of the soln. was the same and independent of the temp. The difference $\sigma_{soln.} - \sigma H_2O$ = const. and $\sigma_{soln.} = \sigma'_{soln.} (\partial\sigma_{soln.}/\partial T)(T - T_1) = \sigma'_{soln.} + (\partial\sigma H_{2O}/\partial T)(T - T_1)$, where $(\partial\sigma H_2O/\partial T)(T - T_1)$ is independent of the concn. C and on differentiation becomes $\partial\sigma_{soln.}/\partial C \pm f(T)(\sigma'$ is σ at some specific temp. T). The temp. coeff. of σ is independent of the electrolyte and the compn. of the soln. and is equal to that of H_2O. The surface activity, however, is a function of the concn., the nature of the solute, and the temp. (CA-51-10971b)

1308. Gleim, V. G., Shelomov, I. K. and Shidlovskii, B. R.

PROCESSES LEADING TO GENERATION OF DROPLET BY THE RUPTURE OF BUBBLES AT THE LIQUID-GAS INTERFACE, Zhur. Priklad, Khim 32, 218-22 (1959), English Translation: Journal Appl. Chem. (USSR), 32, 222 (1959).

The shape of bubbles formed at the liquid-air interface was observed photographically. The mass, m, of the droplets formed as the bubble rose to a height, h, was detd. The bubble at the interface consisted of 2 hemispheres; in liquid forming thin films the upper part approached the shape of a hemisphere. Droplets formed only when the radius of the bubble, r, exceeded a crit. value, γ_{cr}. The exptl. data were correlated with the theoretical equation $mgh = K(2\pi r^2/r_{cr})(\gamma_{cr} - \gamma)\sigma$, where σ is the surface tension of the liquid. In 0.1N $NaSO_4$, NaCl, NaOH, and Na_2CO_3 and in H_2O the values of K were 0.0124, 0.0123, 0.96, 0.95, 0.0122. $h = A(\gamma_{cr} - \gamma)$ and m = Br_2, where A and B are consts. (CA-53-9779c)

1309. Goltz, G. E.

INTERFACE PHENOMENA IN LIQUID LIQUID EXTRACTION, J. Imp. Coll. Chem. Eng. Soc. 12, 40-50 (1958-59).

Phenomena assocd. with mass transfer across an interface between 2 liquid phases were studied qual. by the Schlieren technique. Eruptions and oscillations were caused by local changes in interfacial tension owing to concn. differences. Convective streams within the droplet were chiefly responsible for the concn. inhomogeneities.

1310. Hazelhurst, T. H.

DEMONSTRATION OF PHENOMENA AT INTERFACES-HANGING BUBBLES AND ROLLING DROPS, J. Chem. Educ. 25, 252-3 (1948).

1311. McTaggart, H. A.

THE ELECTRIFICATION AT THE BOUNDARY BETWEEN A LIQUID AND GAS, Phil. Mag. 44, 386-95 (1922).

In continuation of previous work the author has investigated the electric charges on small spheres of air immersed in an aqueous solution of thorium nitrate. The spheres become positively charged in solutions of the salt as dilute as $8 \cdot 10^6$ normal. For

concentrations in the neighbourhood of $6 \cdot 10^6$ normal, a sphere initially negatively charged becomes gradually positively charged as the sphere decreases in size. It is suggested that the reversal of sign affords evidence of a relation between the curvature of the surface and its adsorptive power. (CA-16-4102-3)

1312. Plesset, M. S.

THE STABILITY OF FLUID FLOW WITH SPHERICAL SYMMETRY, J. Appl. Phys. 25, 96-8 (1954).

The conditions for the stability of instability of the interface between two immiscible incompressible fluids in radial motion are deduced. The stability conditions derived by Taylor (Proc. Roy. Soc. London) A201, 192(1950) for the interface of 2 fluids in plane motion do not apply to spherical flows without significant modifications.

1313. Rehbinder, P. and Wenstrom, E.

THE STABILIZING ACTION OF ADSORPTION LAYERS OF SURFACE-ACTIVE SUBSTANCES ON DISPERSE SYSTEMS. II. THE STABILITY OF BUBBLES AND DROPS AT INTERFACES, Kolloid-Z, 53, 145-58 (1930).

Several definitions for stability of disperse systems are discussed. It is shown that the maximum degree of stability of aqueous suspensions (of graphite and carbon) and emulsions (e.g., aqueous mercury emulsions) by the addition of surface active substances of sufficient boundary-surface active stability is attained by completely satisfying the adsorptive surface. Foam possesses in certain cases "liquid" adsorption surfaces (i-amyl alcohol in water). The results of Bartsch are confirmed. In certain cases "semi-solid" adsorption surfaces are shown. Ways of measuring and considering the emulsification and foam building capacity are given with reference to the life of an air bubble on the free surface of a solution of boundary-surface active substances as well as for droplets of one of the two of the contracting liquids on their smooth surfaces of separation. (CA-25-630-2)

1314. Sklyarenko, S. I. and Baranaev, M. K.

THE RELATION OF THE VAPORIZATION VELOCITY TO THE NATURE OF THE INTERFACE BETWEEN BOILING LIQUID AND FLOWING GAS, Z. physik. Chem. A175, 214-18 (1935).

The equation $W_1/W_0 = \sqrt{D_1/D_0}$ holds for those cases in which the vapor of a substance is heavier than the gas passing over it. Accordingly the ratio of the vaporization velocities of a substance in a stream of gas (W_1) and in air (W_0) depends on the ratio of the diffusion coeffs. of the vapors of the substance in the gas (D_1) and in air (D_0). The presence of convection streams must be considered in those cases in which the vapor of the liquid is lighter than the gas passing over it.

1315. Spalding, D. B.

HEAT AND MASS TRANSFER BETWEEN THE GASEOUS AND LIQUID PHASES OF A BINARY MIXTURE, Internat. J. Heat Transfer, 4, 47-62 (Dec. 1961).

A rigorous theoretical analysis is presented of the heat and mass transfer occurring at an element of the interface separating the liquid and gaseous phases of a binary mixture. Solutions of the equations are presented for ethanol-water mixtures, three separate cases being considered, namely: (i) the bulk liquid and gas states are not saturated, and both Lewis numbers equal to unity; (ii) the bulk states are saturated and both Lewis numbers equal unity; and (iii) the liquid Lewis number is close to zero, while the gaseous one equals unity, the bulk states being either saturated or not. Results are compared with the predictions of the approximate (equi-molal transfer) treatment conventionally used. It is shown that the conventional theory only gives tolerable accuracy for case (ii); in the other cases its prediction bears almost no relation to those of the rigorous theory. The rigorous theory shows that, in the examples considered, either net condensation or net vapourization may occur, depending on the conductance values and the bulk states. In some cases the more volatile component is caused to condense despite having a higher gas-phase concentration at the interface than in the bulk of the gas.

1316. Sterman, L. S. and Lepilin, R. S.

ON THE PROBLEM OF DETERMINING OF THE TRUE INTERFACE DURING BUBBLING OF STEAM THROUGH LIQUIDS, Teploenergetika, V. 7, No. 1, 45 (1960).

1317. Strawson, D. G.

A STUDY OF THE CONDITIONS REQUIRED FOR A STABLE INTERFACE BETWEEN PHASES IN TWO PHASE FLOW, B. S. Thesis, Massachusetts Inst. of Tech. (1957).

1318. Taylor, Sir G.

THE STABILITY OF LIQUID SURFACES WHEN ACCELERATED IN A DIRECTION PERPENDICULAR TO THEIR PLANES: I, Proc. Roy. Soc. (London) A201, 192 (1950).

It is shown that, when two superposed fluids of different densities are accelerated in a direction perpendicular to their interface, this surface is stable or unstable according to whether the acceleration is directed from the heavier to the lighter fluid or vice versa. The relationship between the rate of development of the instability and the length of wave-like disturbances, the acceleration and the densities is found, and similar calculations are made for the case when a sheet of liquid of uniform depth is accelerated.

1319. Taylor, G.

A DISCUSSION ON THE FIRST AND SECOND VISCOSITIES OF FLUIDS: NOTE ON THE VOLUME VISCOSITY OF WATER CONTAINING BUBBLES, Proc. Roy Soc. (London) A226, 38-39 (1954).

Incompressible fluids possess only one coefficient of viscosity because, by definition, no changes in volume can occur. If such a fluid contains air bubbles it becomes compressible, and any changes in volume involve a contraction or expansion of the bubbles which is resisted by the ordinary viscosity of the surrounding fluid. The resulting second coefficient of viscosity is found to be $4\mu/3v$, where μ is the viscosity of

the incompressible fluid and v the (small) proportion of the total volume which is occupied by the bubbles.

The effect of compressibility in the fluid is discussed in Notes by Taylor and Davies (abstracts following). In the second of these it is shown that a relaxation time must exist and in the first the volume viscosity of water containing air bubbles is calculated. This is found to reach a maximum value of 6700 times the viscosity of water when $v = 5 \times 10^{-5}$. (Sci. A.-58-84)

1320. Tchen, C. M.

APPROXIMATE THEORY ON THE STABILITY OF INTERFACIAL WAVES BETWEEN TWO STREAMS, Jour. Appl. Phys. 27, 1533-36 (1956).

The stability of the interface of two superposed streams is studied by extending the theory of Helmholtz stability to include the viscosity and surface tension in the waves. The two uniform layers of incompressible fluids are of different densities, viscosities and stream velocities. Gravity, Taylor acceleration, and surface tension are taken into consideration. An approximate theory is developed and is valid in three ranges of wave numbers. Neutral stability, rate of growth, and rate of decay are illustrated graphically.

1321. Wada, Masayoshi

INTERFACIAL TENSIONS IN FLOTATION. V. FLOW OF LIQUIDS UNDER INTERFACIAL TENSION, Science Repts. Research Inst. Tohoku Univ. Ser. A, 2, 645-62 (1950).

The life period of a bubble formed at the liquid surface was considered to depend on the decrease in thickness of the liquid film caused by draining and evapn. During the 1st stage of the life of the bubble, draining is the most important factor in diminishing its thickness. The following equation was derived to account for the flow of liquids in vertical capillary tubes: $t = 8v/R^2Dg(h - z + z_0 \ln [(z_0 - h)/(z_0 - z)]$, where t is the time, v is the viscosity, D is the d., R is the radius of the capillary tube, g is the acceleration due to gravity, h is the initial height of the liquid column from the free surface, z is the height of the column in time t, and z_0 is the height of the liquid column at equil. The following theoretical formula was developed and was applied satisfactorily to aq. solns. of EtOH and PrOH: $y = 1 + ac + b(\log c)^n$, where y is the relative viscosity, c is the concn., and a, b, and n, are consts. The following empirical formula was developed for relating the d. of aq. solns. of EtOH and PrOH to the concn.: $\log (D_0 - D) = A + B \log c + C (\log c)^2$, where D is the d. of the soln., D_0 is that of the solvent, and A, B, and C are consts. The time of flow of aq solns. of EtOH in a vertical capillary tube of 0.01 cm inner radius at 25° exhibited max. at low and high concns.

MASS TRANSFER ACROSS PHASE BOUNDARIES

1322. Baird, M. H. I. and Davidson, J. F.

GAS ABSORPTION BY LARGE RISING BUBBLES, Chem. Eng. Sci. 17, 87-93 (1962).

The absorption rate of CO_2 from single rising bubbles of equiv. diam. 0.8-4.2 cm was measured. Bubble velocities, which were in the range 20-40 cm/sec, correspond to values reported by others. For small bubbles, the mass transfer rate remains const. after 1-2 sec. For larger bubbles, the rate is unsteady and decreasing. This is attributed to the gradual satn. of the liquid being carried along behind the bubble. Rate scatter occurs with tap water, probably due to traces of surface-active impurities. Added detergent reduces the absorption rate. It is believed this is caused by a stagnant layer on the front surface of the bubble and a redn. in ripples in the rear surface.

1323. Belkin, H. M.

MASS TRANSFER IN TURBULENT LIQUID FILMS, Ph.D. Thesis Carnegie Inst. of Tech. (1953).

1324. Benjamin, C., Lu, Y. and Graydon, W. F.

PREDICTION OF VAPOR LIQUID EQUILIBRIUM DATA, Ind. Eng. Che. 49, 1058-1060 (1957).

Empirical equations are used for predicting the vapor-liquid equilibrium data at 1 atm. for binary systems composed of hydrocarbons, one of which is an aromatic compound. The data required as primary information are the vapor pressures and internal pressures of the pure components. All of these systems show considerable deviation from ideality and some of the systems show a minimum boiling azeotrope.

1325. Berman, L. D.

THE TREATMENT OF EXPERIMENTAL DATA ON THE OVER-ALL COEFFICIENTS OF HEAT AND MASS TRANSFER BETWEEN LIQUID AND GAS (STEAM) PHASES, Zhur. Priklad. Khim 29, 138-41 (1956). English Trans. in: J. Appl. Chem. USSR 29, 151-3 (1956).

The use of Korpichev's criteria Ki as a short cut to the difficult exptl. detn. of the necessary coeffs. of film resistances is not justified theoretically and leads to errors. Ki is only another form of Nusselt's criteria, and expressing it as a function of Reynold's and Prandtl's nos. does not remove the fact that it is only an empirical relation not based on the theory of similitude.

1326. Brandstaetter, F.

REMARKS ON H. MACHE'S METHOD FOR THE DETERMINATION OF THE DIFFUSION COEFFICIENT OF AIR IN WATER, S. B. Osterr. Akad. Wiss. IIA, 161, No. 4-6, 107-30 (1952).

H. Mache's gas bubble method for the quick determination of the d.c. of gases in liquids gave an apparent dependence of the d.c. on the bubble radius. In the present paper it is shown by systematic experiments that this dependence is probably due to a surface effect as the transfer of the gases through the bubble surface is influenced by the unavoidable presence of solutes. (Sci. A-56-4649)

1327. Calderbank, P. H. and Moo-Young, M. B.

CONTINUOUS PHASE HEAT AND MASS TRANSFER PROPERTIES OF DISPERSIONS, Chem. Eng. Sci. 16, 39-54 (1961).

Previous mass transfer data for bubble swarms have been extended to include solns. with high viscosities and the high diffusion coeffs. obtained when using H as a solute. These new data are combined with published work in presentation of correlations of liquid-phase mass-transfer coeffs. for bubble swarms passing through liquids in sieve and sintered plate columns and in aerated mixing vessels. When a dispersed phase is suspended, or in free rise or fall under the effect of gravity, the heat- and mass-transfer coeffs. are almost completely unaffected by mech. power dissipated in the system. For gas-liquid dispersion, increasing the power increases the interfacial area and the rate of transfer, but does not increase the mass-transfer coeff. Where difference in d. between phases is small, the transfer rates are extremely low.

1328. Chilton, T. H. and Colburn, A. P.

MASS TRANSFER (ABSORPTION) COEFFICIENTS, Ind. Eng. Chem. 26, 1183-87 (1934).

Prediction from data on heat transfer and fluid friction; it is shown that curves given in separate paper, by A. P. Colburn and O. Houzen, predict forms of mass transfer coefficients in close agreement with data for flow inside of tubes taken from work of Greenwalt, that of Sherwood and Gilliland, and some unpublished data of authors.

1329. Coates, J. and Pressburg, B. S.

SIMULTANEOUS TRANSFER OF HEAT AND MASS, Chem. Eng. 68, 95-8 (1961).

Gas-liquid systems in which simultaneous heat and mass transfer processes occur are studied. This type of system includes humidifiers, dehumidifiers, and water coolers. Heat and mass transfer equations are derived for humidifiers and dehumidifiers. It is noted that liquid entrainment, large pressure drops and other mechanical problems must be considered, in addition to the physical aspects of the system.

1330. Collins, D. E.

COCURRENT GAS ABSORPTION, PhD Thesis, Purdue Univ. (1958).

1331. Coppock, P. D. and Meiklejohn, G. T.

BEHAVIOR OF GAS BUBBLES IN RELATION TO MASS TRANSFER, Trans. Inst. Chem. Engrs. (London) 29, 75-86 (1951).

The equation $V_B = CD\sqrt{\rho}$ describes satisfactorily the relation between the size of bubble formed at a circular orifice, the diam. of the orifice, the surface tension and the liquid d. so long as the value of the numerical factor C is related to the rate of bubble formation. An empirical relation between C and the rate of bubble formation is given. The upward velocity of a bubble in water varies with the diams. of both

the bubble and the column of liquid in which it moves, and also with the rate of production of bubbles. The mass-transfer coeff. K_L from O_2 to water was measured and found to vary from 0.028 to 0.055g O_2/sq cm x sec x g O_2/cc. The apparent effect of velocity on the coeff. was considerable within the range measured. Although a strict comparison with coeffs. measured in packed towers is not possible, the values of K_L for bubbles are slightly higher than those measured in packed towers for the desorption of O_2. (CA-46-7375h)

1332. Deindoerfer, F. H. and Humphrey, A. E.

MASS TRANSFER FROM INDIVIDUAL GAS BUBBLES, Ind. Eng. Chem. 53, 755 (1961).

Motion pictures were taken of the rise of CO_2 bubbles through H_2O. Bubble diams. were 0.1-0.6 cm. Mass-transfer rates were detd. by measuring the decrease of bubble vol. At 0.5 sec after release, mass-transfer coeffs. were about 10 times greater than at 6 sec. The decrease with time is ascribed to the decay of internal circulation.

1333. Dmitrevskii, G. E. and Bol'shakov, A. G.

ABSORPTION OF GASES BY LIQUIDS ON BUBBLE-CAP PLATES. I. HUMIDIFICATION OF AIR, Nauch. Ezhegodnik, Odessk, Gosudarst. Univ., Khim. Fak. No. 2, 23-8 (1961).

The evapn. of water is a process in which the rate of vaporization is limited by the mass transfer resistance of the gas phase. The mass transfer coeff. is detd. by the dynamic method. Two kinds of bubble caps with triangular slots are used, (1) closed caps with a single slot, and (2) open-bottomed caps with slots distributed about the circumference. Exptl. data are given in tables and graphs. The following equation is used: $Nu = A(Re)^x(Pr)^y(a/h_{eff})^z$ where: $Nu = [(P \cdot K_g \cdot h_{eff}/D\gamma_A)]\cdot(\sigma 1/\gamma 1)^{1/2}$, a modification of the Nusselt no.; $Re = w \cdot d_{eq}/\eta$, Reynold's no.; $Pr = \eta/\gamma \cdot D$, a Prandtl-type no.; K_g = the conventional vol. coeff. of absorption, in kg/cu m hr atm; P = total pressure, in atm; h_{eff} = effective height of the foam layer, in m; σ_1 = surface tension of the liquid, in kg/m; γ_1 = d. of liquid, in kg/cu m; D = gas-phase diffusion coeff. of the material vaporized, in sq m/hr; γA = gas-phase d. of the substance vaporized in kg/cu m; w = slot velocity, in kg/cu m/hr; d_{eq} = equiv. diam. of the slot, in m; η = gas viscosity, in kg/m hr; and a = width of the slot.

1334. Englehard, H. and Schillke, W.

ABSORPTION OF AEROSOLS IN LIQUIDS, Kolloid-Z, 86, 213-19 (1939).

The absorption of CO_2 and NH_4Cl fumes in H_2O and KOH soln. was measured by bubbling the vapor or smoke into the liquid through calibrated capillary tubes. The following phenomena were observed during the passage of the fume bubbles through liquids: Brownian movement, motion of the bubbles, growth of the fume particles through the absorption of water and aggregation of the fume particles. The absorption of aerosols (fumes, smokes) is detd. by the mobility of the individual particles and the size of the gas bubbles, whereas the absorption of gases such as CO_2 depends almost entirely on the state of the liquid phase. (CA-33-3654-9)

1335. Eucken, A.

ENERGY AND MATERIAL EXCHANGE ON BOUNDARY SURFACES, Naturwissenschaften 25, 209-218 (1937).

From a consideration of a number of examples, including the condensation of water vapour in the form of both drops and thin films, the critical condensation temperatures of metal vapours, and the accommodation coefficients of gases, it is shown that an energy transfer usually accompanies a material transfer at the bounding surface between gas and solid. This is particularly true for processes involving absorption, and, on the other hand, the material transfers concerned are conditioned by the energy flow. A satisfactory explanation of the molecular processes called into play at the boundary can only be forthcoming if the two effects are considered jointly.

1336. Fallah, R., Hunger, T. G. and Nash, A. W.

UNDERLYING DESIGN OF LIQUID-GAS CONTACT EQUIPMENT, J. Soc. Chem. Ind. 53, 369 (1934).

Coefficients of mass transfer through gas film; general equation derived for gas absorption.

1337. Finzi, S., et al.

MASS AND HEAT TRANSFER IN CONCURRENT LIQUID GAS FLOW. POSSIBLE APPLICATION TO SOME SEPARATING PROCESSES AND TO SOME SEPARATING UNITS, Energia nucleare (Milan) 4, 211-21 (1957)June.

Isothermal mass transfer is studied in the case when liquid water is forced to raise by water vapor and experimental results are presented for the HDO-H_2O system. In the case of non-isothermal heat and mass transfer, results are applied to the possible recovery of heat in separating units, based on the chemical exchange between hydrogen and water.

1338. Garner, F. H.

MECHANICS OF DROPS AND BUBBLES IN DIFFUSION PROCESSES, Chemistry and Industry, 8, 141-5 (Feb. 25, 1956).

Evidence that mass transfer between gas and liquid or between liquid and liquid involves diffusional resistance in both phases; in two-film theory assumption is made that there is equilibrium at interface and diffusive resistance takes place in films adjacent to interface; drops and bubbles investigated were usually in range of 0.2 to 0.6 cm, but are applicable within certain limitations to smaller droplets.

1339. Grassman, P.

MASS AND HEAT TRANSFER BETWEEN TWO FLUID PHASES, Chem. Ing. Tech. 31, 148-53 (1959).

A comprehensive treatise of transfer phenomena involving gas bubbles and liquids. If 3 assumptions can be made, which hold reasonably well in many cases, the problem can be simplified to presentation in a 2-dimensional diagram. Basic principles, literature data, and generalized math. formulations are treated. 25 refs.

1340. Grossman, U.

MASS AND HEAT TRANSFER BETWEEN LIQUID AND VAPOR BUBBLES IN ALCOHOL-WATER MIXTURES, Chem.-Ing.-Tech. 28, 107-112 (1956).

Heat and mass exchange between liquid and vapor of system alcohol/water, investigated in simple apparatus; it was possible to measure enrichment ratios and change in diameters of bubbles, formed from vapor mixtures at jet, as functions of various parameters; from change of bubble diameters heat transfer numbers could be calculated.

1341. Guyer, A. and Pfister, X.

THE ABSORPTION OF GAS BUBBLES, Helv. Chim. Acta, 29, 1173-83 (1946).

The rate of absorption of CO_2 in water was detd. as a function of the depth of the liquid and the size of the bubbles. The percent absorbed of bubbles of different sizes in rising through a layer of const. thickness was also detd. Similar expts. were carried out in NaOH solns. of varying concn., in solns. of mixts. of K_2CO_3 and $KHCO_3$ with a const. total concn. of 2 N, in triethanolamine soln., and in Na glycoholate solns. The speed of ascent in water of bubbles of various sizes was found. All results are presented in the form of curves. The most rapid absorption in water occurs with bubbles of approx. 0.02 cc vol. (CA-40-6922-4)

1342. Guyer, A. and Pfister, X.

THE ABSORPTION OF GAS BUBBLES II, Helv. Chim. Acta. 29, 1400-12 (1946).

The rate and completeness of absorption of CO_2 from bubbles contg. air and CO_2 was detd. as a function of the height of the column, the bubble size, and the initial concn. of CO_2. In comparison to bubble size, gas soly., and the velocity of the chem. reaction, the diffusion rate within bubbles contg. an inert gas is decisive in detg. absorption speed. For large bubbles this factor causes a large decrease in the absorption rate; the effect is less pronounced for small bubbles. For short columns and for low bubble frequencies the absorption occurring at the surface of the liquid column is important. (CA-41-4026g)

1343. Guyer, A., Richarz, W. and Guyer, A., Jr.

THE ABSORPTION PROCESS FOR GAS BUBBLES, Helv. Chim. Acta 38, 1192-1202 (1955). In German.

The absorption of SO_2 from air in H_2O was investigated in a bubble tower. By use of the experimentally detd. transition unit, the influence of liquid- and gas-flow on the efficiency of absorption can be shown. By excluding the influence of the exchange surface which varies with varying gas flow, the specific exchange surface was detd. with the help of photographs. The empirical equation for the dependence of partial transition no. is set up for gas- and liquid-flow: $k_1 = 0.09 G_M^{-0.75} L_M^{0.05}$, where G_M is inert-gas flow and L_M is flow of the pure solvent. (CA-49-14390c).

1344. Hobler, T. and Machej, Karol

SATURATION OF AIR WITH WATER VAPOR IN A SCRUBBER OPERATED WITH CONTINUOUS AND PULSATING WATER SUPPLY, Chem. Stosowana 6, 3-43 (1962).

The mass-transfer coeff. (β_A) was studied for the satn. of air with water vapor in a packed column, filled with Raschig rings (25 x 25 x 2.5 mm). The results were correlated by the equation $Sh = 0.0304\, Re^{0.83} Sc^{0.33}\, \phi$ (ϕ = effectiveness of packing surface), where $\phi = 1$ for $6370 \leqq g_W \leqq 25{,}500$ and $\phi = 0.1423\, g_W^{0.223}$ for $1800 \leqq g_W \leqq 6370$. Tests were conducted at $290 \leqq Re \leqq 1200$ and $1.8 \leqq W_0 \leqq 25.5$. β_A depends on W_0 in the range $1.8 \leqq W_0 \leqq 6.37$ (W_0 = liquid rate in cu m/sq m hr). Attempts were also made to intensify the heat transfer during air humidification by means of pulsating spraying of the packing. Since the highest intensification of heat transfer was ~10% and design difficulties were involved, the method was unsuitable for industrial purposes.

1345. Hsieh, Din-Yu and Plesset, M. S.

THEORY OF RECTIFIED DIFFUSION OF MASS INTO GAS BUBBLES, J. Acoust. Soc. Amer., 33, 206-15, (Feb. 1961).

The problem considered is the behaviour of a gas bubble in a liquid saturated with dissolved gas when oscillating pressures are imposed on the system. This situation is encountered in experiments on cavitation and in the propagation of sonic and ultrasonic waves in liquids. Since gas diffuses into the bubble during the expansion half-cycle in which the pressure drops below its mean value, and diffuses out of the bubble during the compression half-cycle in which the pressure rises above its mean value, there is no net transfer of mass into or out of the bubble in first order. There is, however, in second order a net inflow of gas into the bubble which is called rectified diffusion. The equations which determine the system include the equation of state of the gas in the bubble, the equation of motion for the bubble boundary in the liquid, and the equation for the diffusion of dissolved gas in the liquid. In the solution presented here, the acoustic approximation is made; that is, the amplitude of the pressure oscillation is taken to be small. It is also assumed that the gas in the bubble remains isothermal throughout the oscillations; this assumption is valid provided the oscillation frequency is not too high. Under these conditions one finds for the mean rate of gas flow into the bubble the expression

$$\langle dm/dt \rangle = (8\pi/3) D C_\infty R_0 (\Delta P/P_0)^2 \quad ,$$

where D is the diffusivity of the dissolved gas in the liquid, C_∞ is the equilibrium dissolved gas concentration for the mean ambient pressure P_0, R_0 is the mean radius of the bubble, and ΔP is the amplitude of the acoustic pressure oscillations. It may be remarked that the most important contribution to the rectification effect comes from the convection contribution to the diffusion process.

1346. Kafarov, V. V.

CALCULATION OF MASS TRANSFER PROCESSES, Zhurnal Prikladnoi Khimii, 31, 706-711 (1958).

Generalized equations of mass transfer in two-phase flow systems were obtained, taking into account the hydrodynamic interaction of phases. The concept of the dynamic surface fluctuation coefficient describing similitude of two-phase systems is introduced, which is based on fully developed free turbulence (emulsification) conditions. Analysis of available experimental data indicates that the calculation method proposed may be used in the design of diffusion equipment.

1347. Kamei, S., et al.

DESORPTION OF CARBON DIOXIDE BY BUBBLING AND SPRAYING, Chem. Eng. (Japan) 17, 309-15 (1953).

Two methods for recovering and removing CO_2 dissolved in high-pressure water are compared. In one method, a pressure vessel contg. water with dissolved CO_2 is connected to the atm. through a reducing nozzle; the dissolved gas, bubbling, is slowly desorbed to the atm. In the 2nd method, the water is sprayed at the top of a tower at atm. pressure. If the CO_2 is recovered, the latter method is superior. Factors affecting the rate of desorption and liquid concn. are detd. and discussed. (CA-47-9064h)

1348. Kamei, Saburo and Oishi, Jun

MASS AND HEAT TRANSFER IN A FALLING LIQUID FILM OF WETTED WALL TOWER, Kyoto Univ. Mem. Fac. Eng., 17, 277-89 (1955).

The flow state of a liquid film is said to have in important effect on the mass transfer as shown by the CO_2 absorption rate in water fed into the tower. All observed values of absorption rate were 1.5-3.5 times as large as the theoretical values computed on the basis of true mol. diffusion in a perfect laminar liquid film. However, the film at low values of R_eL, the Reynolds no. of liquid flow, is not in a perfect laminar state except at very small values, but has a pseudo-laminar flow in which ripples appear on the surface. An empirical formula was developed to account for discrepancies in the case of a stagnant gas and countercurrent flow of gas. In order to calc. heat-transfer rate in a falling liquid film, the enthalpy of gas as a driving force of transfer was used. Heated air at 88-100° entered the bottom of the tower and H_2O at 20-30° entered the top. The feed rate of H_2O was limited to within 260-940 R_eL. The temp. of air decreased 43-59° and the temp. of H_2O increased 1-7°.

1349. Li, P. S.

UNSTEADY-STATE MASS TRANSFER FROM GAS BUBBLES: LIQUID PHASE RESISTANCE, Thesis, U. of Wash., Seattle, Dissertion Abstr. 13, 741-2 (1953).

1350. Liang, S. Y. and Smith, W.

EFFECT OF HEAT TRANSFER BETWEEN THE PHASES ON THE PERFORMANCE OF COUNTER-CURRENT DISTILLATION COLUMNS, Chem. Eng. Sci. 17, 11-21 (1962).

If there is a mismatch between the rates of heat and mass transfer during a distn. process, evapn. or condensation will occur. This is termed thermal distn. Considering thermal distn.,it is shown that the performance of distn. columns should depend on compn. and should show a max.

1351. Liebermann, Leonard

AIR BUBBLES IN WATER, J. Appl. Phys. 28, 205-11 (1957).

The soly. of air bubbles was observed in a variety of expts. Freely rising bubbles exhibit a soln. rate more than twice that of bubbles that are stationary; i.e., trapped on the walls of the container. The theory of son. of stationary bubbles is given, but the theory of a free bubble is difficult and has not been solved. Stationary bubble observations lead to a detn. of the coeff. of diffusivity; 2.9×10^{-5} sq cm/sec at 27°; the temp. dependence is considerable, obeying Einstein's equation relating diffusion and viscosity. The effect of surface contamination on diffusion is analyzed; bubble soln. in the presence of contaminants is not greatly altered.

1352. Long, J. T.

RECENT ADVANCES IN GAS ABSORPTION APPARATUS IN RUSSIA, CF 58-11-77 (1959) 34 pp.

A survey was made of articles dealing with gas-liquid contacting appearing in Russian chemical engineering publications of the last decade. The mechanism of absorption under the nonideal conditions encountered industrially was studied and the theory advanced that absorption kinetics was a function of the time required for renewal of surface layers. The hydrodynamics of gas passage through a liquid was examined with respect to number, size, and shape of bubbles and rates of bubble ascent. The depth of the dynamically stable gas-liquid foam layer was determined for various conditions of initial liquid depth, physical properties of the liquid, and size and spacing of plate perforations. Equipment was developed which operates in the foam regime rather than in the bubble regime and has a lower pressure drop for a given effectiveness. A dynamically stable foam is produced which has a high gas content and a high degree of turbulence. Data reported on mass transfer, heat transfer, and removal of dusts or mists from gases in foam apparatus. (NSA-10143)

1353. Lykov, A. V.

HEAT AND MASS TRANSFER IN DISPERSE MEDIA WITH PHASE CHANGES, Inzhen.-fiz. zh, 1, No. 6, 12-19 (1958).

1354. McLeod, A. A.

LIQUID TURBULENCE IN A GAS-LIQUID ABSORPTION SYSTEM, Ph.D. Thesis Carnegie Inst. of Tech. (1951).

1355. Mochalova, L. A. and Kishinevskii, M. Kh.

KINETICS OF BUBBLE ABSORPTION, J. Appl. Chem. (USSR) 28, 25-33 (1955).

The rate of absorption of CO_2 in 0.43-2.70N NaOH (1), 0.85-1.70N monoethanolamine (2), and 0.414-1.57N Na_2CO_3 (3), and SO_2 in 0.35-0.68N Na_2CO_3(4) was detd. The temp. and the concn. were adjusted to maintain a const. viscosity. To eliminate the error caused by different size bubbles formed at different gas rates the opening of the bubbling tube, 2.5 mm diam., was submerged only 4 mm below the surface of the soln. The results in systems (1) and (2) are expressed by a somewhat modified basic equation: $d\omega/dr = \{(C_0/m)[1 - e^{-mHPiK} + HP]\}/[\rho + (H/\beta)]$ where Pi is the partial pressure of the gas in the phase interface and β and ρ are the gas and liquid film resistances, resp. A simplified expression $d\omega/dr = HP(KC + 1)/\rho$ applies to system (3) and $d\omega/dr = (C_0 + C_t)/[\rho + (H/\beta)]$ to system (4). The evaluation of the several variables and the procedure of simplification of the last 2 equations are analytically discussed in detail. Absorption of SO_2 is distinguished from that of CO_2 as not a phys. process but one controlled by the reaction $H_2O + SO_2 \rightleftharpoons H_2SO_3 \rightleftharpoons H^+ + HSO_3^-$; the total SO_2 dissolved in H_2O, C_t, is the sum of the unionized and ionized SO_2. β is obtained from $d\omega/dr = \beta P$ which holds at high concns. where Pi ≈ 0 and the rate is independent of C. (CA-49-10024e)

1356. Oyama, Y. and Iwase, K.

STUDIES ON ABSORPTION OF GAS IN THE FORM OF BUBBLES, Sci. Papers. Inst. Phys. Chem. Research, Japan, 35, 131-57 (Jan. 1939).

Results of experiment on absorption of carbon dioxide and air mixture by caustic soda solution with comparatively larger bubbles, 8.5 to 15 mm in equivalent diameter. (CA-33-3239-7)

1357. Oyama, Y. and Iwase, K.

SUPPLEMENT TO THE STUDIES ON ABSORPTION OF GAS IN THE FORM OF BUBBLES, Sci. Papers, Inst. Phys. Chem. Research, Japan, 36, 371-4 (Oct. 1939).

Reporting on studies of absorption of mixture of carbon dioxide and air in form of bubbles by solution of caustic soda, absorption of mixture of CO_2 and air in form of bubbles by caustic soda solution, using bubbles ranging up to 6.65 cc were studied. (CA-1534-3)

1358. Pichelkin, Y. N.

HEAT AND MASS TRANSFER OF MOIST AIR, Teploenergetika No. 6, 72-75 (1961).

1359. Ravdel, A. A.

THE PROBLEM OF SOLUTION OF GAS BUBBLES IN LIQUID, Zhur. Priklad Khim. 26, 752 (1953) English Translation in: J. Appl. Chem. (USSR) 26, 703-7 (1953).

Math. discussion of the detn. of the rate of soln. of gas bubbles in a liquid. The process of dissolving of the bubbles in water was considered for the following cases: (1) water that does not contain dissolved gases and (2) water that does contain dissolved gas e.g., O. Math. relations are introduced for the purpose of detg. the rate of soln. of floating bubbles of gas at different rates of bubble flow, and for calcg. the length of path passed over by the bubble until it is completely dissolved.

1360. Reid, K. J.

DIFFUSION AND EQUILIBRIUM IN TWO PHASE BINARY LIQUID SYSTEMS, J. Chem. Phys. 36, 559-60 (1962).

It is contended that any analysis of this problem must allow for independent transfer of the components and that to obtain a regular-solution criterion for true equilibrium one must consider also possible movement of the interface, which in a truly non-diffusing state must be stationary.

1361. Roesler, F. C.

COMMENT ON 'GAS BUBBLES IN SOLUTIONS', J. Chem. Phys. 19, 512-3 (1951).

Epstein and Plesset [J. Chem. Phys. 18, 1505 (1950)] have derived formulas for growth and dissolving of gas bubbles in a liquid phase when transport of the dissolved gas takes place by diffusion only. A theoretical discussion is presented of the opposite limiting case, in which the mechanical motions in the system more than match the diffusion. (NSA-5-5645)

1362. Saunders, A. R.

THE EFFECT OF GAS FILM RESISTANCE IN DIFFUSION FROM A POROUS SEPTUM INTO A FLUID STREAM, CF-60-10-40 (Oct. 1960) 10 p.

The theory of mass transfer into a flowing fluid is utilized to estimate the effect of gas film resistance on over-all rates of transfer through a porous septum. The expressions developed for the mass transfer ratio, Nu_f/N_M are given. In laminar rodlike flow at $Gz > 50$

$$Nu_f/Nu_M = 1.27 \frac{D_G}{D_{EM}} Gz^{0.5}$$

and for turbulent flow at $Re > 2100$

$$Nu_f/Nu_M = 0.023 \frac{D_G}{D_{EM}} Re^{0.80} Sc^{0.44}$$

For the system under consideration the mass transfer ratio is 100 to 1000, indicating that transfer through a gas film is ordinarily a fast process compared to diffusion across a porous membrane.

1363. Scala, S. M. and Sutton, G. W.

THE TWO-PHASE HYPERSONIC LAMINAR BOUNDARY LAYER - A STUDY OF SURFACE MELTING, 1958 Heat Transfer and Fluid Mechanics Inst. 231, (1958).

The rate of energy transfer to the surface of a hypersonic vehicle may be sufficiently great that in the absence of a heat absorption system, the surface may melt. For short flight times, this may be possible without the interaction between the gaseous boundary layer and a melting surface has been analyzed at a stagnation point of a blunt body.

The energy and momentum equations were solved for the liquid phase for Pyrex glass, whose viscosity

varies greatly with temperature. The energy, momentum, and diffusion equations were solved separately for the gaseous boundary layer, which was treated as a dissociated mixture of atoms and molecules, whose thermodynamic and transport properties were evaluated locally using the local composition and temperature at each point in the boundary layer.

The solution to the problem was then obtained by correctly matching the six pertinent gas-liquid interface conditions. The effect of interphase mass transfer is included; that is, some of the liquid glass evaporates at the liquid-gas interface in accordance with the local conditions. The results then yielded the rate at which the surface recedes.

1364. Schlegel, R.

SOLUBILITY AND DIFFUSION CONSTANTS FOR GASES, CP-2883 (1945), 16 p.

The solubility constants are presented for He, Kr, Xe, O_2, N_2, and air in H_2O. Inter-diffusion constants for gases and the diffusion of gases in H_2O are discussed.

1365. Scouller, W. D. and Nixon, J.

SOLUTION OF OXYGEN FROM AIR BUBBLES, J. Inst. Sewage Purification, 258-75 (1934).

Compilation of existing data and results; surface aeration; oxygen requirements of activated-sludge plants. (CA-30-3304-5)

1366. Shrange, R. W.

A THEORETICAL STUDY OF INTERPHASE MASS TRANSFER, New York, Columbia Univ. Press (1953).

1367. Solomakha, G. P. and Planovskii, A. N.

THE RELATION BETWEEN MASS TRANSFER IN THE GAS PHASE AND THE HYDRAULIC PARAMETERS DURING BUBBLING THROUGH PERFORATED PLATES, Khim. I. Tekhnol. Topliv. I. Masel. 7, 1-7 (1962).

On the basis of the results of 13 runs on the system, NH_3-air-H_2O in a column with perforated plates, the correlation of mass transfer $K_g a = 1575 W_k^{0.72} \times h_{st}^{0.5}$ is proposed, where W_k is the gas velocity in m/sec and h_{st} the static head of the liquid on the plate. This may be easily converted to det. the no. of transfer units $N_g = 0.437 W_k^{-0.28} \times h_{st}^{0.5} \times F_t/F_k$, where the latter factor is the ratio of the area of the perforated part of the plate to the cross section of the column. 17 references.

1368. Spalding, D. B.

GRAPHICAL METHOD OF CALCULATING HEAT TRANSFER, CONDENSATION, AND VAPORIZATION RATES IN PROCESSES INVOLVING H_2O-STEAM-AIR WATER MIXTURES, Proc. Inst. Mech. Engrs. 172, 839-63 (1958).

The properties of a plot of the isotherms and phase boundaries of water-steam-air mixts. on an enthalpy-compn. diagram for const. total pressure are shown to permit graphical constructions enabling surface conditions, heat- and mass-transfer rates, and equipment size to be deduced for convection, steam-drum, and radiant drying, cooling towers, condensers, gas coolers, and trickle coolers.

1369. Spalding, D. B. and Tyler, R. D.

GRAPHICAL REPRESENTATION OF THERMODYNAMIC PROPERTIES OF REACTING TWO PHASE MIXTURES, WITH SPECIAL REFERENCE TO HEAT AND MASS TRANSFER CALCULATIONS, Proc. Conf. Thermodynamic, and Transport Properties Fluids, London 1957, 150-8 (Pub. 1958).

A graphical formulation of the thermodynamic properties of chemically reacting 2-phase mixts. is presented which enabled the heat and mass-transfer calcns. to be performed simply. The properties of mixts. of the 2 reacting substances were plotted on a chart with enthalpy as ordinate and the mass content or unit mass of mixt. as abscissa. The charts were valid for a single total pressure and consisted of lines of const. temp. (isotherms) and lines indicating where phase changes occurred. The isotherms generally were straight lines except in regions where changes of temp. or fuel content involved changes in phase or chem. reaction, and they showed marked kinks at these phase boundaries and at stoichiometric fuel contents. Gradual curvature usually indicated dissocn. Charts are presented for (1) mixts. of a typical oil in the kerosene range with dry air at 1-atm. total pressure, and (2) mixts. of C with dry air at 1-atm. total pressure. Use of the charts in simple detns. of transfer rates is discussed, and the main features of the charts are described. Liquid hydrocarbons and solid C showed considerable similarities when reacting with air.

1370. Tang, Y. S., Duncan, J. M. and Schweyer, H. E.

HEAT AND MOMENTUM TRANSFER BETWEEN A SPHERICAL PARTICLE AND AIR STREAMS, NACA-TN-2867 (PB-109100) (1953), 48 p.

These transfers are becoming of increased importance in catalytic operations, flow in packed beds, calcining, gas absorption, combustion chambers, and other solid gas and liquid gas reactions.

1371. Thomas, W. J. and Houston, P.

SIMULTANEOUS HEAT AND MASS TRANSFER IN COOLING TOWERS, Brit. Chem. Eng. 4, 160-3, 217-22 (1959).

An analysis was made of mass- and heat-transfer processes in a cooling tower by the Mickley method, with 3 variables; water rate, air rate, and packed height. Tables are included of tie-line slopes at different levels of water rate and packed height, gas film mass-transfer coeffs., gas film heat-transfer coeff., liquid film heat transfer coeff., and no. of transfer units at different water rate and packed height levels. The results show that the liquid-film resistance to heat transfer is not negligible, and that satn. of the air in a cooling tower normally occurs in the packing before the top of the tower is reached. Equations are proposed for the effect of air rate, water rate, and packed height on the transfer coeffs.

1372. Toor, H. L. and Marchello, J. M.

FILM PENETRATION MODEL FOR MASS AND HEAT TRANSFER, A.I.Ch.E. Journal 4, 97-101, (1958).

The two major models of the mechanism of mass and heat transfer between two phases are the film theory and penetration theory; these are not unrelated concepts, but are limiting cases of a more general model. Quantitative transfer to old, intermediate, and young elements is discussed, along with mathematical development and curves.

1373. Tsoy, P. V.

THE PROBLEM OF HEAT AND MOISTURE TRANSFER IN EVAPORATION AND THE BOUNDARY CONDITIONS OF SECOND KIND, Inzhenerno-fizicheskiy zhurnal, 3, No. 12, 53-57 (1960).

The heat and mass transfer in capillary-porous bodies is described by differential equations suggested by A. V. Lykov, which have the form:

$$\left.\begin{aligned} \partial U/\partial t &= a_1^2 \partial^2 U/\partial x^2 + a_2^2 \partial^2 T/\partial x^2 \\ \partial T/\partial t &= a_3^2 \partial^2 T/\partial x^2 + a_4 \partial U/\partial t \end{aligned}\right\} (x \geq 0,\ t > 0) \qquad (1)$$

for a unilaterally bounded, one-dimensional body. T is the temperature; U is a potential function; and t is the time. This set of equations is investigated under the boundary conditions of second kind:

$$U(x,0) = f_1(x), \quad T(x,0) = f_2(x) \qquad (2)$$

$$\partial U/\partial x \Big|_{x=0} = \phi_1(t) \quad , \quad \partial T/\partial x \Big|_{x=0} = \phi_2(t) \qquad (3)$$

General solutions of the set and particular solutions to it are obtained for $a_2^2 = 0$. There are 3 Soviet references.

1374. Warner, C.

GAS DIFFUSION INTO A BUBBLE OF FIXED RADIUS, NAA-SR-Memo-5479 (1960), 5 p.

The problem of radiolytic gas diffusion into a bubble of fixed radius is solved. A constant source of radiolytic gas is assumed. The concentration of gas at the bubble surface is related to the pressure within the bubble by Henry's constant.

MEASUREMENT TECHNIQUES

1375. Abas-Zade, A. K.

A NEW INSTRUMENT FOR MEASURING THE HEAT CONDUCTIVITY OF LIQUIDS AND VAPORS AT HIGH TEMPERATURES AND PRESSURES, Transl. from Doklady Akad. Nauk Azerbaidzhan. S.S.R. 3, 3-7, AEC-TR-3796 (1947), 7 p.

An apparatus designed for use at pressures of 200 atm. and 400°C is described. The heat conductivity of some liquids can be measured both at and above their critical state using this device. Operation and measurement results of selected examples are also included.

1376. Ager-Hanssen, H. and Dæderlein, J. M.

A METHOD OF MEASURING STEAM VOIDS IN BOILING WATER REACTORS: A paper (582) presented at the 2nd Geneva Conf. on the Peaceful Uses of Atomic Energy, held at Geneva, 1-13, September, 1958 (Volume 11, p. 463-465).

It was found that the thermal neutron flux at the surface of an absorbing rod in a water moderated reactor is highly dependent on the density of the moderator close to the rod. Some experiments to investigate the effect were carried out in a D_2O-moderated reactor. The results indicate the feasibility of utilizing the effect for the construction of a void meter.

1377. Anderson, W. K. and Eno, B. E.

CALCULATION OF ATTENUATION FACTORS AND PERCENT SIGNAL CHANGE FOR X-RAY VOID DETECTION METHOD IN THE LIMITING CASE OF LOW QUALITY MIXED PHASE WATER SYSTEMS, KAPL-M-WKA-15 (1960), 18 p.

The effects of container material and wall thickness, x-ray quantum energy, and water channel thickness on attenuation factors and percent change in attenuation were examined in the region between zero and ten volume percent voids for water in the neighborhood of 500°F. Results indicate that, if nucleate boiling effects are to be detected an optimum experiment will require thin-walled tubes of a metal of low atomic number probably no higher than that for aluminum. Energies at 0.015 to 0.02 Mev must be selected to produce adequate meter ranges.

1378. Bartolomei, Ya G., et al.

UTILIZATION OF GAMMA RADIATION IN THE STUDY OF THE BUBBLING PROCESS. Translated from: Trudy Vsesoyuz. Nauch. Tekh. Konf. Primenen. Radioaktiv. i Stabil. Izotopov i Izluchenii v Narod. Khoz. i Nauke, AEC-tr-4206 (p8-11), 1957, 4 (Publ. 1958).

A γ-radiation technique for studying bubble formation in the boiling process is described. The distribution of steam and liquid phases in a volume under different conditions of bubbling was determined.

1379. Bodnar, L. H. and Himmelblau, D. M.

CONTINUOUS MEASUREMENT OF DIFFUSION COEFFICIENTS OF GASES IN LIQUIDS USING GLASS SCINTILLATORS, Intern. J. Appl. Radiation and Isotopes 13, 1-6 (1962).

Glass scintillators were used to measure the diffusion of $C^{14}O_2$ in water in a sealed diffusion capillary. These scintillators, while only 10% as efficient as plastic scintillators for C^{14} particles, are relatively inert and non-absorbing. By employing radioactive tracers and standard counting equipment, it was possible to monitor the slow process of diffusion for as long as several hundred hours without disturbing the system by sampling. The diffusion coefficient obtained at 30°C for carbon dioxide agreed with previous coefficients.

1380. Boudan, J.

APPARATUS FOR MEASURING SPATIAL CONCENTRATIONS IN CURRENT OF AIR AND WATER MIXED, Houille Blanche 6, No. 3, 406-10 (1951).

Electric principles of gages used to measure spatial concentrations both in case of air bubbles and of solid particles.

1381. Boyd, L. R.

DETECTION OF NUCLEATE BOILING BY FLUX VARIATION MEASUREMENT, KAPL-M-LRB-3, (1956), 13 p.

Nucleate boiling in a reactor neutron flux can be detected by means of an ion chamber located in the vicinity of the boiling. The variation of the moderator density by the formation of vapor bubbles superimposes a characteristic fluctuation on the local neutron flux, which is reflected in the signal from the ion chamber.

1382. Boyd, L. R.

ION CHAMBER CAN DETECT NUCLEATE BOILING, Nucleonics 17, No. 3, 96-102 (1959).

In-pile and other experiments prove the feasibility of using neutron-sensitive ion chambers to detect nucleate boiling in a reactor core. The ion chamber is placed in the region of the reactor core most likely to boil. Voids in the water moderator caused by boiling decrease the moderation and thus cause fluctuations in the thermal-neutron flux. The a-c component of the ion-chamber signal then correspond to the magnitude of bubble formation and thus indicates the intensity of boiling.

1383. Burgholz, R.

A METHOD OF MEASURING FLOW OF FLUIDS IN PIPES WITH ROENTGEN OR GAMMA-RAYS, Archiv. fuer Technisches Messen n 167, p.T 107 (2 pages) (Dec. 1949).

Includes diagrammatic drawings.

1384. Clayton, C. G., Ball, A. M. and Clark, W. E.

THE ACCURATE MEASUREMENT OF TURBULENT FLOW IN PIPES USING RADIOACTIVE ISOTOPES. THE ISOTOPE VELOCITY TECHNIQUE, AERE-R-3090 (1959), 17 p.

The ultimate accuracy of the isotope velocity method for measuring the flow of fluids in turbulent motion contained in pipes and open channels of constant and known cross section was investigated. The measurements were made using water flowing at 7 and 17 cfs. in a pipe of 20 in. diameter. The results, which were obtained by comparison with an absolute system of direct weighing, indicate that the isotope velocity method can be operated with an error of ±1%.

1385. Clayton, C. G., Ball, A. M. and Spencer, E. A.

THE MEASUREMENT OF TURBULENT FLOW IN PIPES USING RADIOACTIVE ISOTOPES. THE ISOTOPE DILUTION TECHNIQUE, AERE-R-3028 (1959) 28 p.

Experimental investigation which was carried out to determine the ultimate accuracy of the dilution technique using radioactive sodium-24 is described. The measurements were made on a standard 20 in. diameter pipe operating with flow rates of approximately 4 and 20 cu secs. (cu ft per sec.). Initial comparisons with absolute measurements based on direct weighing resulted in a deviation of the mean from the absolute value of -2.63 per cent with a standard mean deviation of ±1.5 per cent.

1386. Coulter, E. and Campbell, T.

STEAM PURITY DETERMINATION BY TRACERS TECHNIQUES, Combustion, 28, 63 (July 1956).

Technique consists of adding radioactive material to boiler water and determining amount of mechanical carryover in steam by measuring level of radioactivity; for steam purity applications beta emitters are most suitable; flame photometer with photomultiplier tube for Beckman model DU spectrophotometer should be adequate for boiler test work. From paper before Am. Soc. Testing Matls., June 17-23, 1956.

1387. Cravarolo, L., Hassid, A. and Villani, S.

A BETA-RAY ATTENUATION METHOD FOR DENSITY MEASUREMENTS OF LIQUID-GAS MIXTURES IN ADIABATIC FLOW, Energia Nucleare, 8, 751-7 (1961).

Beta-ray attenuation was used for measuring the density of liquid-gas mixtures flowing in vertical circular ducts in dispersed regime. For this purpose a small size source was constructed, which can be placed in different positions along the duct diameter thus allowing density measurements in a non-uniform absorbing medium. The experimental results are in a reasonable agreement with those obtained through other methods. These experiments were performed on behalf of EURATOM under contract 002-59-11-RDI.

1388. Dennis, J. A.

INVESTIGATION OF THE POSSIBILITY OF USING A NEUTRON SOURCE TO MEASURE THE SPECIFIC GRAVITIES OF STEAM WATER MIXTURES IN A THICK PIPE, AERE-EL/M-97 (1957), 24 p.

Moderation neutron methods by a Ra-Be source and a BF_3 counter for measuring the sp. gr. of steam-H_2O mixts. in a 1-in. bore steel pipe give about the same relative change in counting rate for a given change in sp. gr. as would a method with γ rays. The γ-ray method is preferable for pipe-wall thicknesses up to 1 in. because of low cost of equipment and the higher counting rate that can be obtained with the γ-ray method for a given source activity.

1389. Dixon, A. D.

GAMMA ABSORPTION TECHNIQUES APPLIED TO STEAM DRYNESS DETERMINATIONS, IGR-TN/W-489 (1957), 8 p.

An instrument employing gamma-ray absorption techniques has been developed for measuring the steam-water ratio in a thick walled steel tube. The instrument was developed to enable this measurement to be made during heat transfer tests on an evaporator in which heat was transferred from sodium to high pressure water. The method depends on the change with steam content in the amount of absorption of gamma radiation passing through the tube. The limitations are examined and an instrument is described applying the method to estimate the steam content in the water flow in a $\frac{3}{4}$ in. nominal bore mild steel tube. The instrument is calibrated up to 2.5% steam by weight, the useful range in its present use, but methods of improving the performance are described and recommendations made.

1390. Garvitch, Z. S.

A FIELD INSTRUMENT FOR MEASURING TEMPERATURES OF NATURAL BOILING POOLS, J. Sci. Instrum. 32, 261-2 (1955).

A prototype instrument is described by which the temperature of natural boiling pools may be compared with the local boiling point of pure water. The difference in temperature is indicated by a meter on which changes of 0.02 deg. C are easily detectable. The power required is provided by a motor-cycle battery, and the whole instrument is mounted on a pack frame. A proposal for an improved lighter model of the instrument is included. The equipment may also have a use as an alpine height-finder.

1391. Glaser, D. A., et al.

BUBBLE COUNTING FOR THE DETERMINATION OF THE VELOCITIES OF CHARGED PARTICLES IN BUBBLE CHAMBERS, Phys. Rev. 102, 1653-8 (1956).

1392. Gouse, S. W.

METHODS OF MEASURING VOID FRACTIONS, NAA-SR-MEMO-5597 (1960), 41 p.

A literature survey of methods of void-fraction measurement was accomplished, and the results are summarized in tabular form. A detailed uncertainty analysis of the proposed γ or x-ray attenuation

technique was performed. A method for choosing a system sensitivity for minimum over-all uncertainty is presented.

1393. Hewitt, G. F. and Lovegrove, P. C.

THE APPLICATION OF THE LIGHT ABSORPTION TECHNIQUE TO CONTINUOUS FILM THICKNESS RECORDING IN ANNULAR TWO-PHASE FLOW, AERE-R-3953 (1962), 19 p.

An attempt was made to measure continuously the instantaneous thickness of the climbing film in vertical co-current air/water flow by means of the absorption of a light beam in a dye added to the water. A single passage of the light through the film was arranged by bringing it up close to the inner surface of the film through an air-purged capillary tube which penetrated one wall and traversed most of the droplet-laden air core; after passage through the film and the transparent wall the light fell on a photo-voltaic cell whose signal was amplified and displayed on an oscilloscope. Although this general method has been reported as satisfactory with falling films, the sharp wave profiles and presence of spray in the climbing film regime of interest were found to introduce gross refraction and scattering effects which swamped other signals. The technique had, therefore, to be abandoned.

1394. Hooker, H. H. and Popper, G. F.

A GAMMA-RAY ATTENUATION METHOD FOR VOID FRACTION DETERMINATIONS IN EXPERIMENTAL BOILING HEAT TRANSFER TEST FACILITIES, ANL-5766 (1958), 40 p.

Gamma rays emanating from a radioactive source are beamed through and are attenuated by steam-water mixtures contained in a simulated reactor flow channel. The emergent radiation is detected by a scintillation crystal-photomultiplier tube assembly. An expression is developed which yields the void fraction when the detector output with the channel empty, filled with water, and containing the mixture in question is known. The principal sources of errors inherent in the method are analyzed and their magnitudes computed for a specific test facility. With a uniform bubble distribution in this facility, the maximum possible error in void fraction is approximately ±0.03. The method is also applied to three idealized preferential phase distributions simulated in Lucite. However, the large discrepancy between calculated and measured void fractions illustrates the need for more refined experimental techniques where non-uniform distribution of voids are encountered. Such techniques are being developed.

1395. Jackson, M. L.

LIQUID FILMS IN VISCOUS FLOW, AIChE Jour. 1, 231-40 (1955).

Trace of radioactive material dissolved in liquid enables thickness of moving film to be determined by measurement of radiation emitted; method is rapid and accurate and average thickness is obtained directly even though surface of film may be irregular; six liquids, for viscosities range from 0.5 to 20 centipoises were observed in flow down inner wall of vertical tube.

1396. Karplus, H. B.

SUGGESTION FOR AN INVESTIGATION LEADING TO THE DEVELOPMENT OF A "STEAM-QUALITY" GAGE, AECU-4123 (1959?), 14 p.

An instrument was developed for measuring the water droplet content of steam through its relationship to the acoustic properties of the steam. The experimental work associated with this particular phase was directed toward the more immediately pressing problems of reactor safety, and measurements were made on the propagation of large-amplitude waves through boiling water. The velocity of sound varies with the water content of steam; hence, a measurement of this velocity provides a good technique for determining the water content of any given sample of steam.

1397. Katarzhis, A. K., Kosterin, S. I. and Sheinin, B. I.

AN ELECTRIC METHOD OF RECORDING THE STRATIFICATION OF THE STEAM-WATER MIXTURE, Translated from: Izvest. Akad. Nauk S.S.S.R., Otdel Tekh. Nauk, No. 2, 132-6, AERE-Lib/Trans-590 (1955).

The temperature and the ohmic resistance of an electrically heated filament, which we shall call the indicator, placed in a steam-water mixture at a definite pressure, will vary according to the phase (steam or water) which surrounds this filament, in consequence of the markedly different amount of heat transfer from the filament to a current of steam or water at a given temperature. This makes it possible to find, from a measurement of the ohmic resistance of the indicator, whether the steam or water medium is present.

1398. Korsunskii, M. I., et al.

THE USE OF RADIOACTIVE ISOTOPES FOR THE MEASUREMENT OF MOISTURE IN STEAM, Izmeritel'naya Tekh. No. 5, 50-2 (1960).

A method for the detn. of the moisture content in steam tubes, without sepg. samples and independent of the size of the suspended droplets, is described. The absorption of β-particles from a radioactive source was measured and the d. of the steam calcd. From the relation of the d. to the d. of dry steam the moisture content was calcd. S^{35} was selected as the β-particle source for most expts., as most prepns. of Ca^{45} tried provided too small a sp. activity. The main difficulty was in providing a hermetic radiation source; a fluorine layer was used. A radiometer 10-14 cm from the source recorded the data. Specifications are given for the lab. set-up and an actual installation at the Kharbarovsk turbine plant. The mass absorption coeff. of electrons in steam, exptl. detd. from a lab. mock-up and in plant conditions, was found to be 197-200 sq cm/g. Values for moisture content to 6% at a rate of flow of 150 m/sec closely agreed with values by an established method.

1399. Lamb, O. P. and Killen, J. M.

ELECTRICAL METHOD FOR MEASURING AIR CONCENTRATION IN FLOWING AIR-WATER MIXTURES, Minn. Univ. St. Anthony Falls Hydraulic Lab., Tech. paper n. 2, series B (1950), 36 p.

Illustrated descriptions of apparatus; method which consists of measurement of difference between conductivity of mixture of air and water and conductivity of water alone is adaptation of methods used in biological investigations of disperse systems; analysis of measurements. Bibliography.

1400. Margulova, T. H.

APPLICATION OF RADIOACTIVE ISOTOPES IN AN INVESTIGATION OF STEAM PURITY IN INDUSTRIAL BOILERS AT HIGH PRESSURES, Izv. Akad. Nauk, SSSR, O.T.N., No. 8, 29-36 (1954).

Radioactive isotopes give very accurate information on the steam purity. Isotopes of S and P are most convenient for the detn. of moisture in steam, while Na can best be used for the general salt content. (CA-49-5732c)

1401. Martin, G. E. and Grohse, E. W.

X-RAY ABSORPTION MEASUREMENT OF STEAM VOIDS IN WATER AT HIGH PRESSURES, TID-14156 (1961), 16 p.

X-ray absorption, was applied to the measurement of steam voids in water flowing through electrically-heated rectangular stainless steel channels under conditions of pressure, temperature, flow rate, and heat flux corresponding to "local boiling" (subcooled water) as well as "bulk boiling" (saturated water) in the coolant channels of water-cooled nuclear reactors. A balanced dual-beam photometer system was employed. A dual-beam x-ray tube and two scintillation crystal-photomultiplier tube detector probes are mounted in a manner permitting remote-operated traversing of the test channel in the horizontal as well as vertical directions. The photomultiplier tubes were used in a difference circuit with one of the tubes monitoring the test channel and the other a remote-operated reference wedge. The difference measuring connection offered common mode rejection so that any differential output was due to a change in attenuation of the test channel beam. This out-put was fed through a differential amplifier to a strip-chart recorder. With a test channel consisting of 0.020 in. thick stainless steel walls, backed by 0.062 in. beryllium windows for strength, void concentrations within a 0.250 in. thickness of water currently could be measured with an absolute accuracy of 2% or better and further improvements in accuracy appeared likely. The test channel was enclosed in a heavy steel housing with windows, permitting void measurements to be made at pressures up to 2000 psia.

1402. Minter, C. C.

AN INSTRUMENT FOR THE RAPID AND CONTINUOUS DETERMINATION OF LOW CONCENTRATIONS OF WATER VAPOR IN GASES, NRL-4437 (1954), 17 p.

A new thermal conductivity apparatus has been developed for the rapid and accurate determination of water vapor in air or other gases over a wide range of concentrations, even down as low as that corresponding to a dew point of -50°C. In this equipment, several sources of error which in the past have restricted the use of thermal conductivity in hygrometry have been eliminated. The absolute pressure of water vapor in air or other gases can be obtained by comparing the thermal conductivity of moist gas with that of dry gas in a Wheatstone bridge, and then applying to the bridge output a correction for barometric pressure which is normally proportional to percent by volume of water vapor. The moist air mixtures used in calibrating the instrument were obtained either by saturating air at a given temperature between 1 and 40°C or by passing into the apparatus moist room air containing known concentrations of water vapor as determined by psychrometric methods.

1403. Miropolsky, Z. L. and Styrikovich, M. A.

THE USE OF γ-RAYS IN THE STUDY OF THE HYDRODYNAMICS OF TWO-PHASE SYSTEMS, Izv. Akad. Nauk S.S.R., Otdel, Tekh. Nauk, No. 9 (1955).

1404. Miropolsky, Z. L. and Shneerova, R. I.

MEASURING THE VOLUMETRIC CONTENT OF STEAM-GENERATING ELEMENTS BY MEANS OF GAMMA RADIATION, Translated from: Trudy Vsesoyuz. Nauch. Tekh. Konf. Primenen. Radioaktiv. i Stabil. Izotopov i Izluchenii v Narod. Khoz. i Nauke, 1957, 4, AEC-tr-4206(Pl-7)(Publ. 1958).

In this report a method of studying two-phase systems based on the use of γ-emitting radioactive isotopes is proposed.

Two methods of determining the true vapor-phase volume are considered: 1) passage of a narrow γ-ray beam through the medium (this makes it possible to derive a diagram of the phase distribution in the object, as well as giving the average vapor volume in the area irradiated); 2) passage of a wide γ-ray beam, this covering the whole area of the object. The influence of the structure in the two-phase flow and the geometry of the object on the absorption of a wide γ-ray beam is dealt with.

Estimates of the possible errors that may occur when the flow structure is unknown are given, and the optimum conditions for using this method are elucidated as functions of the absorption properties and geometrical dimensions of the object.

Experiments are described which confirm that this is a possible method for studying the flow of a liquid vapor mixture in the steam-generating parts of a boiler.

1405. Newman, A. O. and Lerner, B. J.

ELECTRONIC METHOD FOR BUBBLE FREQUENCY MEASUREMENT, Anal. Chem. 26, 417-18 (1954).

A precise mechanico-electronic method is described for bubble frequency measurement in studies involving two-phase gas-liquid contact in bubbling flow. Bubbles are formed and released from a submerged orifice, and the liquid impact on the gas column below the orifice causes a percussive shock which is transmitted to the orifice material and the surrounding

liquid. A microphone is used to pick up the bubble percussions, and signal is amplified and the period of percussion is compared on an oscilloscope screen with a sine wave of known frequency. Bubble frequencies of 3.5-50 bubbles per sec. can be measured with a precision of 1%. (CA-48-4263i)

1406. Perkins, A. S. and Westwater, J. W.

MEASUREMENTS OF BUBBLES FORMED IN BOILING METHANOL, A.I.Ch.E. Journal, 2, 471-6 (1956).

The photographic method was used to measure bubble sizes and frequencies for methanol boiling at atmospheric pressure outside a $\frac{3}{8}$-in. O.D., steam-heated, horizontal copper tube. The average temperature of the tube was measured by use of the tube as a resistance thermometer. For nucleate boiling at heat fluxes up to 80% of the maximum, the product of bubble diameter and frequency was constant at 4 in./sec. In this region both the Rohsenow equation and the Forster-Zuber equation gave good predictions of the heat transfer. At higher fluxes the product f x D increased and the equations were much less suitable. The critical temperature difference for copper to methanol was not a single value but was a region extending from 52° to 62°F. The heat flux was nearly constant throughout this range at a maximum of 115,000 Btu/(hr)(sq ft). For film boiling, f x D was nearly constant at 11 sec^{-1}. Bromley's equation was unsuitable for ΔT values less than 180°F, but it became applicable at this ΔT. The use of Nusselt's equation for steam condensing inside the tube was found to be satisfactory, proof that the slight slope of the tube was sufficient to permit adequate condensate drainage.

1407. Perkins, H. C., Jr., Yusuf, M. and Leppert, G.

A VOID MEASUREMENT TECHNIQUE FOR LOCAL BOILING, Nuclear Sci. and Eng. 11, 304-11 (Nov. 1961).

A beta attenuation method is developed for measuring void fractions which is sensitive enough for use during local boiling. Comparisons are made with gamma attenuation methods, the effects of preferential void location are demonstrated, and typical void fractions measured during forced-convection, subcooled boiling of water are presented. The technique is found to be readily applicable to the accurate determination of void fractions during either saturated or subcooled boiling of water and organic liquids.

1408. Petrick, M. and Swanson, B. S.

RADIATION ATTENUATION METHOD OF MEASURING DENSITY OF A TWO PHASE FLUID, Rev. of Sci. Instruments, 29, 1079-1085 (1958).

A gamma-ray attenuation technique is presented for measuring density and phase distribution in a 2-phase fluid. A comparison is made between a "one-shot" and traverse method. The technique was evaluated on Lucite mock-ups of simulated flow patterns encountered in 2-phase flow and by a series of tests on an air-water system at atmospheric pressure.

1409. Poletavkin, P. G. and Shapkin, N. A.

TAGGED ATOM METHOD OF INVESTIGATION OF WATER AND STEAM CONTENT DURING SURFACE BOILING OF A LIQUID, Translated from Trudy Vsesoyuz. Nauch. Tekh. Konf. Primenen. Radioaktiv. i Stabil. Izotopov i Izluchenii v Narod. Khoz. i Nauke, 1957, 4, AEC-tr-4206 (p. 16-20)(1958).

A tracer technique is described using NaF containing Na^{24} for investigating the water and steam content of a liquid during surface boiling.

1410. Sterman, L. S., Antonov, A. Ya. and Surnov, A. V.

STEAM QUALITY AT A PRESSURE OF 185 ATMOSPHERES, Teploenergetika 4, No. 3, 17-22, Translated in: AEC-tr-4206 (p. 49-54)(1957).

The crit. concns. of Na_2SO_4, NaCl, and NaOH were detd., and the blowdown in a precrit. stage at a pressure of 185 atm. was studied. The results received were compared to those established in similar conditions at different pressures (36 atm.).

1411. Sterman, L. S., Antonov, A. Ya., and Surnov, A. V.

STUDY OF STEAM QUALITY AT 185 ATMOSPHERES PRESSURE WITH AID OF RADIOACTIVE ISOTOPES, Trudy Vsesoyuz. Nauch. Tekh. Konf. Primenen. Radioaktiv. i Stabil. Izotopov i Izluchenii v Narod. Khoz. i Nauke, Teplotekh. i Gidrodinam. 1957, 4, 46-51 (Pub. 1958).

By use of an app. of a type described previously (Teploenergetika 4, No. 3, 17-22 (1957), steam quality was evaluated through use of Na_2SO_4 contg. S^{35}. Activity coeffs. are plotted against pressure.

1412. Straub, L. G., Killen, J. M. and Lamb, O. P.

VELOCITY MEASUREMENT OF AIR WATER MIXTURES, Am. Soc. Civ. Engrs. Proc. 79, Separate No. 193 (May 1953), 14 p.

Development and use of velocity measuring instrument at St. Anthony Falls Hydraulic Lab. at Univ. of Minn; instrument, referred to as St. Anthony Falls (SAF) velocity meter, particularly useful in undertaking of velocity traverses in air water mixtures.

1413. Styrikovich, M. A. and Vinokur, Ya. G.

EXPERIMENT USING RADIOACTIVE ISOTOPES FOR STUDYING THE LOSS OF SALT WITH A VAPOR, Doklady Akad. Nauk S.S.S.R. 90, 179-82 (1953).

By using radioactive isotopes, e.g. P^{32}, S^{35}, Ca^{45}, Na^{24}, a method is described for detg. the amt. of a salt carried off by escaping vapors. The vapors were condensed and the activity detd. Expts. showed that there is a significant adsorption of the active material on the walls of the vessel.

1414. Styrikovich, M. A., Sterman, L. S. and Surnov, A. V.

AN INVESTIGATION OF THE CARRY OVER OF SALT BY STEAM USING RADIOACTIVE ISOTOPES, Teploenergetika, 2, No. 2, pg. 43 (1955).

1415. Styrikovich, M. A.

INVESTIGATION OF STEAM CONTAMINATION AND THE STRUCTURE OF THE STEAM-WATER MIXTURE BY MEANS OF RADIOACTIVE ISOTOPES, Sessiya Akad. Nauk S.S.S.R. po Mirnomu Ispol'zovaniyu Atomnoi Energii 1955, Zasedaniya Otdel. Tekh. Nauk 210-26 (English summary 226-7), translated in: Conf. Acad. Sci. U.S.S.R. on Peaceful Uses of Atomic Energy. Session Div. Tech. Sci. 1955, 119-27 (1956).

An app. is described for the detn. of the d. of the medium composed of steam and water droplets by having a radiator and a counter of the γ-radiation enclosed in thick Pb envelopes with narrow coaxial channel for the formation of a γ-ray bundle. The radiator and the counter of γ radiations are located on the 2 sides of a column and can be relocated along the column height and cross section. Measurements were made on the steam contamination with water droplets and of the soln. of substances in the steam. The layering steam in boiler tubes was also studied. S^{35}, P^{31}, Ca^{45}, etc. were used in the investigation of the soly. of various substances in high-pressure steam.

1416. Styrikovich, M. A.

INVESTIGATION OF THE SOLUBILITY OF LOW VOLATILITY SUBSTANCES IN HIGH PRESSURE STEAM IN RADIOISOTOPES, presented at the International Conference on Radioisotopes in Scientific Research, Sept. 9-20, 1957 at Paris. No. UNESCO/NS/RIC/73. London, Pergamon Press, Ltd., 1957. 11 p.

Radioisotopes were used to determine accurately the very small concentrations of substances dissolved in steam.

1417. Styrikovich, M. A., Khaibullin, I. Kh. and Khokhlov, L. K.

USE OF RADIOACTIVE ISOTOPES FOR INVESTIGATING SOLUBILITY OF SALTS IN WATER VAPOR OF LARGE PARAMETERS, AEC-tr-4206 (p.44-8), In Heat Engineering and Hydrodynamics, Vol IV)(1958).

The solubilities of Na_2SO_4, $CaSO_4$, NaCl, $CaCl_2$, and $CaCO_3$ in water vapor at 350 to 650°C were investigated using tracer techniques.

1418. Styrikovich, M. A. and Nevstrueva, E. I.

INVESTIGATION OF VAPOR-CONTENT DISTRIBUTION IN BOILING BOUNDARY LAYER BY THE BETA-RADIOSCOPY METHOD, Dokl. Akad. Nauk SSSR, 130, No. 5, 1019-22 (1960).

Water, circulating in a closed circuit and preheated to a suitable temperature, was brought to boil in a special cell (width 4 mm, height ~20 mm) with a built-in β source (window width 10 mm height 0.3 mm) the heating element being provided in the adjustable bottom of the cell, so that a 10 x 0.3 mm layer of the boiling liquid could be examined with β rays at a distance 0-6 mm from the bottom. The vapour content was found to change little with temperature at higher temperatures, when the examination was carried out at a distance from the bottom (heat source) smaller than the thickness of the layer in which bubbles form and increase; the effect of the velocity of circulating water was particularly great in the zone where the separated vapour bubbles condense. The final conclusion is that, when the temperature of the stream and the heat load approach critical values, the thickness of the boiling layer is relatively small, while local vapour contents attain sometimes 0.98. The higher the critical heat load the thicker the boiling layer and the smaller the local vapour contents.

1419. Vinokur, Ya. G. and Dil'man, V. V.

INVESTIGATION OF THE BUBBLE LAYER BY THE METHOD OF TRANSLUCENCE OF GAMMA RAYS, Khim, Prom., No. 7, 619-21 (1959).

The method of translucence of γ-rays, with Co^{60}, is shown to be suitable for detg. the actual vol. of the gaseous content of bubble layers without disturbing the layer. This method is applicable to any section of the bubble layer and can give accurate detns. of the height of the layer. Changes in the wall thickness of the bubble column have essentially no effect upon the accuracy of the method (approx. 5%). The design of the Co^{60} source and the radiation counter used is shown and described in detail.

1420. Wadleigh, K. R. and Oman, R. A.

INSTRUMENTATION TO MEASURE GAS-PHASE COMPOSITION OF HIGH VELOCITY, TWO-PHASE TWO-COMPONENT FLOWS, Jet Propulsion 27, 769-75, 783 (1957).

Investigation carried out at Mass. Institute of Technology stimulated by Aerothermopressor project, device which produces rise in stagnation pressure of high velocity, high temperature gas stream; state of development of probe to measure local water vapor-air mass flow ratio (specific humidity).

1421. Ziegler, E. E. and Chiangkasri, I.

GAMMA-RAY TECHNIQUES FOR THE DETERMINATION OF THE STATIC VOLUME QUALITY OF TWO-PHASE FLOW IN A VERTICAL PIPE, S. B. Thesis, M.I.T., M.E. Dept. (1958).

1422. Technische Hogeschool, Eindhoven, Netherlands.

HEAT TRANSFER AND STABILITY STUDIES IN BOILING WATER REACTOR. Special Technical Report No. 2. STUDY OF POSSIBLE APPLICATION OF ACOUSTICAL METHODS FOR DETERMINING VOID FRACTION IN BOILING WATER REACTORS, EURAEC 278 (Feb. 1962). Work performed under United States - Euratom Joint Research and Development Program. Contract 032-60-11-RDH. 52 p.

A survey was made of the acoustical properties of liquid-gas bubble mixtures. The available theories were extended to the case of liquid-vapor bubble mixtures. Expressions for speed of sound and damping were derived and numerical values were calculated and plotted. It is shown that it is possible in principle to determine volume fraction of vapor and bubble size distribution from measurements of speed of sound and damping in a mixture as a function of frequency. The method is a sensitive one for small void ratios whereas it is rather insensitive for volume ratios around 50%. The possibilities for application as a measuring technique for determining void fractions in reactors and associated experimental set-ups are discussed. (NSA 62-31201)

NUCLEAR REACTOR HEAT REMOVAL

1423. Alekseenko, Y. N.

THE USE OF A DIRECT FLOW CYCLE IN A BOILING-WATER REACTOR, Atomnaia Energiia, 4, p. 366-7 (April 1958). English Translation in: Soviet J. of Atomic Energy 4, 479-80 (1958).

A boiling reactor with direct flow cycle was studied to determine the reaction of neutron density drop in the upper section of the reactor and to find the coefficient of irregular heat exchange along the active zone.

1424. Altman, M.

HEAT TRANSFER IN REACTORS COOLED BY WATER, Nucleonics, 14, 66 (Feb. 1956).

Three separate designs are incorporated in every nuclear power reactor. These cover the thermal, nuclear, and mechanical aspects. The problems of thermal design are largely unappreciated. But incomplete understanding of such basic phenomena as boiling has created a serious bottleneck in nuclear-power development.

Here basic problems of heat-transfer in reactors cooled and moderated by water are described to acquaint designers with these key factors in reactor design. For clarification, emphasis is placed on frontiers of heat-transfer reactor technology rather than on detailed information. Suggestions are made concerning factors needing clearer definition.

1425. Arsen'ev, Y. D.

THE SECONDARY LOOP IN A BOILING WATER REACTOR, Atomnaia Energiia, 4, p. 367 (April 1958). English Translation in: Soviet J. of Atomic Energy 4, 481-4 (1958).

The design and performance of secondary loops with heat exchangers and self-evaporators were analyzed. It was found that the scheme with a self-evaporator simplifies construction and is more efficient in spite of the required excess power for its operation and the differential on circulation pumps. Lower temperatures for water preheating, which permits reducing the number of regenerators and reduces the differential on circulation pumps, are recommended.

1426. Asijee, J.

STUDY OF HEAT REMOVAL FROM A FUEL ELEMENT OF A NUCLEAR REACTOR OF THE BOILING WATER TYPE, AEC-TR-4011 (1959), 88 p.

This paper was previously abstracted from the original language and appears in NSA, 14, as abstract No. 12343. (which follows)

The relationship between reactor power and the vapor content in a boiling reactor may yield a high degree of self-regulation. It is not possible to predict with sufficient accuracy the vapor content in a given coolant channel without the aid of experimental data. For the Halden Boiling Water Reactor (Norway) such information has been obtained from experiments with a full scale model of a coolant channel. For 3 different geometrical situations, the relationships between steam-production, water circulation rate, steam void fractions, and temperature or pressure were investigated for the natural circulation evaporation of water in annular space around an electrically heated, vertical, cylindrical heating element. Special measures were taken in order to obtain results under steady-state conditions.

1427. Asyee, J., et al.

ADVANCED COURSE ON HEAT EXTRACTION FROM BOILING WATER POWER REACTORS AND ASSOCIATED DYNAMIC PROBLEMS (Pt. 1), NP-9285, (1959), 256 p.

A series of lectures was presented including topics on history and current status of boiling water reactor development, physics of boiling water reactors, BORAX and SPERT experiments, reactor transfer functions, small oscillations in boiling water reactors, hydraulic model of boiling reactor dynamics, boiling experiments in connection with the Halden core, general types of power cycles and plant components, power plant control, principles of analogue and digital computers, control analysis with a digital computer, and economics of nuclear ship propulsion. (NSA-15-10532)

1428. Asyee, J.

SUMMARY OF AN EXPERIMENTAL INVESTIGATION ON THE HEAT-REMOVAL OF THE FIRST FUEL-CHARGE OF THE HBWR, Halden Internal Report HIR-11, May 1959.

1429. Aven, R. E. and Haubenreich, P. H.

RADIOLYTIC GAS GENERATION RATES IN THE HRT, CF-55-8-77 (1955), 28 p.

Estimates were made of the gas production rates in the core circulating system, reflector circulating system, core pressurizer, fuel dump tanks, and thermal shield, when the HRT was operating at 10 MW with a D_2O reflector. (NSA-11-646)

1430. Bailey, R. V. and Zmola, P. C.

A PRELIMINARY INVESTIGATION OF POWER REMOVAL FROM A BOILING REACTOR, Oak Ridge National Laboratory, 1 November 1953, CF-53-11-145 (1957), 73 p.

A preliminary investigation of three power removal mechanisms for boiling reactors is presented. The problem of relating core power density to mean weight density as a function of pressure is considered for processes involving surface evaporation, bubble growth and rise in a fluid with negligible internal circulation, and bubble growth and rise in a fluid with large internal circulation velocities compared with relative bubble velocity. Results of this analysis indicate that surface evaporation is a negligible factor in power removal except for small reactors. For larger reactors, 3 or 4 ft high the predominant removal mechanism is natural bubble rise. It is further concluded that vapor entrainment in the circulating fluid limits removal for reactors with a free surface, in which circulation exists.

1431. Bankoff, S. G.

REACTOR HEAT TRANSFER CONFERENCE OF 1956. COLLECTED PAPERS AND REPORTS OF A CONFERENCE HELD AT NEW YORK NOV. 1-2, 1956, J. E. Viscardi, comp., Book 1 - 323 p., Book 2 - 318 p., TID-7529 (Pt. 1)(1957).

Papers included in Book 1 cover: a general method of determining the total time interval of transients in linear systems, the basic equations describing energy flow and pressure drop relationships for transient coolant flow conditions in a nonhomogeneous plate-type reactor, rapid flow transients in closed loops, fast transient heat transfer in a clad element-stagnant H_2O system, transient heat conduction in solid cylindrical nuclear fuel elements, the response of a nuclear reactor coolant to power transients, a transient thermal analysis by means of analog computers, an analysis of fuel-plate temperature rise during a burnout transient, in-pile molten metal-water reaction experiments, pressure drop in rectangular channels at 2000 psia, flow redistribution due to boiling in a matrix, an investigation of burnout heat flux, nucleate and film boiling due to repetitive pulse heating of small wires immersed in H_2O, tubular vs. plate fuel elements: heat transfer and flow analysis, heat transfer within the cores of circulating-fuel reactors, heat transfer and hydraulic characteristics of the SRE fuel element, and heat transfer rates to cross-flowing Hg in a staggered tube bank. Papers included in Book 2 are on: heat transfer to Pb-Bi in turbulent flow in an annulus, pool-boiling heat transfer with Hg, heat transfer investigations of polyphenyl coolants, heat transfer in a radial spray chamber, the dependence of the heat transfer coefficient on the ratio of the heat fluxes from the walls of parallel plane flow channels, heat transfer and pressure drop characteristics of wire-coil-type turbulence promoters, an analysis of axial turbulent flow and heat transfer through banks of rods or tubes, heat transfer from parallel rods in axial flow, high-temperature heat transfer to a gas flowing in heat-generating tubes with high heat flux, the use of the Mach-Zehnder interferometer in heat transfer studies, compact tubular heat exchangers, and temperature and flow distribution in air-cooled reactors. Discussions are included from the working conferences on the following subjects: two-phase flow pressure drop, burnout in natural and forced convection, heat transfer performance of reactor systems utilizing solutions, suspensions and slurries as fuel-bearing fluids, fused-salt heat transfer systems, transient boiling heat transfer and fluid flow characteristics, and analog and digital computer techniques useful in core heat transfer studies.

1432. Bankoff, S. G.

NATURAL CIRCULATION BOILING REACTOR WITH TAPERED COOLANT CHANNELS, Chemical Engineering Progress 55, Sym. Ser. No. 27, 113-16 (1959).

It is suggested that some of the heat transfer characteristics of natural-circulation boiling reactors might be improved by employing tapered coolant channels.

A previously developed flow model for straight channels is used to predict frictional losses in tapered channels with uniform and with cosine heat-flux distributions. The ratio of the predicted frictional pressure drop in a straight channel to that of an equivalent tapered channel exhibits, as the angle of taper is varied, a rather sharp maximum at a value substantially greater than unity.

1433. Beckjord, E. S., et al.

OPERATION OF A HIGH PERFORMANCE LIGHT WATER BOILING REACTOR, P/1923, Second International Conference on Peaceful Uses of Atomic Energy, Geneva, 9, 455-67 (1958).

The Vallecitos Boiling Water Reactor is briefly described. The operating experience is summarized under the following subjects: Nuclear calculations, initial power loading, startup and operating characteristics, water decomposition, separation factor and residual water activities, neutron flux distribution, and coolant flow and steam voids. The stability of this reactor is discussed. Sketches and photographs of the plant and graphs on the reactor performance and characteristics are presented.

1434. Bergua, H. and Palacios, L.

COMPARISON OF BOILING WATER REACTORS WITH OTHER TYPES OF POWER REACTORS (In Spanish), En. Nucl. (Madrid), 2, No. 7, 60-7 (1958).

A comparison is made of the boiling water reactors with the pressurized water reactor and the gas-cooled, graphite-moderated reactors of the Calder Hall type. The initial cost, operating characteristics, maintenance cost, and future development are considered.

1435. Bick, J. H.

A NEW METHOD FOR DETERMINING THE STABILITY OF TWO PHASE FLOW IN PARALLEL HEATED CHANNELS WITH APPLICATIONS TO NUCLEAR REACTORS, NAA-SR-4927 (1960), 15 p.

A method is derived for determining whether a particular set of flows through a system of parallel channels is stable and the changes in them when instability occurs. A criterion is derived to determine if a particular reactor is subject to "boiling disease."

1436. Boadle, C. D.

LIQUID METALS - II. NUCLEAR POWER, Atomics and Nuclear Energy, 8, p. 83-5 (March 1957).

Advantages and disadvantages of liquid metals for high-temperature heat extraction from nuclear reactors are discussed. (CA-11099f)

1437. Breazeale, W. M., Cole, T. E. and Cox, J. A.

PRELIMINARY BOILING EXPERIMENT IN THE LITR, TID-5065 (1953), 7 p.

An experiment which involved boiling the water in the active lattice of the LITR with the circulation pump shut off was performed to determine the power level at which boiling would first take place and to observe the flux variation with time while boiling. (NSA-11-2726)

1438. Breazeale, W. M., Cole, T. E. and Cox, J. A.

FURTHER BOILING EXPERIMENTS IN THE LITR, AECD-3670 (March 1955), 6 p.

The water in the active lattice of the Low Intensity Test Reactor was boiled, and the relation between the rate of boiling and the change in reactivity was measured. Pertinent data are summarized, and oscillograph tracings of neutron-flux transients are shown. (NSA-10-1545)

1439. Bright, G. O. and Toole, C. R.

NOTE ON THE EFFECT ON REACTIVITY OF WATER ANNULI IN LARGE VOID SPACES IN THE SPERT I REACTOR CORE, IDO-16382 (July 1957), 9 p.

An experiment was performed in SPERT I to determine the effect of various water annuli in large core void spaces. Results show that the maximum reactivity effect with a 3 x 3 x 24 in. void occurs with a 0.25 in. thick water annulus. The effect of these results on the evaluation of potential reactor hazards is discussed. (NSA-11-10732)

1440. Brooks, R. D. and Rosenblatt, A. L.

NUCLEAR POWER PLANTS, DESIGN AND PERFORMANCE OF LIQUID METAL HEAT EXCHANGERS AND STEAM GENERATORS, Mech. Eng. 75, 363-8 (May 1953). See also: KAPL-P-888.

Use of sodium and NaK for heat transfer fluids has required development of specialized heat exchange equipment; construction of these units described; requirements which dictated construction; liquid metal heat transfer data obtained from pilot plant scale heat exchanger and steam generators for nuclear plants; performance data. (NSA-7-4112)

1441. Byrnes, J. J. and Diehl, K.

FLASH COOLING OF PRIMARY COOLING WATER, AECD-3902 (Jan. 1952), 11 p.

An evaluation is made of the practicality of removing heat from reactor cooling water by means of a flash cooler. The economics of such a system are compared with those of conventional heat exchange systems. Designs for the system, based on the design of the MTR units, are given. It is concluded that the flash cooler is competitive with conventional heat exchange from the standpoint of economics, and that continuous removal of gases formed by dissociation is obtained as an inherent feature of the system.

1442. Christensen, P. S.

ON SOME BOILING PHENOMENA ON THE HOMOGENEOUS REACTOR DR 1, RISE-21 (1961), 32 p.

A discussion is given of boiling phenomena in a homogeneous reactor studied with regard to reactivity loss and heat output as a function of nuclear power, and with certain temperatures as parameters. It was proven that the boiling acts on the reactivity in the same way as the usual power-coefficient. As the boiling is undesirable, counter measures were taken to prevent this. Experiments were carried out to confirm the results of the counter-measures. (NSA-15-31889)

1443. Clough, R.

POWER INPUT FROM A BOILING REACTOR WITH NATURAL CIRCULATION, UKAEA, Research Group AERE Harwell, BWR-4 (1955), 24 p.

The heat output from the central channel of a LEO-size boiling reactor with natural circulation of the coolant has been found for a number of pressure, feedwater temperatures and circulation ratios.

1444. Cochran, D. L. and Buck, K. E.

BOILING VS NON-BOILING LIQUID METAL COOLED REACTORS, 1960. Paper No. 1340-60. Presented at the ARS Space Power Systems Conference, Santa Monica, Calif., September 27-30, 1960 (1960), 16 p.

The relative merits of boiling and non-boiling reactors for use in Rankine Cycle space power plants over the power level range of from 1 to 20 Mw(e) are evaluated. A lithium-cooled fast reactor is most attractive for the non-boiling system, and a potassium-cooled boiling fast reactor is most attractive for the boiling system. Potassium is the cycle working fluid in each system. A turbine inlet temperature of 2000°F and shielding weights commensurate with manned applications are assumed. It was found that unless risks in reactor safety are accepted in the boiling reactor system, the non-boiling reactor system is more attractive in terms of size and weight. The weight savings resulting from such risks in the boiling system are only marginal and may actually be nonexistent. The non-boiling reactor does not have the uncertainties caused by boiling in the core, and its development would be cheaper and less involved. Experimental data on boiling flow, heat transfer, and pressure drop are required to determine the relative desirability of the boiling reactor system. (NSA-15-3638)

1445. Collier, J. G.

SUGGESTED DESIGN METHODS FOR THE APPLICATION OF SPRAY EVAPORATION TO A STEAM COOLED HEAVY WATER MODERATED REACTOR, AERE-M707 (1960), 19 p.

Spray evaporation is a method of reactor cooling in which a steam-water mixture is injected into the fuel channels. Characters of heat transfer, fluid dynamics, thermodynamics and steam cycles, and reactor physics are discussed for the system. Construction materials for a spray cool reactor are considered for fuel material as well as canning and structural materials. The design under consideration is for 2.5 Mw at a maximum temperature of 2100°C and reactor operating pressure at 700 psi.

1446. Collier, J. G. and Lacey, P. M. C.

THE SPRAY COOLED REACTOR, Nuclear Power 5 No. 52, 68-74 (1960).

Preliminary design studies confirm that this system combines many of the advantages of boiling and steam cooling.

1447. Collier, J. G.

SPRAY EVAPORATION FOR A STEAM-COOLED HEAVY WATER MODERATED REACTOR, Chem. and Process Eng., 43, 162, 1962.

Spray evaporation, defined as cooling by means of a two-phase mixture of steam and water, was suggested as an efficient method of heat removal from a reactor core. In order to make some assessment of the feasibility of using such a coolant in a steam-cooled heavy water moderated system, provisional design methods are outlined for the heat transfer and hydrodynamical aspects of the core. Although the degree of uncertainty using these methods is large, considerable improvements should become possible as soon as further data are available from experiments.

1448. Cunningham, J. P., Gallagher, J. M. and Gogniat, T.

TRANSIENT BOILING BEHAVIOR OF THE YANKEE REACTOR FOLLOWING LOSS OF COOLANT FLOW, YAEC-132 (1961), 62 p.

A study was performed to determine the consequences of a complete and simultaneous loss of power to all the main coolant pumps of the Yankee reactor during full power operation. The neutron kinetics equations, including feed-back effects and scram, and the heat transfer equations in a three-section hot channel and in the average channel were solved on an analogue computer. Coolant conditions in the hot and average channels were calculated as functions of time and position by use of the CAT digital computer code for open lattice cores. The solutions were iterated to convergence, to determine the time and location of departure from nucleate boiling. Analogue calculation of the hot spot clad temperature before and during film boiling indicated that the clad temperature would not exceed 1430°F. Since this is well below the annealing temperature of 1875°F, at which clad rupture would occur, there is no danger of clad rupture. A later review of the analysis led to changes in several major assumptions. A re-evaluation of the accident with these modifications did not change the conclusion. (NSA-16-14323)

1449. DeShong, J. A., Jr.

STYROFOAM SIMULATION OF BOILING AND TEMPERATURE EFFECTS IN THE EBWR COLD CRITICAL EXPERIMENTS, ANL-5697 (1957), 18 p.

Styrofoam was used successfully as a void material in the representation of hot reactor conditions during the EBWR zero power experiments.

The void requirements were determined from available heat transfer data and then Styrofoam strips were designed and manufactured by special equipment. These strips were inserted in the fuel element water channels and the reactivity changes noted. The data were then converted to boiling and temperature coefficients.

The nuclear properties of the material were excellent, and its use proved economical. The experimental accuracy was good, but probably could be improved by sealing the surface of the material against water absorption. (NSA-11-6522)

1450. DeShong, J. A., Jr. and Lipinski, W. C.

ANALYSIS OF EXPERIMENTAL POWER-REACTIVITY FEEDBACK TRANSFER FUNCTIONS FOR A NATURAL CIRCULATION BOILING REACTOR, ANL-5850 (1958), 53 p.

Experimental power reactivity feedback transfer functions were calculated from the EBWR power transfer function measurements. A simplified model of the EBWR kinetics was developed, using an analog computer, and an analytic expression was obtained for the feedback function. The analytic solution was fitted to the experimental functions to obtain power coefficients and time constants for various modes of operation. These data were extrapolated, and a power transfer function was predicted for 40 Mw. The reactor function was measured and compared with the prediction. A stability study was carried out, using open loop transfer functions containing the experimental feedback functions. Extrapolation of the gain and phase margins indicated stability at least 66 Mw. The reactor was successfully operated at 61.7 Mw following this, with power limited by the capacity of the feedwater pumps. The use of the simplified model for parameter studies is demonstrated by a series of calculations to evaluate the effect of heat transfer time constant on stability. (NSA-12-13450)

1451. DeShong, J. A., Jr.

FLUX, REACTIVITY, STEAM VOID, AND STEAM-WATER INTER-LAYER NOISE SPECTRUMS IN THE EBWR, Reactor Sci. 10, 147 (1959).

The reactor flux noise was recorded and Fourier analyzed. It showed a resonance peak in the energy-frequency spectrum and was not a 'white' noise. Such was also the case for the reactivity spectrum, obtained by operating on the flux spectrum with a measured power transfer function. A transfer function relating the power (N) to a steam-water inter-layer input was calculated by using the reactor dynamic model. The inter-layer spectrum obtained by operating on the flux spectrum with this function was 'white' over a frequency range of 30 to 1, and probably is the result of random variation of the steam generation rate due to discrete steam bubbles entering the steam space. Such noise spectrums can be employed for gross stability investigations if a fair knowledge of the dynamic model is in hand.

1452. Dietrich, J. R., Layman, D. and Schulze, O.

THE PROPOSED BOILING REACTOR EXPERIMENT, ANL-4921 (Nov. 12, 1952), 47 p.

The stability and safety of boiling reactors will be investigated in a small reactor of variable structure and geometry. Design of the test facility, the experimental program, a cost estimate, and an evaluation of hazards of the experiment are described. Appendices include variables in self-limitation of reactor power, boiling experiments with electrical heating, effect of steam content on reactivity, and a method of estimating power level during equilibrium boiling. (NSA-11-9781)

1453. Dietrich, J. R. and Layman, D. C.

TRANSIENT AND STEADY STATE CHARACTERISTICS OF A BOILING REACTOR, ANL-5211 (1954), 136 p.

The characteristics of transient and steady state boiling in a water-cooled, water-moderated reactor have been investigated in a reactor which was set up and operated at the Reactor Testing Station during the Summer and Fall of 1953.

In a series of about 70 intentional "runaway" type tests it was demonstrated that the formation of steam and consequent ejection of water from the reactor core can provide inherent protection against the runaway hazard in suitably designed reactors of the water-cooled, water-moderated (H_2O or D_2O) type. Power excursions of periods as short as 0.005 second (2.1 excess reactivity in the experimental reactor) were terminated by this process. Although the maximum power in the excursions went as high as 2600 megawatts, fuel plate temperature never exceeded 640F. Maximum power, total energy liberation, and fuel plate temperatures were investigated at atmospheric pressure as functions of excess reactivity in the excursion and initial reactor temperature.

Operation of the reactor in steady boiling at pressures up to 130 psig and powers up to 1200 kw demonstrated that quite smooth operation is attainable up to the point where the steam content of the reactor represents about - 2% k_{eff} in reactivity. At higher steam contents characteristic power fluctuations were observed. The reactor steam power was shown to be self-regulating. The effects of various operating conditions and system variables on reactor power and operating characteristics were investigated.

Results of the investigation are believed to point the way toward more economical power reactors through minimization of the hazard problem, simplification of reactor design, and reduction of the temperature demands on reactor materials. (NSA-10-8941)

1454. Dietrich, J. R., Lichtenberger, H. V. and Zinn, W. H.

DESIGN AND OPERATING EXPERIENCE OF A PROTOTYPE BOILING WATER POWER REACTOR, UN-851 (1955), 27 p.

Heat transfer data are included in a general study of three boiling water reactors.

1455. Dietrich, J. R.

EXPERIMENTAL DETERMINATIONS OF THE SELF-REGULATION AND SAFETY OF OPERATING WATER-MODERATED REACTOR, P/481, First International Conference on Peaceful Uses of Atomic Energy, Geneva, 13, 88-101 (1955).

1456. Dolezhal, N. A., et al.

URANIUM-GRAPHITE REACTOR WITH SUPERHEATED HIGH PRESSURE STEAM, 2nd U.N. International Conf. on the Peaceful Uses of Atomic Energy, A/conf 15/P/2139, 8, 398 (1958).

The basic physical and engineering characteristics are given of the thermal graphite-uranium reactor now under construction, with two groups of working channels. In the first group of channels, the heat generated is transmitted by the boiling water in the steam generator to the water of the second circuit. The secondary steam generated in the steam generator enters the second group of channels, where it is superheated at a pressure of 100 atm. to the required temperature and is supplied directly to the turbine. The reactor with the 100,000 Mw turbogenerator and other equipment forms a complete unit. The design of the reactor and the technological scheme of the reactor-turbine unit are described. Some considerations are given concerning the further possible development and improvement of power reactors of this type. The possibility of increasing the capacity of a single reactor and improving the economies of the discussed station is given.

1457. Durham, F. P.

RADIOLYTIC-GAS BUBBLES IMPROVE CONVECTIVE HEAT TRANSFER IN SUPO, Los Alamos Scientific Lab., Nucleonics 13, 42-6 (May 1955).

Agitation from radiolytic bubbles is the main cause of 150% higher heat transfer coefficient than predicted by theory, in the water boiler reactor. Effects of thermal-boundary-layer heat generation and tube-wall gamma heating are also analyzed.

1458. Fleck, J. A.

THE DYNAMIC BEHAVIOR OF BOILING WATER REACTORS, J. Nucl. Energy, Part A: Reactor Science, 11, 114-130 (1960).

Using the laws of conservation of mass, energy, and momentum stated in integral form, it is possible to derive a set of ordinary differential equations governing the hydrodynamics of natural circulation boiling systems. The variables which can be determined as functions of time by solving these equations are the water velocities at the inlet and outlet of the heated section, the outlet void fraction, and the total fluid momentum. The effect of a layer of water above the convection circuit also can be taken into account. When these equations are added to the reactor kinetics equations, the equations governing the transfer of heat from reactor fuel elements to water, and the relation between reactivity and the average void fraction, one obtains a model for the dynamic behaviour of a boiling water reactor. Calculations made using this model indicate that under certain conditions boiling water reactors can operate stably even for very substantial reactivity additions. Further analysis reveals that under proper conditions purely hydrodynamic instability can occur independently of any coupling between void and power. The onset of this unstable behaviour would be independent of nuclear and thermal parameters although the ensuing dynamic behaviour of the reactor would depend on them.

1459. Fleck, J. A.

THE INFLUENCE OF PRESSURE ON BOILING WATER REACTOR DYNAMIC BEHAVIOR AT ATMOSPHERIC PRESSURE, Nuclear Sci. and Eng., 9, 271-80 (Feb. 1961). See also: (UCRL 5938 T).

Boiling water reactor dynamic behavior is most sensitive to pressure variations at atmospheric due

to the strong dependence of saturation temperature on pressure. The two important pressure variation effects at atmospheric pressure are the variation of hydrostatic pressure within the core, which leads to a change in saturation temperature with position, and the pressure variations resulting from the acceleration of water by changing steam volume. A system of equations that takes into account these pressure effects in a natural circulation boiling water reactor was derived by means of conservation principles stated in integral form. The resulting equations were solved numerically. Sample calculations revealed no special tendency toward instability other than a form of hydraulic instability that does not depend on the inclusion of pressure effects in the model.

1460. Flinn, W. S. and Petrick, M.

PERFORMANCE AND POTENTIAL OF NATURAL CIRCULATION BOILING REACTORS, ANL-5720 (1957), 46 p.

A parametric study of the potential and performance of natural circulation boiling nuclear reactors is presented. Analyses are based on engineering data and correlation extrapolations obtained from boiling studies at Argonne. Graphs are used extensively to show interrelationships of power density, system pressure, average core coolant density, core height, riser height, channel hydraulic diameter, recirculation flow rate, and exit steam volume fraction. Interesting aspects of reactor design and their effects on performance are discussed briefly.

1461. Fortescue, P.

BOILING REACTORS, AERE ED/M 14 (1954), 14 p.

1462. Foure, C.

IMPROVEMENT OF HEAT TRANSFER IN BOILING WATER REACTORS, Quarterly Report No. 2, July-September, 1960, EURAEC-34 (1960), 17 p.

Discussions are given of work done on two-phase discharges with single vortex, water-steam separation, and thermal tests with single vortex Freon and water. (NSA-16-17793)

1463. Fromm, L. W., et al.

PRELIMINARY DESIGN REQUIREMENTS: Argonne Boiling Reactor (ARBOR) facility, ANL-5761 (1957), 159 p.

Descriptions of the functional requirements of the facility, together with preliminary concepts of methods for meeting them, are presented. The facility will provide the physical plant for experiments designed to yield data on performance and operation for various light and heavy water natural and forced circulation boiling reactor concepts over a wide range of temperature, pressure, and flow conditions. The design requirements and drawings are included.

1464. Fryar, R. M.

A PRELIMINARY ANALYSIS OF THE PROBLEMS OF IN-PILE BOILING, HW-30058 (1953).

1465. Goodlet, B. L.

FIRST REPORT OF THE (BOILING REACTOR WORKING) PARTY, UKAEA, Research Group AERE Harwell, BWR-1 (1954).

American tests have proved that boiling inside reactor need not be disastrous, and that a condition of steady boiling can be achieved. Discusses question raised by these tests (1) what is to be gained by designing LEO-like water reactors much closer to boiling conditions (2) what are advantages and disadvantages of a continuously boiling reactor.

1466. Graham, C. B., et al.

A CONTROLLED RECIRCULATION BOILING WATER REACTOR WITH NUCLEAR SUPERHEATER. A paper (1852) presented at the 2nd Geneva Conference on the Peaceful Uses of Atomic Energy, held in Geneva, 1-13 September 1958, 9, 74-78.

1467. Harrer, J. M.

EXPERIMENTAL BOILING WATER REACTOR: A paper presented at 4th Annual Conference of Atomic Industrial Forum, held in New York, 28-31 (October 1957).

The performance of the Experimental Boiling Water Reactor during operation is described. During cold hydrostatic tests on the pressure vessel closure, a leakage of 184 cc/hr at 1,040 psig was measured. After 14 thermal cycles from room temperature to 478°F, a leakage of 1700 cc/hr at 1200 psig was measured. No leakage was ever detected during operation at power. The steam decomposition rate at 20 Mw was measured at 9,000 cc/min at 600 psig and 13,000 cc/min at 300 psig. A time of 24 hr was found sufficient to complete removal of fuel from the reactor if cooling is maintained at a rate of about 50°F/hr and temperature differentials across the vessel are kept below 100°F. The complete operation cycle from shutdown to startup required 40 to 48 hours plus the time to change fuel. In BORAX tests the absolute kw liter value at which the reactor became unstable (chugging) was above 30 kw/liter. During chugging, the flux was found to change cycles from the operating value to 0 about once every second. Computer results indicated that instability would occur between 65 and 80 Mw of heat, or at 65 to 80 kw/liter of core power density. The detection of a fuel element failure is discussed. The economics of the program are discussed relative to amortization, fuel costs, maintenance, and operation.

1468. Harrer, J. M.

PROTOTYPE BOILING WATER REACTOR, ANL-6019 (1959), 79 p.

Design of a nuclear power plant of 50-Mw(e) capacity which can be used to demonstrate advanced performance concepts for boiling water reactors is described. Included are diagrams and data on core design, mechanical design, and heat transfer and fluid flow. Also included are sections containing information on physics, fuel cycle evaluation, and recommendations. 26 references.

1469. Harrer, J. M., et al.

PERFORMANCE EVALUATION OF DIRECT CYCLE BOILING WATER NUCLEAR POWER PLANTS BASED ON RECENT EBWR AND BORAX DATA, P/2379, Second International Conference on Peaceful Uses of Atomic Energy, Geneva, 9, 264 (1958).

1470. Haubenreich, P. N.

A POWER CYCLE STUDY, CF-51-11-28 (1951), 11 p.

A flash chamber-recombiner-heat exchanger system is proposed to prevent the formation of gas bubbles in the core of a homogeneous reactor. The case of the H_2O-moderated reactor is considered in greater detail. Performance characteristics of such a system are given in graphical form. (NSA-11-7760)

1471. Hetrick, D. L. and Remley, M. E.

TRANSIENT PRESSURE IN THE WATER BOILER KINETIC EXPERIMENT, NAA-SR-MEMO-1306 (1955), 23 p.

The results of theoretical studies on the effect of inertial pressures in water boiler transients are summarized as follows: (1) derivation of the equation for transient pressures in a partially enclosed container of water, (2) development of the equation of state for a mixture of water and radiolytic decomposition gas, (3) calculation of peak power as a function of reactor period, and (4) discussion of the effect of limited void space above the solution. It is intended that these results should serve as an indication of the magnitude of the inertial effects as a guide for planning the experimental program for KEWB. It is concluded that the attainable pressures represent no hazard to equipment, personnel or environs. (NSA-12-1092)

1472. Hetrick, D. I.

THE EFFECT OF RADIOLYTIC DECOMPOSITION GAS ON THE KINETIC BEHAVIOR OF A WATER BOILER REACTOR, ANS Paper 15-4 (1957).

The response of KEWB to step inputs of reactivity was explored in 62 self-limiting excursions, covering the range up to 0.94% reactivity. Parameters affecting shutdown behavior were determined. It was concluded that radiolytic decomposition gas is approximately seven times as effective as thermal expansion in limiting a neutron burst in a water boiler reactor at atmospheric pressure, provided the burst is rapid enough that most gas bubbles remain in the solution until after peak power is attained, and provided the dynamic pressures achieved are not large enough to interfere with the effect of gas bubbles on the reactivity.

1473. Holl, R. J., Klecker, R. W. and Graham, C. B.

NUCLEAR SUPERHEATER FOR BOILING WATER REACTOR, May 15, 1962, U. S. Patent 3,034,977.

A description is given of a boiling water reactor having a superheating region integral with the core. The core consists essentially of an annular boiling region surrounding an inner superheating region. Both regions contain fuel elements and are separated by a cylindrical wall, perforations being provided in the lower portion of the cylindrical wall to permit circulation of a common water moderator between the two regions. The superheater region comprises a plurality of tubular fuel assemblies through which the steam emanating from the boiling region passes to the steam outlet. Each superheater fuel assembly has an outer double-walled cylinder, the double walls being concentrically spaced and connected together at their upper ends but open at the bottom to provide for differential thermal expansion of the inner and outer walls. Gas is entrapped in the annulus between the walls which acts as an insulating space between the fissionable material inside and the moderator outside. (NSA-16-17304)

1474. Hubers, C.

DEPENDENCE OF THE EFFECTIVE MULTIPLICATION FACTOR ON THE COMPRESSIBLE STEAM VOLUME IN A BOILING REACTOR, Naples Conf. on Power Reactors, Harwell, HAR-1151 (11), May, 1956, p. 10.

1475. Hurst, R. and McLain, S.

PROGRESS IN NUCLEAR ENERGY, SERIES IV. TECHNOLOGY AND ENGINEERING, New York, McGraw-Hill Book Co., Inc., 1956, 432 p.

Methods of producing and purifying such reactor materials as D_2O, graphite, BeO, Na, and NaK alloys are reviewed, and the efficiencies of the various methods are discussed. Many of the problems associated with reactor cooling and heat transfer are considered; specific treatment being given to the cases of boiling and liquid metal heat transfer. Coolant pump requirements and development are noted. Papers are included which treat specific chemical and corrosion problems in both heterogeneous and homogeneous, and water and metal cooled reactors.

1476. Jens, W. H. and Lottes, P. A.

BOILING HEAT TRANSFER. THE REACTOR HANDBOOK, VOL. 2, ENGINEERING, AECD-3646 (1955), 1083 p.

Various phases of reactor engineering are discussed, specifically light- and heavy- water-cooled systems, liquid-metal-cooled systems, gas-cooled systems, aqueous fuel systems, liquid-metal fuel systems, fused-salt systems, handling and control, and reactor designs.

1477. Kalafati, D. D.

THERMODYNAMIC ANALYSIS OF THE CONDITIONS OF HEAT EXCHANGE IN THE VAPORIZER OF A NUCLEAR POWER PLANT, AEC-TR-4943 (1961) 18 p. [Translated from: Teploenergetika, No. 6, 16-20 (1961)].

The optimum temperature drop in the vaporizer of a nuclear power plant under various operating conditions was determined on the basis of a thermodynamic and technical-economic analysis of the conditions of heat exchange.

1478. Kasten, P. R.

BOILING REACTORS: VARIATION OF REACTOR STABILITY WITH OPERATING POWER LEVEL AND AVERAGE BUBBLE SIZE, CF-51-11-130, (1951), 9 p.

The effect of average bubble size and operating power level upon reactor stability was studied. Boiling reactor stability increases with the power level and with a decrease in bubble size. The operating pressure should be high to improve the power density attainable and yet have sufficient bubble nuclei for good stability. Bubble delay times of the order of 0.1 second appear feasible if many small gas bubbles are formed throughout the reactor due to liquid decomposition.

1479. Katz, K. and Hopkins, W. E., Jr.

EFFECT OF IN-PILE LOCAL BOILING ON SURFACE DEPOSITION AND CORROSION, Nuclear Sci. and Eng., 4, 673-89 (1958)

Many advantages can be realized by operating pressurized water reactor at steady state local boiling conditions; however, before this mode of operation can be factored into thermal and hydraulics of reactor design, its effect on cladding corrosion and surface crud deposition must be established; author described evaluation of local boiling test at pH7, for crud deposition and corrosion.

1480. Kolflat, A.

SPECIAL ENGINEERING FEATURES IN DESIGN OF THE EXPERIMENTAL BOILING WATER REACTOR PLANT, Proceedings of the American Power Conf: 18, p. 79 (1956).

1481. Kroeger, H. R. and Stephenson, P. H.

THE EFFECT OF SODIUM VAPOR FORMATION ON THE OPERATION OF THE ENRICO FERMI REACTOR.AN ESTIMATE, AECU-3697 (July 1957) 53 pages.

The results of calculations concerning two-phase sodium flow in the Fermi Fast Breeder Reactor are presented. The large specific volume of sodium vapor coupled with the resistance of the top axial blanket section resulted in large pressure drops for small values of net vapor. Once the coolant reached the saturation temperature, the pressure drop resulting from vapor formation exceeded the added pressure drop from flow reduction. Although there appears to be a region of stable operation with vapor formation, the lowest value of pressure drop in this region is much greater than that at the initiating flow rate. It is concluded that any vapor formation in the reactor produces an unstable condition which would lead to burnout. (NSA-12-10968)

1482. Labuntsov, D. A.

CRITICAL THERMAL LOADS ON FORCED MOTION OF WATER WHICH WAS NOT HEATED TO THE SATURATION TEMPERATURE, Atomnaya energiya, v. 10, 1961, 523-525 [Transl. in Soviet J. of Atomic Energy 10, 516-18 (1962)].

One of the possibilities for the increase of the thermal reactor power consists in increasing the intensity of heat exchange in the core. Experiments of this kind are, however, limited on account of a critical thermal load (which for underheated water can amount to 10^7 kcal/m^2·hr). When this load is reached there is a sudden deterioration of heat transfer (instead of bubble formation surface film is formed). Numerous experimental studies of this critical thermal load showed that it depends on pressure, current velocity, and underheating of the liquid; and is practically independent of the length, shape, and diameter of the pipe line. An effect of the diameter is first noticeable when the diameter is smaller than 2 mm. In the numerous publications pertaining to this problem the dependence of the critical thermal load on the parameters in the whole region of interest has not yet been investigated. The object of the author of the present "Letter to the Editor" was to obtain an empirical formula for the critical thermal loads during pumping through of underheated water and water-steam mixture with zero steam content which should be valid in the entire range of the parameters. For this purpose experimental data of other authors are employed. The following formula is given:

$$q_{cr} = 1.25 \cdot 10^6 \phi(p) \sqrt[4]{1 + \frac{2.5}{\phi(p)}}\, w^2 \theta(\Delta t_{u \cdot h})\ \text{kcal/m}^2\text{·hr},$$

where,

$$\phi(p) = p^{1/3}(1 - p/p_{cr})^{4/3};\ \theta(\Delta t_{u \cdot h}) = 1 + \frac{15}{\sqrt{p}} \frac{c_p}{r} \Delta t_{u \cdot h}.$$

Here w is the velocity of water current (in m/sec), p the pressure (in atm), $\Delta t_{u \cdot h} = t_{sat} - t_{liqu}$ (in °C) the underheating of water under the saturation temperature, c_p the specific heat of water, and r the heat of vaporization on the saturation curve. The formula holds in the region of parameter values that occur experimentally. There are 4 figures and 13 Soviet-bloc references.

1483. Lomer, W. M.

EFFECT OF REACTOR FLUX ON BOILING WATER, AERE-T/M-136 (1956), 13 p.

The detailed behavior of any boiling system depends quite strongly on the supply of suitable nucleation sites where small vapor bubbles may form. The highly localized deposition of the kinetic energy of protons and oxygen ions which have been knocked on by the neutron flux in a reactor could serve as a nucleating agent under some circumstances. It is shown here that this could not be expected in water boiling at atmospheric pressure, but that at 600 psi it is impossible at present to state whether there will be any such effect, or its significance as far as heat transport is concerned. It is also argued that there is little significance for reactor kinetics in the fact that 5% of the fission energy is carried in long range neutron and γ radiation, thus bypassing some thermal conduction delays. (NSA-10-7621)

1484. Lottes, P. A., Marchaterre, J. F. and Petrick, M.

ADVANCED COURSE ON HEAT EXTRACTION FROM BOILING WATER POWER REACTORS AND ASSOCIATED DYNAMIC PROBLEMS, Pt. II, NP-9286 (1959), 231 p.

A series of lectures was presented on heat extraction from boiling water power reactors including topics on Heat Transfer, Two-Phase Pressure Drop, The Prediction of Steam Volume Fractions, Critical Heat Flux or Burnout, Calculation Procedures for Boiling Systems, Thermal and Hydraulic Design Procedures for Boiling Water Reactors, and Properties of Light and Heavy Water. (NSA-15-10533)

1485. Lottes, P. A., Petrick, M. and Marchaterre, J. F.

LECTURE NOTES ON HEAT EXTRACTION FROM BOILING WATER POWER REACTORS, ANL-6063 (1959), 172 p.

Calculation procedures for the thermal and hydraulic performance of boiling reactors are outlined relative to boiling heat transfer, evaporator-condenser heat transfer, fuel element heat transfer, and steam heat transfer equations. Various engineering systems for evaluating the two-phase pressure drop are given; the corrected Martinelli-Nelson method was found most adequate. Working curves for calculating velocity ratios and steam volume fractions are given which are accurate to within ±15%. Expressions are given for calculating pool and film boiling and net and local boiling burnout for various geometrical arrangements. Calculation procedures are given for natural and forced circulation system analysis and compared to experimental data. Design criteria are discussed with calculation procedure given for the design parameters: moderator to fuel ratio, critical maximum heat flux, vapor-liquid separation, and reactor geometry, natural vs forced circulation. The calculation procedure is illustrated by a sample core analysis. The physical and thermodynamic properties of light and heavy water are given.

1486. Lottes, Paul A.

NUCLEAR REACTOR HEAT TRANSFER, ANL-6469 (1961), 201 p.

A review, with emphasis on two-phase systems, used as notes for a graduate course.

1487. Lyon, R. N.

PRELIMINARY REPORT ON THE 1953 LOS ALAMOS BOILING REACTOR EXPERIMENTS, CF-53-11-210 (1953), 21 p.

Boiling reactor experiments were designed to indicate the response to large reactivity changes. Preparations for these experiments are reviewed, and a chronological statement of experimental events is given. The results indicate that boiling reactors are capable of self-adjustment to rapid reactivity changes, but further analysis of the data is planned.

1488. Marbury, F., et al.

SUPER HEATING WATER BOILER, CF-57-8-10 (1957), 236 p.

A preliminary design is presented for a boiling-water reactor with integral nuclear superheater, which produces steam at 1200 psia, 950°F. The design uses stainless steel, UO_2, and water for materials and stays generally within the limits of existing reactor technology. The design output is 129,445 lbs of steam per hour at the stated conditions, which corresponds to 17,500 shaft horsepower in a naval steam plant and to 47.25 Mw of heat. This is thought of as a ship propulsion reactor, and its capacity, arrangement, shielding, and control system are appropriate to that application. The feasibility, size, and weight were studied; also the biological shielding and mechanical design were studied in relation to plant size and weight. Water treatment, mechanical design of control rod drives, and the steam plant are not considered. The reactor core is cylindrical and divided radially into three regions; a central superheater, an annular boiler, and a surrounding reflector.

1489. Margulova, T. H.

SOME PROBLEMS OF THE DEVELOPMENT OF NUCLEAR POWER PLANTS WITH REACTORS USING WATER, WATER-VAPOR MIXTURE, OR SUPERHEATED STEAM AS HEAT REMOVAL MEDIA, Jaderná energie, No. 7, pp. 222-227 (1960).

The article analyzes some design problems of nuclear power plants with reactors using either water, water-steam mixture, or superheated steam as heat removal media. The author presents several possible designs of such plants with special attention paid to the possibility of replacing expensive austenitic stainless steels by less expensive steel types for reactor building. Extensive corrosion tests with austenitic stainless steels were conducted at the Department of Nuclear Power Plants of the Moscow Power Institute. The tests were made in water within a pressure range of 2.5 - 100 atm at boiling temperatures for various concentrations of chlorine and oxygen in the water. They revealed that the corrosion depended on the oxygen content (no corrosion was observed in the absence of oxygen) and still more on the pressure (temperature) of the medium. At a pressure of 2.5 atm and a Cl concentration of 200 mg/l there was no corrosion at all, while considerable corrosion was observed at a pressure of 200 atm and a Cl concentration of only 1 mg/l. These results demonstrate the necessity of as complete a degassing of the feed water as possible and such a selection of a thermal design of the power plant that the heat-exchanger surfaces made of austenitic stainless steel be in the range of possibly lowest pressures (temperatures) for both the heat-exchanging and working media. The problem of the replacement of austenitic stainless steels by other steel types can be solved by the following three approaches: 1) Introduction of such water treatment methods as would greatly reduce corrosion processes, especially by maintaining a sufficient alkalinity of the water. 2) Use of such steel types that would be free of shortcomings of austenitic steels and yet have a corrosion resistance in high-purity water only slightly less than

austenitic steels. Most promising in this respect appear to be ferritic steels without nickel and with a minimum chromium content of 12%. 3) Development of such thermal designs of nuclear power plants at which the corrosion processes would rapidly decrease. In the following the latter approach is dealt with more in detail describing nuclear power plant designs with turbines using saturated steam, high-parameter steam, or supercritical-parameter steam. In the first group, 4 designs are proposed with their flow-charts shown in Figures 1 through 4. Of these, the design shown in Figure 4 combines the advantages of the previous three, doing away with a number of their disadvantages at the same time. It is a boiling-water, two-loop design with the steam-generator operating pressure only slightly above the atmospheric pressure. This feature eliminates the need for austenitic stainless steel in the heat exchanger and has the additional advantage that the steam generator requires only light shielding or none at all since only slightly radioactive steam is used as heat-exchanging medium. The disadvantage of this design is that the main stage of the turbine uses radioactive steam. In designing turbines for this arrangement, the following requirements have to be observed: the steam moisture at the outlet of the first turbine stage must not exceed 11- 13%; the steam pressure at the inlet to the second turbine stage has to be higher than 1 atm; the temperature gradient between the heat-exchanging and working media has to be 15°C. The design provides for forced circulation inside the reactor and moisture separation outside. However, several proposals for reactors with natural circulation have been worked out, too. - The second group with turbines using high-parameter steam also comprises 4 design proposals whose flow-charts are shown in Figures 5 through 8. Of these, the design shown in Figure 7 was prepared for a nuclear power plant now being built in the USSR. It is a modified (incomplete) two-loop design with a separate high-pressure steam generator. The steam of the secondary loop is reheated in the reactor core, which permits to reduce temperature and pressure in the calandria tubes. The disadvantages of this design are the following: 1) The entire power plant equipment operates with radioactive steam. 2) Due to the high pressures and temperatures, the heat-exchanger surfaces have to be made of austenitic stainless steel. 3) The steam generator must be shielded as radioactive water of the primary loop is used as heat-exchanging medium. 4) The calandria tubes of the reactor operate at a pressure substantially higher than the working pressure at the turbine inlet. 5) The residue of the steam generator is radioactive and requires special processing equipment. - Also feasible is a design featuring an arrangement comparable to that shown in Figure 4, but operating at high steam parameters. It is a complete two-loop arrangement with a separate low-pressure steam generator whose flow-chart is shown in Figure 8. Pressure and temperature in the calandria and superheater tubes correspond with those of the steam at the inlet of the turbine. The steam generator does not require shielding since only slightly active steam is used as heat-exchanging medium. The secondary-loop water requires but inexpensive treatment with ion exchangers operating at temperatures at which the corrosion of austenitic stainless steel parts in Cl environment is negligible and the water need not be demineralized. The use of austenitic steel is also greatly reduced. For this design, the steam at the outlet of the high-pressure turbine has to have a pressure above 1 atm and a moisture content not exceeding 11%. A standard VK-100 turbine can be used in this arrangement requiring only slight modifications. - Based on the arrangements shown in Figures 4 and 8, a design of a nuclear power plant with turbines using supercritical steam parameters is proposed. Its flow-chart is shown in Figure 9. It has a two-loop arrangement with a separate low-pressure steam generator. The principal advantage of this design is that it does not require a steam reheater. The turbines for this arrangement have to be such that the steam moisture at the low-pressure turbine section must not exceed 11 - 13%, the temperature gradient between the heat-exchanging and working media has to be 15°C and the initial steam pressure of the secondary loop has to be higher than 1 atm. It can be seen that for nuclear power plants with reactors using either water, water-steam-mixture, or superheated steam as heat-removing media a two-loop arrangement is the most advantageous and safest design. (Translator: J. Korycánek). There are 9 figures.

1490. Noderer, L. C.

ANALYSIS OF BOILING WATER REACTORS, in Proceedings of the ANPP Reactor Analysis Seminar, Oct. 11-12, 1960, MND-C-2487 (p. 123-30), (1961).

A brief review of pressurized water physics is presented since the problems in the analysis of a boiling water reactor include whatever problems are encountered in pressurized water reactors plus the presence of steam voids. Methods of analyzing the void distribution are discussed. A boiling water reactor thermal and hydraulic code called STREAC is described. A method of predicting stability for boiling water reactors by expressing the conditions in terms of the transfer functions of power to reactivity input is outlined. A transfer function code, TPFI, is described.

1491. Nylund, O.

SIMULATED BOILING EXPERIMENT IN AB ATOMENERGI'S RESEARCH REACTOR R1, RFX-11 (1958), 32 p.

In the calculation of boiling reactors and the dimensions of the control and safety systems for ordinary D_2O reactors, it is of value to know the reactivity changes induced by boiling in the reactor. Simulated boiling experiments were made in the Swedish R1 reactor with 7 uranium fuel rods and with 19 uranium oxide fuel rods. In the experiments with metal fuels, boiling was simulated by air bubbles, and in experiments with oxide fuels the moderator was completely replaced with air. The changes in the reactor parameters are calculated for both cases.

1492. Owen, E. R.

COMBINED REACTOR AND POWER SYSTEM ANALYSIS FOR A BOILING WATER REACTOR, Proceedings of the Conference on Transfer Function Measurements and Reactor Stability Analysis held at Argonne National Laboratory, Argonne, Illinois, ANL-6205 (p. 74-89) May 2-3, 1960.

A few of the obvious considerations and objectives involved in a combined reactor and power system analysis are briefly reviewed. Some of the methods used to study or analyze the more basic areas peculiar to a boiling water reactor plant are reviewed. The analysis method or models of other non-nuclear components, such as heat exchangers, etc., are not considered. Methods of analysis of the reactor-steam void loop used in system studies of a boiling-water reactor system are discussed.

1493. Parrish, W. C.

TRANSIENT HEAT TRANSFER IN HETEROGENEOUS REACTORS, NAA-SR-47 (1949), 31 p.

A study has been made of transient heat generation and transfer in a thermal heterogeneous reactor cooled and moderated by D_2O, after super-criticality produced by a sudden release of 2% excess k. Two cases are considered: (1) the D_2O is at a mean temperature of 170°F during steady state of operation; (2) the steady-state D_2O temperature is that of saturation (212°F).

1494. Petrick, M. and Marchaterre, J. F.

A PRELIMINARY DESIGN STUDY OF A BOILING SLURRY REACTOR EXPERIMENT, ANL-6148 (1960), 39 p.

An experiment is described which would test the feasibility of the boiling slurry reactor concept and investigate its potential as a practical nuclear power reactor. The experiment would yield data and information on reactor stability and safety characteristics, performance parameters, feasible slurry concentration limits, behavior of slurries under actual reactor operations, rates of radiolytic gas evolution, rates of fission gas release, etc.

1495. Pratt, H. R. C.

THE APPLICATION OF THE CLIMBING FILM PRINCIPLE TO BOILING WATER REACTORS, UKAEA, Research Group, AERE Harwell, AERE CE/M 157, 11 January, 1956.

1496. Pruschek, R.

HEAT TRANSFER FROM A BOILING WATER REACTOR, Energie, 12, 41-7 (Feb 1960).

A study was made for a dual-cycle boiling-water reactor (similar to the Dresden BWR) of the possibility of heat dissipation in a natural convection system as well as of the temperature relation in the fuel element. In addition, the permissible heat-flux density in a pressure loop system was established.

1497. Purcell, R. H.

IN-PILE BOILING CAPABILITIES-1706-KER FACILITY, HW-36136 (1955).

1498. Recht, R. F.

PILE COOLANT BOILING - CAUSES AND EFFECTS. TOLERABLE FLOW REDUCTIONS, POWER EXCURSIONS BEFORE UNSTABLE FLOW DUE TO BOILING, HW-31649 (1954).

1499. Ricci, A.

INTRODUCTORY BIBLIOGRAPHY FOR BOILING WATER REACTORS, CISE-56 (April, 1957), 8 p.

1500. Roberts, H. A. and Bowring, R. W.

BOILING EFFECTS IN LIQUID-COOLED REACTORS. Nuclear Power 4, 69-73 (Feb. 1959).

Full understanding of boiling effects is important for both BWRs and non-boiling, liquid-cooled reactors. This begins a two part (for part II see Nuclear Power 4, 96-101 (Mar. 1959)) article reviewing the present position of boiling theory, particularly where it touches on the related fields of heat transfer and burnout.

1501. Roberts, H. A. and Bowring, R. W.

BOILING EFFECTS IN LIQUID COOLED REACTORS. Nuclear Power 4, 96-101 (March 1959).

In the second of a two-part article, boiling heat transfer is dealt with. The effects of various types of boiling, recent correlations for calculating fuel element temperatures, and reactor safety limits set by burnout are considered.

1502. Rohrmann, C. A.

REACTOR HEAT TRANSFER BY BOILING MERCURY-204, HW-60564 (June 1959), 29 p.

This report is a revised version of HW-56161. In order to emphasize the advantage of boiling Hg^{204} as a reactor coolant, a liquid metal slurry fueled thermal reactor concept is studied in detail.

1503. Sanders, J. P.

GAS PRODUCTION IN THE ISHR, CF-53-1-110 (Jan. 6, 1953), 10 p.

The rate of formation of D_2 and O_2 in the ISHR is calculated and the composition of the evolved gas is discussed along with partial pressures in the gas separator. Steady state concentrations of gases dissolved in the liquid entering and leaving the core are calculated using the assumption that the gas in the bubbles is in equilibrium with the liquid and that all the undissolved gas is removed in the separator.

1504. Schroeder, F.

STABILITY TESTS WITH THE SPERT-I REACTOR, IDO-16383 (July 1957), 13 p.

The existence of unstable behavior in the SPERT-I reactor has been previously reported. Recent tests, in which the conditions for the onset of this instability were investigated, are discussed. Tests were conducted with the initial bulk water temperature at 20

and 97°C (boiling), and with the initial height of the water head over the core at 2 and 9 feet. The reproducibility of all such stability tests is discussed.

1505. Shaw, J. W. W.

SUPPLY AND REGULATION OF BOILER FEED WATER Part I, Control, 4, 96-8 (May 1961).

The method for replacing the steam generated by an equal quantity of water is discussed. It consists of high-pressure feed pumps forcing the water into the boilers and feed regulators adjusting the feed rate to match the steaming rate. Problems of supply and regulation in nuclear power stations are discussed, and principles of single-, double-, and triple-element regulators are briefly described. Feed regulation is discussed in relation to reactor control, and reference to the situation at Calder Hall is made.

1506. Shaw, J. W. W.

SUPPLY AND REGULATION OF BOILER FEED WATER, PART II, Control, 4, 94-7 (June 1961).

Methods of controlling reactor inlet temperatures and the effects of regulation on these temperatures are discussed. The Robot and Steadiflow feed regulators and their performances in the Calder Hall reactor are described. Data are presented graphically, and diagrams are given.

1507. Skinner, R. E. and Hetrick, D. L.

THE TRANSFER FUNCTION OF A WATER BOILER REACTOR, NAA-SR-1948 (August 1957), 42 p.

The power and temperature transfer functions for a water boiler reactor are obtained for the case of m groups of delayed neutrons including the effects of temperature and radiolytic gas generation. The nature of the water boiler reactor transfer function is investigated, and important results discussed. A number of asymptotic and approximate expressions are given. Representations other than Bode plots are investigated. These include the inverse polar plot, complex power coefficient of reactivity, and modified Nyquist plots. The derivation and limitations of the space-independent reactor kinetics equations used are discussed briefly.

1508. Soldaini, G.

SURVEY OF HEAT TRANSFER STUDIES BY MEANS OF BOILING WATER IN THE UNITED STATES. ENERGIA NUCLEARE (MILAN) 7, 159 (March 1960).

A report is given of a trip, organized by Euratom, to many universities and nuclear laboratories in the United States. Information gathered from specialists on problems of reactor cooling with steam-water mixtures is presented.

1509. Spigt, C. L., Simon-Thomas, J. P. and Bogaardt, M.

INTRODUCTORY LABORATORY STUDIES OF BOILING-WATER REACTOR STABILITY, Paper No. 8, Symposium (Preprint of Proceedings) on Two-Phase Fluid Flow, Inst. Mech. Engrs., London, England, February 7, 1962.

After a short description of the aim of the investigations and of the experimental set-up, results are given of natural circulation experiments in the pressure range of 0-30 kg/cm^2 and 0-200 kw power dissipation of a fuel-rod dummy identical in dimensions with the fuel rod used in the Halden heavy-water boiling reactor (Norway).

Slip ratios and two-phase pressure drop values are reported and compared with data obtained by other investigators.

In a number of natural circulation calculations the effect of variations in sub-cooling and slip ratio is shown. The importance of accounting for the axial power distribution is also indicated.

Finally, attention has been given to the onset of instabilities in the natural circulation loop.

An outline is given of the subsequent experimental programme.

1510. Stein, R. P., et al.

INVESTIGATION OF WET STEAM AS A REACTOR COOLANT (CAN-2) UNC-5008-I (1962).

1511. Thie, J. A.

BOILING WATER REACTOR INSTABILITY, Nucleonics, 16, 3 (March 1958).

The observed oscillatory behavior of five ANL boiling reactors - the BORAX I, II, III, IV, and the Experimental Boiling Water Reactor - are described. The amplitude, frequency, temperature, and threshold of the oscillation are recorded. The kinetic theory of oscillations is illustrated by a simplified model using a single series feedback loop and linearized one group kinetic equations. Experimental approaches to more complete understanding of reactor instability are described. Semiempirical techniques which can be used to obtain information about the unstable point from a rod oscillator experiment are given.

1512. Thie, J. A.

THEORETICAL REACTOR STATICS AND KINETICS OF BOILING REACTORS, P/638, Second International Conference on Peaceful Uses of Atomic Energy, Geneva, 11, 440 (1958).

1513. Thie, J. A.

DYNAMIC BEHAVIOR OF BOILING REACTORS, ANL-5849 (1959), 51 p.

Eight boiling reactors, BORAX I, II, III, IV, EBWR, LITR, VBWR, and SPERT I have been operated to date, and a considerable amount of information exists in regard to their tendencies toward self-induced power oscillations. Data are presented on the following characteristics of the oscillations: power, pressure, temperature, reactivity amplitudes and their rate of change; thresholds, and harmonic content. Results from three techniques of measuring the reactor transfer function are presented: the rod oscillation, the reactivity step, and the autocorrelation methods. Quantitative definitions of instability are introduced.

Theoretical analysis of these reactors' kinetic behavior, based on a simple model where steam void feedbacks dominate, shows an adequate understanding

of many of the phenomena, some even quantitatively. It is concluded that it is possible within the framework of existing experimental and theoretical boiling reactor dynamic technology, to design these reactors with reduced instability limitations on the power, and obtain power densities in excess of the current 50 kilowatts/liter of core.

1514. Thomas, D. G.

PRELIMINARY BOILING EXPERIMENTS IN THE SUPO MODEL OF THE WATER BOILER, CF-53-7-221 (1953), 19 p.

It has been demonstrated that it is possible to operate a homogeneous reactor under boiling conditions and that under the particular conditions encountered, a boiling homogeneous reactor is not inherently unstable. The solution density change on going from non-boiling to boiling conditions has been calculated using the two-group two-region method. The maximum density change found was 0.8% corresponding to a total nuclear power of 5.4 kw. For small reactivity additions the relationship $\Delta k/k = 0.3\ \Delta d/d$ is good to ±10%. Average bubble rise rates of 10 ft/sec were calculated assuming that 1 kw of heat was dissipated in uniform volume boiling. This suggests that the onset of vapor evolution in the solution increased the rate of circulation and thereby the rate of surface evaporation. Disengagement velocities from the free surface of the water boiler were found to be 30 to 50 lbs. of vapor/(hr)(sq ft).

1515. Thompson, W. E.

HOMOGENEOUS REACTOR PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JANUARY 1, 1953, ORNL-1478 (DEL.)(1953), 133 p.

Homogeneous Reactor Experiment. The status of HRE operation is discussed. Corrosion of the HRE fuel system is briefly discussed. Power and temperature response curves for the HRE simulator are shown. Boiling Reactor Research. Diagrams of the BRE shield proposal are given, and γ radiation through the shielding is plotted. The piping drawing for the proposed Teapot design is also given. Data are also given on the response of a boiling homogeneous reactor to changes in steam demand. General Homogeneous Reactor Studies. Tentative design data and the preliminary flow sheet of the Intermediate Scale Homogeneous Reactor are given. Proposed ISHR core vessel and heat exchanger designs are also shown. An analysis is made of the gas separator operation. The flow diagram for the ISHR steam system is also given. Some criticality data are summarized. Flow sheets are given for a test loop to test various sample valves with flowing uranyl sulfate solution. Reactor core development is discussed. Proposed slurry pumps are described. A complete summary of data collected on pin-type corrosion specimens are given. Data on the effect of velocity on the corrosion of type 347 stainless steel are also given. Corrosion data of type 347 stainless steel in oxygenated uranyl fluoride are summarized. Impact test results on commercial purity Ti specimens are compiled. The corrosion of stainless steel by UO_2F_2 and UO_2SO_4 under neutron irradiation is studied. Progress in slurry chemistry is summarized.

1516. Treshow, M.

DESIGN STUDY OF SMALL BOILING REACTOR FOR POWER AND HEAT PRODUCTION, ANL-5327 (DEL.) (1954), 63 p.

A design study has been made of a small "Package" nuclear power plant for the production of electric power and heat in remotely located, inaccessible areas devoid of natural fuels. The design utilizes a horizontal boiling reactor as a steam generator consistent with safe and simple equipment and a minimum building height. A reactor design of $5\frac{1}{2}$ Mw capacity, with a combined net electric power output of 750 kw and a heat plant output of 4500 kw, was studied in detail. Tentative cost estimates are presented on the basis of this combination. General comparisons have been made between different systems designed for either independent or combined production of 425 kw net electric power and 2500 kw available heat.

1517. Treshow, M., et al.

A STUDY OF HEAVY WATER CENTRAL STATION BOILING REACTORS, ANL-5881, September, 1958, 81 p.

Reactors designed for economic operation in stationary central power plants were studied. Certain objectives presented themselves as being of particular importance if an attractive economy were to be obtained. These objectives are: use of ceramic (UO_2) rather than metallic fuel; use of natural uranium; high conversion ratio; long fuel life; natural convection for heat transfer; production of superheated steam; a high power output; a limited size of pressure tank; fuel handling without use of large pressure lid; and moderator control. Three different types of power reactors are presented; a natural uranium, boiling heavy water reactor with forced circulation; a boiling reactor with natural convection and slightly enriched fuel; and two heavy water boiling and superheating reactors using slightly enriched fuel and natural convection. A chapter on summarized operating data indicates the degree of success achieved in meeting the objectives.

1518. Ulrich, A. J.

RESULTS OF RECENT ANALYSES OF BORAX II TRANSIENT EXPERIMENTS, ANL-5532 (1956), 30 p.

Heat transfer information relating to the shutdown mechanism of the BORAX II reactor is discussed. Pertinent quantities are presented as a function of time for a typical power transient. A proportionality is established between the transient steam pressure pulse and $-\ddot{k}_{ex}$. The heat transfer from fuel plate to water is divided into conduction and boiling phases. Conduction and boiling are shown to exhibit equilibrium behavior except during the transient steam pressure pulse. Because of the incompleteness of the data a definitive description of the phenomena during this pulse is not possible.

1519. Untermyer, S.

BOILING REACTORS, DIRECT STEAM GENERATION FOR POWER, Nucleonics, 12, 43 (July 1954).

Results of experiments which prove that boiling, originally thought to make reactors unstable, can provide self regulation of reactor and at same time directly transfer reactor heat to steam capable of driving power generating turbine, economic and technical advantages gained by elimination of secondary coolant system; progress in boiling reactor development.

1520. Untermyer, S. A.

DUAL CYCLE IMPROVES BOILING-WATER REACTORS, Nucleonics 13, 34-5 (July 1955).

Power output of a simple direct-boiling reactor is limited due to density fluctuations in the moderator caused by boiling. The relatively low power densities, 10 kw/liter, available in large reactors under these conditions are not attractive for central station operation. To improve maximum power and load-demand performance, the use of a flask tank for feedwater subcooling is suggested. (NSA-9-7532)

1521. Viscardi, J. E.

REACTOR HEAT TRANSFER CONFERENCE OF 1956, Collected Papers and Reports of a Conf. Held at New York, November 1 and 2, 1956 (Issued in two books (Bk. 1), 323 p. and (Bk. 2), 318 p., TID-7529, November 1957.

Papers included in Book 1 cover: a general method of determining the total time interval of transients in linear systems, the basic equations describing energy flow and pressure drop relationships for transient coolant flow conditions in a nonhomogeneous plate-type reactor, rapid flow transients in closed loops, fast transient heat transfer in a clad element-stagnant H_2O system, transient heat conduction in solid cylindrical nuclear fuel elements, the response of a nuclear reactor coolant to power transients, a transient thermal analysis by means of analog computers, an analysis of fuel-plate temperature rise during a burnout transient, in-pile molten metal-water reaction experiments, pressure drop in rectangular channels at 2000 psia, flow redistribution due to boiling in a matrix, an investigation of burnout heat flux, nucleate and film boiling due to repetitive pulse heating of small wires immersed in H_2O, tubular vs plate fuel elements: heat transfer and flow analysis, heat transfer within the cores of circulating fuel reactors, heat transfer and hydraulic characteristics of the SRE fuel element and heat transfer rates to cross-flowing Hg in a staggered tube bank. Papers included in Book 2 are on: heat transfer to Pb-Bi in turbulent flow in an annulus, pool-boiling heat transfer with Hg, heat transfer investigations of polyphenyl coolants, heat transfer in a radial spray chamber, the dependence of the heat transfer coefficient on the ratio of the heat fluxes from the walls of parallel plane flow channels, heat transfer and pressure drop characteristics of wire-coil-type turbulence promoters, an analysis of axial turbulent flow and heat transfer through banks of rods or tubes, heat transfer from parallel rods in axial flow, high-temperature heat transfer to a gas flowing in heat-generating tubes with high heat flux, the use of the Mach-Zehnder interferometer in heat transfer studies, compact tubular heat exchangers, and temperature and flow distribution in air-cooled reactors. Discussions are included from the working conferences on the following subjects: two-phase flow pressure drop, burnout in natural and forced convection, heat transfer performance of reactor systems utilizing solutions, suspensions and slurries as fuel-bearing fluids, fused-salt heat transfer systems, transient boiling heat transfer and fluid flow characteristics, and analog and digital computer techniques useful in core heat transfer studies. (NSA-12-6195)

1522. Viscardi, J. E.

REACTOR HEAT TRANSFER PROGRESS (Issue No. 10)(1956), Includes Trans: Characteristics of Mercury Boiling in the Tubes of a Mercury Vapor Generator, by A. N. Loshkin and P. I. Drol. Transl. from: Zhur. Tekh. Fiz. 8, 1872-81, NDA-28 (1938), 26 p.

Some preliminary results of studies on heat transfer in polyphenyls are given. A transition state theory of the linear oxidation rates of metals is offered. A translation of an article on "Characteristics of Mercury Boiling in the Tubes of a Mercury-Vapor Generator" is included in part.

1523. Weatherhead, R. J.

REACTOR ENGINEERING DIVISION QUARTERLY REPORT, SECTION II, APRIL 1-JUNE 30, 1955, ANL-5471 (Sept. 1955), p. 89-93.

Development of the thermal power reactor program is summarized. A complete conceptual design study is given for a nuclear power plant for 100-kw electric and 400-kw heat capacity. Calculations were made to evaluate the inherent safety of 20-Mw D_2O-cooled and moderated EBWR-type boiling reactors. The effects of rapid and slow, but large, increases in reactivity are summarized. Methods of calculating reactivity variation as a function of total energy production for enriched fuel, thermal reactors are discussed, and the methods were applied to two reactors. Results of the analysis are given in graphical form. Results of measuring fission cross section ratios in the EBR are also summarized. A brief account is given of neutron flux measurements using Np^{237} foils and of the foil preparation technique. Heat transfer tests include studies of the multichannel natural circulation boiling density at 600 psig, a discussion of the representation of average voids in boiling length with measurable parameters, normalized plots of void distribution along the boiling length, local boiling pressure drop in round and rectangular vertical channels, and burnout heat flux for wires in cross-flow at atmospheric pressure. Fabrication and corrosion test history of EBWR fuel plates are tabulated. Zircaloy-2 specimens which had been heliarc spot welded are shown. The EBR-II core subassembly is shown. Designs are given for a Na-bond filling device for EBR-II pin-type fuel elements. Further attempts were made to produce a protective coating for uranium. The corrosion of high-U alloys in 500 and 550°F H_2O and the corrosion-irradiation of unclad high-U alloy pins are summarized. Water solubility

tests on urania-thoria bodies were made. Corrosion data for nickel-plated 2S Al in 600°F H_2O are given, as are data on the dynamic H_2O corrosion of Al-Ni alloys. Static corrosion of anodized 2S Al in H_2O is also reported. Results of experiments of the fission product contamination of NaK bond in contact with U during irradiation are reported. The results of examination of the in-reactor tube tip from the Argonne Water Loop at the MTR are given. Water pressure drop tests of EBR-II core subassemblies were made. Heat capacity characteristics for the EBR-II working model electromagnetic pump are given. The primary EBR-II Na system is shown. Summaries of packing gland tests for liquid metal service are given. A study was made to estimate the rate of water decomposition in the EBWR. Corrosion inhibition studies have been continued. A dynamic cold trap liquid metal purification facility was installed in the EBR-II working model, and the initial results are reported. Schematics are given for the Na transfer system for the EBR-II working model. A manually operated electronic Na level probe is also shown. (For preceding period see ANL-5345).

1524. West, J. M. and Roy, G. M.

THE FUTURE OF BOILING WATER REACTORS, Nucleonics, 17, 42 (January 1959).

The recent operation of the Experimental Boiling Water Reactor (EBWR) at more than three times its design-power level and the prospects of reaching still higher power outputs have aroused interest and speculation about the present competitive status of boiling reactors for commercial power plants.

In this article, two authors with considerable boiling reactor experience present their estimates for the performance and costs of boiling reactor plants that could be built today, based on the latest EBWR experience. J. M. West was project manager of EBWR at Argonne National Laboratory throughout the design, construction and early operational phases. More recently he has been in charge of boiling reactor design work at the General Nuclear Engineering Corp. G. M. Roy played a prominent role in design of the Dresden and Pacific Gas and Electric boiling-reactor plants with the General Electric Co. before joining GNEC.

1525. Westinghouse Electric Corp.

REVIEW OF THERMAL DESIGN CRITERIA FOR PRESSURIZED WATER REACTORS AT 2000 PSIA, WAPD-SFR-RS-444 (1956), 18 p.

1526. Woods, W. K.

ALLOWABLE TEMPERATURE RISE IN TUBES OF THE PILES: PRECAUTIONS AGAINST BOILING, HW-7-2562 (1945).

1527. Zmola, P. C.

SUMMARY OF BOILING SYSTEMS SESSION AT THE REACTOR HEAT TRANSFER INFORMATION MEETING AT BROOKHAVEN NATIONAL LABORATORY, BNL-2446, October 18-19, 1954.

Both favorable and unfavorable features of boiling in reactors are briefly discussed.

1528. Zmola, P. C. and Bailey, R. V.

POWER REMOVAL FROM BOILING NUCLEAR REACTORS, Trans. A.S.M.E. 78, 881-892 (May 1956).

A preliminary investigation of three power removal mechanisms for boiling reactors is presented. The problem of relating core power density to mean weight density as a function of pressure is considered for processes involving surface evaporation, bubble growth and rise in a fluid with negligible internal circulation, and bubble growth and rise in a fluid with large internal circulation velocities compared with relative bubble velocity. Results of this analysis indicate that surface evaporation is a negligible factor in power removal except for small reactors. For larger reactors, 3 or 4 ft high, the predominant removal mechanism is natural bubble rise. It is further concluded that vapor entrainment in the circulating fluid limits removal for reactors with a free surface, in which circulation exists.

1529. Nuclear Development Corp. of America

A STUDY OF WET STEAM AS A REACTOR COOLANT, Quarterly Technical Progress Report No. 1, October 1, 1959 through December 31, 1959, NDA-2132-2 (1960), 55 p.

Reactor conceptual designs of fog-cooled, water-moderated reactors are presented. The effects of variables such as burnout, pressure, mass velocity, and steam quality are discussed; they serve as a basis for guiding a series of heat transfer and fluid dynamics tests. The results of a brief study of the phenomenon of burnout as it applies to wet steam as a reactor coolant are presented. A reactivity formulation for use in this project is also presented.

1530. Nuclear Development Corp. of America

A STUDY OF WET STEAM AS A REACTOR COOLANT, Quarterly Technical Progress Report for the Period Jan. 1, 1960 through March 31, 1960, NDA-2132-3 (1960), 27 p.

Test specifications for studying heat transfer, corrosion and erosion, and water injection in the application of wet steam cooling to light-water-moderated reactors are suggested. To evaluate the feasibility of operating a fog-cooled reactor beyond the burnout point, the cladding beyond burnout was calculated for temperature drop of 250 to 550°F between surface and bulk of coolant. The effect of the diameter of the central reflector on the maximum-to-average radial thermal flux and on reactivity was calculated. Derivation of the burnout correlation based on the model which assumes droplet diffusion to a wall is given. Formulas for calculating thermal cross section, thermal regeneration factor, resonance escape probability, fast fission factor, and L^2 and τ were derived. (NSA-14-14571)

1531. Nuclear Development Corp. of America

A STUDY OF WET STEAM AS A REACTOR COOLANT, Progress Report for the Month of September, 1960, TID-6893 (1960), 26 p.

Progress is reported on a research and development program to study water-steam mixtures and their use

as coolants in light-water-moderated power reactors. All heat-transfer and burn-out tests on round tubes were completed. Corrosion and erosion tests indicated that no detectable damage to Zircaloy and stainless-steel samples results after exposure to fog-flow for 120 to 150 hr with velocities of 200 ft/sec at a coolant temperature of 510°F and a pressure of 750 psi. (NSA-15-4771)

1532. United Nuclear Corp.

AN ADVANCED RESEARCH PROGRAM OF THE APPLICATION OF STEAM-WATER SPRAY TO THE COOLING OF LIGHT WATER REACTORS, CAN-2 Quarterly Prog. Report No. 1, May 1 to Sept. 30, 1961, EURAEC 173 (1961), 11 p.

The heat transfer loop and the modifications made in its design are described. Film measurements on an annular test section and a hydrodynamics loop are described. Progress is reported on the corrosion and erosion part of the program.

1533. United Nuclear Corp.

AN ADVANCED RESEARCH PROGRAM ON THE APPLICATION OF STEAM WATER SPRAY TO THE COOLING OF LIGHT WATER REACTORS, CAN-2 Report No. 2, October 1 to December 31, 1961, EURAEC-222 (1962), 12 p.

The reassembling of the heat transfer experimental facility at the Piacenza Power Station was completed, as well as the preliminary tests. A complete set of experiments was carried out at constant pressure (1,000 psi) with a test element 0.52 cm ID. Heat transfer coefficient was measured both at the inlet and at the outlet of the heated section. New codes for data elaboration were prepared. Hydrodynamics experiments were performed with the argon-water mixture with four different test sections (perspex, round, 1.5 cm ID; perspex, annular, 1.5 cm ID and 2.5 cm OD; PVC, round, 1.5 cm ID; and stainless steel, round, 2.5 cm ID). Several experiments were also performed with ethyl alcohol in the PVC round section. The loop was disassembled. Corrosion tests are in progress for investigating the behavior of Zircaloy-2 specimens during long exposures: some specimens reached about 2,500 hours of exposure. The assembling of the second corrosion loop was started.

1534. French Patent Office

BOILING WATER REACTOR (to General Electric Co.) French Patent 1,241,339, August 8, 1960.

In a boiling water reactor the creation of steam bubbles during the operation induces a different depletion of fuel in the different core zones as a result of the different average moderator density caused by the steam bubbles. In order to avoid excessive differences in depletion of the fuel, the fuel elements have an elongated form, so that the average total amount of fuel (fissile and fertile) decreases along the element axis in the direction of flow of the boiling water through the core. The fuel element is provided with a uniform amount of fissile material per unit length. The local multiplication factor K_{eff} is held constant in this way along the path of the boiling water flow.

1535. French Patent Office

BOILING WATER REACTOR (to U. S. Atomic Energy Commission). French Patent 1,237,542, June 20, 1960.

At boiling water reactors with natural circulation of the boiling water through the core, it has been found that the steam tends to accumulate near the exits of the reactor channels, leading to destruction of the fuel elements through overheating. In order to avoid this effect, the reactor comprises a series of elongated fuel elements immersed in the mass of the coolant-moderator constituted by water, each mounted in a general vertical direction, so that they form a reactor core having the shape of a reversed cone. The channels delimited by the fuel elements are designed so that their cross section increases as the density of the coolant flow decreases, i.e. as the coolant is evaporated. This system avoids losses of friction at the exits of the channels and increases the said natural circulation.

1536. Anonymous

BOILING WATER REACTORS (SURVEY OF PAPERS AT 2nd GENEVA CONFERENCE), Engineer, 206, p. 497 (Sept. 26, 1958).

1537. French Patent Office

DEVICE FOR COMPENSATING THE EFFECTS OF VERTICAL ACCELERATION TO A BOILING WATER REACTOR MOUNTED ON A SHIP, French Patent 1,209,632, March 2, 1960.

In order to compensate the influences of density variations in the water-steam mixture in the core of a boiling water reactor mounted on a ship, these variations being caused by vertical accelerations, the flow of the liquid through the reactor is regulated. The compensating device controls the opening of a by-pass of the pump provided to make the liquid circulate through the core, so that this opening is increased in the case of an acceleration in an upward direction and vice versa, with the production of an alteration (a reduction or an increase, respectively) in the circulation. Preferably a regulating mass is supported by elastic means so as to be movable in a vertical direction, this mass being connected with an organ controlling the opening of the by-pass. Suitably a second mass with an elastic support ensures a lead of phase of the circulation relative to the phase of acceleration by controlling the opening of the by-pass by means of a second control device connected with this second mass. For this purpose the movement of the second mass is damped by an adjustable device.

1538. Belgian Patent Office

DEVICE FOR THE PRODUCTION OF SUPERHEATED STEAM IN A REACTOR (to Brown, Bovari et Cie, A. G.). Belgium Patent 583,878. June 6, 1959 (In French).

A boiling water reactor is described that has tubular fuel elements. The outside walls transmit enough heat to vaporize the circulating water; the saturated steam then flows inside the tubes where it is superheated. In each fuel channel, elements are arranged in the following order: an outer moderating material

section with protective lining inside its cylindrical bore, an annular channel, a layer of moderating material lined or canned on both sides, an annular channel, and a hollow cylindrical fuel element.

1539. Anonymous

EXPERIMENTAL BOILING WATER REACTOR STEAM IS DIFFERENT, Power Engng. 61, June 1957, 86-88 (June, 1957).

1540. Argonne National Laboratory

EXPERIMENTAL BOILING WATER REACTOR STUDY PROGRAM, Summer 1961, ANL-AMU, compiled by Glenn E. Schweitzer.

1541. Societe Nationale d'Etude et de Construction de Moteurs d'Aviation

IMPROVEMENT OF HEAT TRANSFER IN BOILING WATER REACTORS, Quarterly Report No. 1, April-June 1960, EURAEC-33 (1960), 15 p.

Studies are being made on two-phase discharges with single vortex. A system using colored, conducting puffs was developed for determining the speed of the liquid at the inlet and outlet tubes. Thermal tests were made with and without spiral strips in the circulation loop. A study of a water-steam separation loop was completed and its manufacture begun. (NSA-16-20596)

1542. Societe Nationale d'Etude et de Construction de Moteurs d'Aviation

IMPROVEMENT OF HEAT TRANSFER IN BOILING WATER REACTORS, Quarterly Report No. 4, January-March, 1961, EURAEC-96 (1961), 30 p.

Measurements of pressure and vacuum fraction losses in two-stage flows were continued. The assembly and experimental methods for use in water-steam separation were tested. Thermal tests were developed to assess the critical burnout fluxes in water and Freon. (NSA-16-18614)

1543. Atomic Power Development Associates

INFORMATION REPORT BY ATOMIC POWER DEVELOPMENT ASSOCIATES COVERING WORK FOR THE PERIOD AUGUST 1, 1954 TO JANUARY 31, 1955. APDA-102 (1955), 82 p.

Five-group diffusion theory equations were used in calculations performed to assist in selection of a fast breeder reactor engineering design, and results are tabulated. The prolonged operation of a piston-type Johnson valve in Na was studied. Progress is reported on fuel element design and development. Analyses of the thermal performance of the elements were made. A cross sectional view of the reactor vessel design is given. The coolant flow characteristics through the reactor core during scram conditions are studied and typical scram histories are shown. A diagram of the liquid and steam-power systems is given. The intermediate heat exchanger is also shown. Diagrams of the once-through-type steam generator and the reactor and steam plant elevation are also shown. A facility for NaK-water reaction tests has been designed. Diagrams of the boiler test facility, the once-through-type test boiler and thermocouple locations for the proposed steam generator unit are shown. The design of the full-scale reactor and Na loop test facility is also discussed.

1544. United Nuclear Corp.

INVESTIGATION OF WET STEAM AS A REACTOR COOLANT (CAN-2), Technical Progress Report for the Period September 1 to November 30, 1961, NDA-2169-3 (1961), 64 p.

Theoretical heat transfer work was continued in an effort to predict phase distribution and critical heat flux data under fog flow conditions. Prediction of reported data on the basis of a simple classical droplet diffusion model met with only limited success. Assembly of a test apparatus intended to permit investigation of the behavior of a stream of water droplets in saturated or superheated steam under atmospheric pressure was completed and preliminary observations of water-steam interactions were made. Reevaluation of critical areas of the reactor conceptual design was initiated. The revised power peaking factors increase the margin available between the maximum operating and critical heat flux, but the influence of the so-called L/D effect tends to reduce previously calculated critical heat flux values.

1545. United Nuclear Corp.

INVESTIGATION OF WET STEAM AS A REACTOR COOLANT (CAN-2), Technical Prog. Report June 1 to Aug. 31, 1961, NDA-2169-2 (1961), 36 p.

Theoretical heat transfer effort was initiated with careful definitions of the quantities associated with two-phase flow and a review of the one-dimensional flow approximation used to predict pressure drop and vapor volume fraction. An initial mathematical application of a droplet diffusion model for predicting behavior of water-steam mixtures under fog flow conditions was undertaken. A test apparatus intended to permit an investigation of the behavior of a stream of water droplets in saturated or superheated steam under atmospheric pressure was designed. Fabrication and assembly are in progress.

1546. Argonne National Laboratory

PAPERS PRESENTED AT THE TECHNICAL BRIEFING SESSION HELD AT ARGONNE NATIONAL LABORATORY, TID-7535, May 27-28, 1957. 164 p.

Papers are presented on the EBWR as follows: a general description; the economic aspects; pressure-vessel design rules, installation history and preliminary performance; design and fabrication of the core structure and fuel-handling system; physics experiments; control-rod drive mechanism; power controls; instrumentation of the power plant; plant equipment, leakage and radioactivity; water treatment, decomposition, and decontamination factor; and safety provisions. Other papers on boiling water reactors include program planning for civilian power reactors, experiments with oxide fuels for BORAX IV, and preliminary design of the Argonne Boiling Reactor Facility.

1547. Argonne National Laboratory

REACTOR INFORMATION MEETING AT ARGONNE NATIONAL LABORATORY, TID-10087, Oct. 7, 8, and 9, 1953. Papers, Part V. Heat Transfer. 94 p.

The following papers are presented: "Heat Transfer in Liquid Metal-Fuel Reactors" by O. E. Dwyer, "Conditions for Maximum Electric Output from Liquid Metal Cooled Reactors" by T. T. Shimazaki and C. H. Robbins, "An Electrical Geometrical Analogue for Two-Directional Steady State Heat Conduction with Uniform Internal Heat Generation" by W. R. Simmons, "Two-Phase Pressure Drop" by George Leppert, "Transient Density Response of Volume-Heated Liquid System" by M. L. Greenfield, and "Relationship Between Void Volume and Power Density Under Atmospheric Boiling" by A. S. Jameson, S. Untermyer, and E. A. Wimunc.

1548. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT March 1, 1953 through May 31, 1953, ANL-5060 (DEL.)(1953), 157 p.

Boiling Reactor Heat Transfer Experiments. Further results have been obtained from natural circulation boiling density tests and investigations of natural circulation flow rates. A special thermocouple design, meeting the rapid-response requirements of high power plate transients, is described. Feasibility studies on heavy water boiling reactors are presented for spherical boiler, pressurized tube, and horizontal pressure tank configurations. Attention has been directed to the study of U alloys with lower corrosion rates in water. Corrosion characteristics are given for UO_2, Zr-clad U plates, U, and Mg in diphenyl, and free energies for chemical reactions commonly occurring in reactor studies are tabulated. A study is reported on the pressure drop characteristics of fuel elements with variations in flow rate, metal-to-water ratio, pitch, and water density. The increased resistance of such fuel wires was found to be less than anticipated.

1549. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT FOR June 1, 1953 through August 31, 1953, ANL-5134 (1953), 134 p.

Progress is reported on the following studies: design and criticality calculations of the Argonne Power Breeder Reactor and the Central Station Water Reactor, water corrosion of Nb-U alloys, corrosion of welded Zr alloys, boiling heat transfer tests, speed of thermocouple response, control rod drive mechanisms, corrosion of Savannah River fuel slugs, rod drop experiments on ZPR-I, organic coolant studies, and temperatures produced by Na-Hg reactions. (For preceding period see ANL-5060).

1550. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT December 1, 1953 through March 30, 1954, ANL-5260 (1954), 185 p.

Reactor Coolant, Heat Transfer, and Power Generation. A new series of tests have been initiated on diphenyl as an organic moderator material, in order to determine the amount of carbonization on heat generating surfaces and the degree of decomposition as a function of neutron dosage. Tar deposits and an 11.1% decomposition was found in a closed loop test operated in the EBR for 73.5 hr at a power level of 1200 kw. Several thermal test loops for organic coolants are described. A liquid-metal level indicator has been developed which measures a change in the electrical inductance of a 60-cycle circuit, according to the amount of metal surrounding the test element. With a view of reducing high D_2O inventories for boiling D_2O reactors, an air-water atmospheric test facility was constructed in order to study separator configurations. A complete description of the apparatus is given, together with some representative test results and separator designs. A technique has been developed for the thermal analysis of complex fuel element designs under steady-state and transient conditions. An electrical, geometrical, analogue device is used, consisting of a resistive plotting surface of conducting paper, a d-c source, a resistive network coupling the plotting surface to the source, and a null-type voltage measuring device. Comparison of the analogue data with analytical results shows close agreement. A group of 16 fuel element configurations have been analyzed from the standpoint of maximum permissible temperatures and heat transfer characteristics, to determine the most feasible design for the PBR. The conclusions include other factors besides heat transfer considerations. A study was also made of the thermal conductivity characteristics of laminated fuel elements, where U particles and stagnant Na are arranged in layers within a containing structure. The condition of parallel heat flow is obtained when the laminations are made thin. Preliminary investigation of power plant cycle and reactor core designs using flashed water to produce steam indicates that a more detailed study is justified. Local heat transfer film coefficients of Na and NaK under conditions of high heat flux and non-circular channels will be measured in a heat transfer loop which is described. The construction of a 600-psi multiple channel boiling density test facility has been completed. A detailed description of the system and test section is presented. The facility will be used for the study of boiling H_2O phenomena at pressures near reactor operating conditions. The flow rate of naturally circulating boiling water was studied as a function of additives such as $HC_2H_3O_2$, Dow-Corning anti-foam, and caustic soda. Slow and rapid heat transients in boiling D_2O reactors were simulated in a water expulsion test apparatus, which was used to obtain considerable data on the characteristics of a 7-tube fuel-element cluster. The removal of core decay heat in the event of a sudden reactor shutdown accompanied by a loss of coolant water will be assumed by the natural circulation of cooling air through the core. In connection with such an event several tests were made to determine the relationship between maximum metal temperature and the heat that can be dissipated to ambient air. Four- and five-ft channels, $\frac{3}{4}$ x $4\frac{1}{2}$ in. were tested.

1551. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT April 1, 1954 through June 30, 1954, ANL-5297 (1954), 206 p.

Heat Transfer. A modified electrical-geometrical analogue has been designed to solve temperature distribution problems within fuel elements of complex geometry. Good accuracy for the device is reported. Factors affecting the precision of a given thermal analysis of EBR-II fuel elements are discussed, including uncertainty factors which are helpful in determining the worst possible effects of a number of thermal parameters. A heat transfer analysis was made for 5 different EBR-II fuel element designs. Three radiator-type and 2 pin-type elements were tested, and their comparative performance is summarized. Natural circulation tests were made to determine the steady-state relationship between maximum plate temperature and power density of shutdown heating. It is concluded that the reactor core will not be adequately cooled during shutdown when there is a loss of water from the core area. A pulse-heating test facility was designed to investigate the fundamentals of water expulsion from a Cu tube to which short pulses of a-c current are applied.

1552. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT FOR October 1, 1954 through Dec. 31, 1954, ANL-5371 (1955), 284 p.

Calculations were made of the expected steady-state nuclear heating of the EBR pressure vessel to establish the relationship between pressure vessel thickness, heat generation, temperature distribution, thermal stress and pressure stress. Studies of natural circulation boiling density at 600 psia are being conducted to provide basic information for the EBR Program. The present objectives are to determine the effects of power input, inlet water temperature, flow rate, and channel geometry upon the density in the channels.

1553. Argonne National Laboratory

REACTOR DEVELOPMENT QUARTERLY PROGRESS REPORT, ANL-5398 (DEL.)(Jan 31, 1955), 63 p.

The design and construction program of the Boiling Experimental Reactor is reviewed. A number of preliminary experiments were performed with BORAX-II at pressures between 75 and 300 psi. Unclad and unirradiated samples of U-Nb and U-Nb-Zr alloys were corrosion tested in H_2O. Corrosion rates were also measured under irradiation conditions in CP-5. Natural circulation boiling density tests at 600 psia were made in order to determine the effects of channel cross section and subcooling on the steam void fraction. Results of autoclave and dynamic corrosion studies of 2-S Al in H_2O are reported. These results include the testing of Ni-clad samples.

1554. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT ON THE POWER REACTOR PROGRAM, Jan. 1 through Mar. 31, 1955, ANL-5461 (1955), 124 p.

Construction drawings and specifications have been completed for the building and power plant of the Experimental Boiling Water Reactor (EBWR). The design of the pressure vessel has been evaluated for safety in case of internal explosion. The results of steam pipe rupture studies and tests of impurity carry-over in the boiling process are reported.

1555. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT, April 1, 1955 through June 30, 1955, ANL-5471 (1955), 173 p.

Development of the thermal power reactor program is summarized. A complete conceptual design study is given for a nuclear power plant for 100-kw electric and 400-kw heat capacity. Calculations were made to evaluate the inherent safety of 20-Mw D_2O-cooled and moderated EBWR-type boiling reactors. The effects of rapid and slow, but large, increases in reactivity are summarized. Heat transfer tests include studies of the multichannel natural circulation boiling density at 600 psig, a discussion of the representation of average voids in boiling length with measurable parameters, normalized plots of void distribution along the boiling length, local boiling pressure drop in round and rectangular vertical channels, and burnout heat flux for wires in cross-flow at atmospheric pressure.

1556. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT July, Aug., Sept., 1955, Section II, ANL-5511 (1956), 186 p.

Experimental Boiling Water Reactor. The boiling water corrosion of Zircaloy-2 clad stainless steel thimbles is shown. Calculated heat generation and thermal stresses in the pressure vessel wall for each type of thermal shielding are tabulated. The mechanical arrangement of the thermal shielding is given. The reactor water purification system is discussed. A schematic flow diagram of the air drying and fluid recovery system is given. Estimated flows in this system are also given, and the operation of the system is briefly discussed. Supporting and Alternate Design Research and Development. The design of a boiling D_2O reactor is briefly discussed. Data given on boiling heat transfer studies include the ratio of steam-to-liquid velocity as a function of the variable inlet temperature, power, flow, and pressure. The analytical and experimental studies made of the 600 psi, unrestricted, single-channel circulation loop (Armadilla) are described, and preliminary data are plotted. These plots show modified Martinelli-Nelson factors as a function of slip ratio and exit and local void fraction. Data from single channel forced and natural circulation boiling density tests at 150 psig are summarized. Slip ratios are also plotted as a function of inlet water velocity at 150 and 250 psig, indicating that there is no significant pressure effect on the slip ratio pattern in going from 150 to 250 psig.

1557. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT, Oct., Nov., Dec., 1955, Section I, ANL-5561 (1956), 169 p.

Experimental Boiling Water Reactor. An analytical prediction was made of the natural circulation performance of EBWR at 600 psig. Calculations were also made to determine whether simple changes in the riser length and/or geometry would favorably affect EBWR performance. Complete results are given in graphical form. The boiling water corrosion of Zircaloy-2 is shown. The thermocouples to be used for measurement of vessel temperatures are shown. The final designs for the pressure vessel shock springs are shown and a load-deflection diagram is given. The gamma-ray flux and corresponding heat generation in the D_2O-moderated EBWR are listed. Boiling heat transfer studies were made. Riser studies indicate that riser height is not too important a parameter in influencing the ratio of velocities of steam and liquid. Data are given on the pressure drop resulting from 2-phase flow. The transient behavior of the multi-channel natural circulation loop is discussed. Single-channel unrestricted and restricted natural circulation boiling studies are summarized in detail. Data showing the relationship between power density, voids, quality, recirculation flow, pressure, and geometry for boiling systems are given in both tabular and graphical form. Pressure drop measurements are included, and an analytical method of calculating natural circulation performance is outlined. The sources of error in steam void measurements are evaluated. A heating power source, which is to be used to determine experimentally the physical response of reactor components during a power excursion, is described.

1558. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT: Jan., Feb., Mar., 1956, Section I, ANL-5571 (1956), 174 p.

Advanced Water Reactor Program. Fuel plate dimensional changes necessitated the calculation of revised thermal data. These new data are given along with the assumptions made in the calculations. Boiling heat transfer studies associated with the EBWR were continued. Natural circulation boiling in single and multiple channels at 600 psig was investigated. Phase velocities, void effects, and friction factors are plotted. An analysis of the electrical characteristics of the power supplies used in those studies is also presented. Fission product activity buildup and decay in H_2O and steam, H_2O decomposition, and reactivity changes due to fission products and burnup were analyzed. Additional high-temperature H_2O corrosion data on U and Al alloys are reported for various pH values, H_2 concentrations, and flow velocities.

1559. Argonne National Laboratory

REACTOR ENGINEERING DIVISION QUARTERLY REPORT-SECTION II, July, August, September, 1956, ANL-5657 (1956), 69 p.

Experimental Breeder Reactor II. A study was made of the coolant flow characteristics of the primary system. A schematic diagram of the system is shown, and flow rates and pressure drops in the system are shown graphically. Data are also included on pump rectifier voltages. Illustrations are given of the pumps for the heat transfer systems. A preliminary test was made of the 5000-gpm Na pump using H_2O as the circulating fluid. A pump efficiency of 79% was obtained at the design flow rate. A test facility was constructed to determine the performance of a low-melting alloy, gas tight seal for the rotating plugs.

1560. Technische Hogeschool, Eindhoven, Netherlands

RESEARCH PROGRAMME ON HEAT TRANSFER IN A BOILING WATER REACTOR, Quarterly Report No. 1, December 1960, EURAEC 105 (Jan., Feb., Mar., 1961), 43 p.

Activities in a programme to investigate heat transfer and stability in a boiling water circuit are described. Included are descriptions of the pressurized boiling loop and the atmospheric pressure glass loops in operation. Results of preliminary experiments on Halden reactor fuel elements concerning heat losses and entrance losses are included.

1561. Technische Hogeschool, Eindhoven, Netherlands

RESEARCH PROGRAMME ON HEAT TRANSFER IN A BOILING WATER REACTOR, Quarterly Progress Report No. 2, EURAEC-158, April, May, June 1961, 10 p.

The development of measuring methods for determining variables such as void fraction, power, pressure, circulation rate, and temperature under non-steady conditions in a boiling water circuit is still under way. The capacitance gage for measuring the void fraction was further improved by using an outer electrode consisting of four small plates instead of one of cylindrical form. A pressure gage for measuring differential pressures up to 25 cm water head with line pressures of 30 atmospheres was constructed using also the capacitance method. Experiments were carried out with a model of the first core loading of the Halden reactor measuring the void fraction and circulation rate as a function of power and pressure up to 30 atmospheres and a heat flux of 1200 kw/m^2. In several conditions large variations in the pressure signal were present with a frequency of about 0.8 Hz and an amplitude of ±50 cm water head. Under normal conditions the boiling noise frequencies as measured with a fast pressure gage had an upper limit for this model of about 10 Hz with amplitudes of about 8 cm water head. During the experiments a burnout of the heating element occurred at a heat flux of 1200 kw/m^2 at 110°C. The results will be further analyzed in the next quarterly report.

1562. Argonne National Laboratory

THE EXPERIMENTAL BOILING WATER REACTOR (EBWR), ANL-5607 (1957), 236 p.

The final design of the EBWR is described in detail. The operational characteristics of the reactor and steam plant are given. Component descriptions are included for the reactor, the steam plant, the auxiliary systems, instrumentation, control systems, control arrangement, electrical generation and distribution system, and building and building services.

1563. Armand, A. A., and Nevstruyeva, Ye. I.

STUDY OF THE MECHANISM OF MOTION OF A TWO-PHASE MIXTURE IN A VERTICAL TUBE, Izv. VTI, Nr 2, 1950.

1564. Bankoff, S. G.

ENTRAPMENT OF GAS IN THE SPREADING OF A LIQUID OVER A ROUGH SURFACE, A. I. Ch. E. Journal 4, 24-6 (1958).

Conditions for the incomplete displacement of gas from the valley between two parallel ridges by a liquid-drop front advancing over the ridges are calcd. The significant parameters are found to be the liquid d., surface tension, contact angle, and geometry of the ridges. The soln. can be obtained analytically or, more conveniently, graphically. Surface roughnesses are divided into 4 classes, one of which can stably switch from liquid-to-gas fill, and another vice versa. Surfaces consisting predominantly of cavities are more likely to follow these considerations than grooved surfaces, owing to displacement of gas by advance of liquid along the grooves. An example in boiling and cavitation theory is worked out, and qual. agreement with the literature is shown.

1565. Bankoff, S. G.

A VARIABLE DENSITY SINGLE FLUID MODEL FOR TWO-PHASE FLOW WITH PARTICULAR REFERENCE TO STEAM WATER FLOW, J. Heat Transfer 82, 265 (1960).

A phys. model has been proposed for the bubble flow regime of liquid-gas flow which is in good agreement with the important features of the process. Some interesting questions are raised by this model: The flow parameter assumes different forms for flow in circular pipes and for flow between 2 flat plates. The equiv. diam. concept has been justified exptl. for single-phase turbulent flow, although some deviation has been observed for narrow wedge-shaped passages in which the laminar sublayer is relatively thick. It has not been demonstrated, however, that the equiv. diam. concept is equally valid for 2-phase turbulent flow. The wall has been assumed to be wetted by a liquid, so that the void fraction at the wall itself is zero. However, if the vapor is being generated at the walls, as in boiling channels, some fraction of the wall will be in continuous contact with the bubbles. These bubbles may act as addnl. roughness, so that the pressure drop characteristics could be different than for nonboiling channels under the same flow conditions, but this has not been resolved.

1566. Behringer, Hans

THE FLOW OF LIQUID GAS MIXTURES IN VERTICAL TUBES, Zeitschrift für die gesamte kälte Industrie, 43, 55-8 (1936).

The characteristics of flow of liquid-gas mixtures in large pumps and vertical-tube boilers is explained by resolving the velocity with which bubbles move through the tube into its two components. The origin and behavior of these components are described.

1567. Beretsky, I.

TWO-PHASE FLOW IN THRUST BEARINGS. Part I - Derivation of Equations. Technical Report. Mechanical Technology Inc., Latham, N. Y., MTI-62TR9 (1962), 40 p.

The governing equations are derived for an externally pressurized vapor thrust bearing in which condensation of the lubricant occurs on one of the surfaces due to an imposed temperature difference. The analysis involves two different problems, depending on whether the cooled surface is either the bearing or the runner. For the case of the cooled runner, the problem involves condensation on the rotating surface; the vapor entering through the nozzle begins condensing on the rotating surface; subsequently, the condensate is continuously pumped out radially due to the shear stress of the vapor resulting from the radial pressure gradient and the centrifugal force. The second problem is the case in which the bearing is cooled. Here the gas phase is adjacent to the rotating surface. The substantial difference between this case and the cooled runner case is that the inertial terms of the liquid phase are significantly smaller since the liquid film is not condensing on the rotating surface.

The equations of motion for the liquid phase in the case of condensation on the rotating surface cannot exclude the effect of the inertial terms. For the liquid phase equations, it is shown that for a thrust bearing the force due to the radial pressure gradient must be considered and not neglected compared to the centrifugal force. The analysis presented in this report reduces the governing equations to a set of four simultaneous first order nonlinear differential equations which can be solved by numerical integration. The analysis has definite applications in heat transfer, e.g., space condensers. Also, the analysis includes simultaneous effects of mass, energy, and momentum coupling for a two phase fluid in a thrust bearing.

1568. Bergelin, O. P.

FLOW OF GAS-LIQUID MIXTURES, Chemical Engineering 56, 104-6 (1949).

Progress in the field is summarized by outlining the scope of gas-liquid flow, reviewing the present correlation, and indicating what may be expected in future developments.

1569. Bertuzzi, A. F., Tek, M. R., and Poettmann, F. H.

SIMULTANEOUS FLOW OF LIQUID AND GAS THROUGH HORIZONTAL PIPE, Jour. Pet. Tech., 8, 17-24 (Jan. 1956).

Problem of transporting oil and gas together in common pipe from oil field to processing plant; method for predicting pressure drop for two-phase fluid flow in horizontal pipes; method reduced to simplified graphical procedure, suitable for field use.

1570. Borg, S. F.

SIMILARITY SOLUTIONS IN FLUID-GAS DYNAMICS, Amer. J. Phys., 28, 336-339 (April 1960).

Following a brief discussion of the general applicability of similarity transformations in solving fluid - gas dynamic problems, certain specific problems solved in this manner are described.

1571. Brauer, H.

CHARACTERISTICS OF TWO PHASE FLOW IN RECTIFICATION IN PACKED COLUMNS, Chem. Ing. Tech., 32, 585-90 (1960).

Respective vapor and liquid countercurrent flow behavior is analyzed by means of dimensionless no. relations. Exptl. data are presented, and 4 flow-rate zones are distinguished, characterized by intensity of liquid loading.

1572. Briggs, L. J.

MAXIMUM SUPERHEATING OF WATER AS A MEASURE OF NEGATIVE PRESSURE, J. Appl. Phy. 26, 1001-03 (1955).

Water superheated to the limit in an open tube develops an internal negative pressure P_n (tending to tear the molecules apart) equal to the saturation vapour at that temperature, less one atmosphere. Kendrick, Gilbert and Wisner heated water in an open thin-walled capillary U-tube to 270°C for 5 sec before it exploded (P_n = 53 atmos). Using their method, the writer heated three tubes to 264, 266 and 267°C for 5 sec or more before explosion occurred (P_n = 48 to 51 atmos). The cohesive strength of water is thus sufficient to withstand an internal negative pressure of over 51 atmos at 267°C. At this temperature an additional negative pressure (applied externally through centrifugal force) would rupture the water column. It has been predicted from van der Waals's equation that the external negative pressure which the system could withstand would vanish at 273°C, in fair agreement with experiment. (Sci. Abst. 68-8693)

1573. Brown, R. A. S., and Govier, G. W.

HIGH-SPEED PHOTOGRAPHY IN THE STUDY OF TWO PHASE FLOW, Can. Jour. Chem. Eng., 39, 159-64 (1961).

Some of the possible applications of high-speed photography in the study of 2-phase, 2-fluid flow are outlined.

1574. Brown, W. S.

UNSTEADY STATE FLOW OF STEAM FROM A HIGH PRESSURE SYSTEM, ORNL-1604 (1953).

1575. Campbell, I. J., and Pitcher, A. S.

SHOCK WAVES IN A LIQUID CONTAINING GAS BUBBLES, Proc. of the Royal Society of London, Series A, 243, 534-545 (1958).

Considerations of continuity, momentum and energy together with an equation of state are applied to the propagation of plane shock waves in a gas + liquid mixture. The shock-wave relations assume a particularly simple form when the temperature rise across a shock, which is shown to be small for a very wide range of conditions, is neglected. In particular, a simple relation emerges between the shock-propagation speed and the pressure on the high-pressure side of the shock, the density of the liquid and the relative proportions, by mass and volume, of gas and liquid in the mixture. It is shown from entropy considerations that a rarefaction wave cannot propagate itself without change of form, and it is argued that a compression wave can be expected to steepen into a shock wave. Consideration of the collision between two normal shock waves, moving in opposite directions, suggests that the strengths of the two shocks are unaltered by the interaction between them. This implies, in particular, that, when a shock impinges normally on a plane wall, the pressure ratio across the reflected shock is equal to that across the incident shock. When the mass ratio of gas to liquid in the mixture is allowed to tend to infinity, the various shock-wave relations for a mixture, derived with the temperature rise across the shock neglected, assume the same limiting form as the corresponding relations for a perfect gas when the ratio of specific heats tends to unity. The theoretical discussion has been illustrated by experiments with a small gas + liquid mixture shock tube. Samples of the records, obtained when the passage of a shock changes the amount of light transmitted through the mixture to a photoelectric cell, illustrate the steepening of a compression wave and the flattening of a rarefaction wave. Measurements confirm the theoretical relation for the propagation speed of shock waves. Reasonably good experimental confirmation is also reported of the theoretical predictions for the pressure which arises following the normal impact of a shock wave on a plane wall.

1576. Carter, C. O., and Huntington, R. L.

CONCURRENT TWO-PHASE UPWARD FLOW OF AIR AND WATER THROUGH AN OPEN VERTICAL PIPE AND THROUGH AN ANNULUS, Can. J. Chem. Eng., 39, 248-51 (1961).

The concurrent vertical upward flow of air and H_2O was studied at various rates and air/H_2O ratios in a $2\frac{1}{8}$ in. x 20 ft tube and in a $1\frac{15}{16}$ in. x $2\frac{1}{8}$ in annulus. Pressure drops and in-place ratios of gas to liquid correlated data with corresponding flow types and patterns.

1577. Castillo, J. R.

STUDY OF TWO-PHASE FLOW IN PIPE BENDS, M. S. Thesis, M.I.T., 1957, M.E. Dept.

1578. Chamberlain, H. V.

AIR LIFT PERFORMANCE AT LOW LIQUID RATES USING OVERSIZED PIPING AND LATERAL RUNS, IDO14561 (1961), 19 p.

The use of oversized piping in an air lift for transferring solutions at rates less than 5 liters per hour was proven feasible with certain limitations. Reliable operation was also obtained with air lifts containing a lateral run inserted between the point of air injection and the final discharge point. Discharge of the air lifts, especially at low liquid flows, was very erratic under the conditions studied.

1579. Choi, H., and Mikol, E. P.

AN EXPERIMENTAL STUDY OF TWO-PHASE FLOW IN CAPILLARY TUBES, Carrier Eng. Rep., CD1001-526 (1956).

1580. Christ, C., Raeth, C., and Maurer, R.

THE RELEASE OF GAS FROM SUPERSATURATED SOLUTIONS, CP-3063 (1945), 14 p.

The rate of release of oxygen from supersaturated solutions has been determined as a function of the velocity of flow through smooth walled pipes. The rate of release is approximately proportional to the velocity of flow and the area of the inner surface of the pipe when the inner surface is not thoroughly wetted by the solution. The rate of release is negligible if the wall of the pipe is clean and wetted.

1581. Clare, N. D.

SUPERSATURATION OF GASES IN LIQUIDS, Trans. Roy Soc. Can. III (3) 19, 32-33 (1925).

Supersatd. solns. of 02 up to about 250 atm. pressure on release of pressure sometimes formed clouds of bubbles in the liquid away from the walls. A metal hydraulic gage and a glass capillary of 0.3 mm. bore provided with a magnetic stirrer were used. (CA-20-319-9)

1582. Darby, R.

MOMENTUM TRANSFER IN A TWO-PHASE LIQUID-LIQUID SYSTEM IN CO-CURRENT STRATIFIED FLOW, Ph.D. Thesis, Rice Univ. (1962), 154 pp.

1583. Edenholm, H.

A MODEL EXPERIMENT AT THE STEAMHEAT INSTITUTE TOUCHING THE BEHAVIOR OF CURRENTS IN BOILERS; WATER CIRCULATION IN HORIZONTAL STEAM BOILER TUBES AND THE CURRENT OF GASES IN ELECTRO FILTERS, Tidskrift for Teknisk-Vetenskaplig Forskning, 72-85 (1938).

Model experiments on a small scale in the laboratory for the obtaining of data on water and gas circulation through pipes are suggested, described and illustrated by specific examples, with special emphasis on the economic advantages to be derived therefrom. For the investigation of gas currents in electro filters, a special apparatus is described and illustrated by a diagram. The through-flow velocities are shown in graphs.

1584. Einstein, H. A., and Sibul, O.

OPEN CHANNEL FLOW OF WATER-AIR MIXTURES, Am. Geophysical Union. Trans, 35, 235-242 (Apr. 1954).

Problem is analyzed in analogy with that of sediment transport; vertical distribution of air in turbulent water mass was found to follow laws of suspension; change of flow velocity and flow depth predicted theoretically as function of air concentration; predicted relationship checked by measurements in model channels.

1585. Engen, J. N.

INTERACTION BETWEEN A TURBULENT AIR STREAM AND A MOVING WATER SURFACE, MS Thesis, Univ. of Illinois, (1956).

1586. Faddeev, I. P.

THE DETERMINATION OF THE VELOCITY OF A DROP OF CONDENSATE OF AVERAGE SIZE IN A FLOW OF SATURATED STEAM, Inzhen-fiz. Zh. (USSR), 4, 56-60 (1961).

To calculate the loss of energy of moist steam in transporting water drops of average size it is necessary to calculate the velocity of these drops carried by a steam flow. The velocity of the water drops is determined by solving a differential equation making various assumptions. A comparison of calculations according to the given formulae for P = 1033 at, t = 100°C shows a great difference in the results obtained. Special experiments are needed to determine the actual velocity in the turbine stage.

1587. Forster, H. K.

DIFFUSION IN A MOVING MEDIUM WITH TIME-DEPENDENT BOUNDARIES, J. of AIChE, 3, 535-38 (1957).

A method is developed for the analytical solution of diffusion in a moving medium, and is applied to the analysis of partial and approximate solutions previously presented for the one-dimensional case of a spherical cavity in a liquid with radial boundary motion induced by evapn.

1588. Furth, R.

THEORY OF THE LIQUID STATE. I. THE STATISTICAL TREATMENT OF THERMODYNAMICS OF LIQUIDS BY THE THEORY OF HOLES. II. APPLICATION OF THE HOLE THEORY TO SUPERSATURATED LIQUIDS AND SUPERSATURATED SOLUTIONS OF GASES IN LIQUIDS, Proc. Cambr. Phil. Soc. 37, 252-80 (1941).

Study covers statistical treatment of thermodynamics of liquids by theory of holes; application of hole-theory to superheated liquids and superheated solutions of gases in liquids; hole theory of viscous flow of liquids. (CA-35-7255-3)

1589. Gavalas, G.

STUDY OF A TWO-PHASE COMPRESSIBLE FLOW BY A "GROWING BUBBLE" MODEL, Bimonthly Report No. 11, TID-15429 (March 1962), 22 p.

An examination was made of vaporization in a steam-water mixture during flow through an aperture. A physical description of the vaporization process is presented. The model used for the detailed calculation is also described. Equations of change for a growing bubble are given. Variation of pressure with time is discussed. Calculations were made of mass and momentum flow rates.

1590. Gazley, C., Jr.

A PRELIMINARY INVESTIGATION OF TWO-PHASE FLOW, University of Delaware, Report No. TPF-1 (1947), 31 p.

Due to the frequent occurrence of two-phase flow in industrial operations a need exists for both experimental and theoretical investigations of the phenomena accompanying two-phase flow. The limiting conditions for the various types of flow and their dependence upon flow rates and fluid properties are not known, and no satisfactory pressure-drop correlation is available.

The present report presents preliminary data for two-phase flow in a horizontal, ten-foot length of one-inch Pyrex pipe with suitable end boxes. Visual, photographic, and pressure-drop observations are reported for the cocurrent flow of air and water. The air flow was varied from 1.5 to 26 lb/hr while the water rate ranged from 0 to 416 lb/hr. Of several entrance sections which were tested in an attempt to obtain minimum initial disturbance, the most satisfactory design consisted of a large-diameter calming section with a cone-shaped transition piece leading to the test section. Pressure-drop data for the "stratified" flow of water and air, and the limits for the initiation of flugging flow are reported.

Semi-theoretical equations are presented for the pressure drop in terms of the flow rates, fluid properties, and pipe diameter. These equations represent the data of the present investigation more closely than do the empirical method of Martinelli, Boelter, et al. The empirical X-function of the latter investigators can be predicted by means of the new equations, and the comparison between the empirical and theoretical functions is reasonably good. The fact that the pressure-drop data of the California investigators are consistently higher than those of the present investigation is believed to be due to differences in entrance sections.

Future work will include pressure-drop measurements at higher air-water flow rates and for air-oil mixtures, further development of theoretical formulations, high-speed photographic study of flow irregularities, and velocity surveys in both phases. Mass and heat transfer will be studied when reproducible steady flow conditions are obtained.

1591. Gazyan, G. S.

CHARACTERISTIC THEORY OF THE MOTION OF TWO-PHASE MIXTURES IN VERTICAL TUBES, Neftyanoe khozyaistvo, (Petroleum Economy), Nr '8-9 (1950).

1592. Gebhardt, G. P.

FORMULAS FOR THE FLOW OF STEAM IN PIPES, Power, 27, 377-381 (1907).

A comparison of accepted formulas, with curves showing the drop in pressure for different pipe sizes and velocities.

1593. Geller, W.

ON THE THEORY OF DEGASSING OF LIQUID METAL BY SCAVENGING GAS, Translated from Z. Metallk., 11, 213-17, NP-tr-110 (1943).

A general theoretical treatment of the removal of dissolved gases from liquid metals by a scavenging gas is given. It is assumed that the gas phase and metal phase are in equilibrium so that the limits which can be attained in practice are established. The laws are derived for gas removal by scavenging with bubbles of finite size, for diffusion in one gaseous volume only, and for scavenging with infinitely small bubbles. Application of the theory to removal of CO_2 from H_2O by air and removal of N_2 from steel by CO is described. (NSA 12-13149)

1594. Golden, G. E.

FLUID FLOW PHENOMENA IN NATURAL CIRCULATION, Ph.D. Thesis, U. of Dela., 68 pp. (June 1953).

1595. Golden, G. E.

FLUID FLOW PHENOMENA IN NATURAL CIRCULATION VERTICAL TUBE BOILERS, Dissertation Abstracts, 22, 3564 (Apr. 1962).

Research was initiated in order to gain a knowledge of the phenomena associated with the flow of boiling fluids in tubes. Two 6-ft heat transfer tubes, 0.75 in. ID and 1.00 in. ID, respectively, were fabricated from brass. The fluids in the tubes, methanol, cyclohexane, benzene, n-pentane, and n-heptane, were vaporized by heat transfer oil which passed through an annular space formed by the tube and a 2.5 in. ID brass pipe. Friction factors were calculated assuming homogeneous flow and plotted vs the average gas phase Reynolds number. With the aid of a dimensionless group, it was possible to correlate all the friction factor data obtained. A flow pattern is proposed for vertical tube boilers operating between 0 to 100% quality. At the low range of qualities, the flow type is homogeneous while at high ranges it is annular. Between these extremes is a transitional region which is difficult to characterize.

1596. Goodenough, G. A.

SUPERSATURATION AND THE FLOW OF STEAM, Power 66, 466-469, 511-514 (1927).

Discusses amount of supersaturation, if any, effect of supersaturation on stage efficiency, and proper design of nozzles and buckets to take account of supersaturation.

1597. Gosline, J. E.

EXPERIMENTS ON VERTICAL FLOW OF GAS-LIQUID MIXTURES IN GLASS PIPES, Transactions of the American Institute of Mining and Metallurgical Engineers, 118, 56-70 (1936).

Paper constitutes part of material on study of applicability of data on single bubble motion to slippage factors, conducted at University of California and forming basis of Ph.D. thesis; motion of single bubbles; non-flow mixtures of air and liquids; pumping experiments; relevancy to oil well gas-lift pumping is indicated.

1598. Govier, G. W., and Omer, M. M.

THE HORIZONTAL PIPELINE FLOW OF AIR-WATER MIXTURES, Paper Presented at the Joint AIChE-C.I.C. Meeting, Cleveland, Ohio, May 7 to 10, 1961.

1599. Grassmann, P., and Lemaire, L. J.

GRAPHICAL PRESENTATION OF TWO-PHASE FLOW PROCESSES, Chem. Ing. Tech., 30, 450-4 (1958).

A treatise covering a graphical method to det. if a set of characteristic numbers represents a complete set according to Langhaar [Dimensional Analysis and Theory of Models, 1951, 166 pp. (C.A. 45, 6478d)], quant. presentation in the triangle and the tetrahedron, units for the movement of a gas bubble in a liquid and of a liquid drop in a gas, and presentation in spatial rectangular coordinates. 30 references.

1600. Green, D. W.

CONCURRENT TWO-PHASE FLOW OF LIQUIDS AND AIR THROUGH INCLINED PIPE, M.S. Thesis, Univ. of Oklahoma (1959).

1601. Gremilov, D. I.

INVESTIGATION OF THE MOVEMENT OF A VAPOR-MERCURY MIXTURE IN TUBES, Trudy TsKTI (Transactions of the Central Scientific Research Institute for Boilers and Turbines), Book 23, 1952.

1602. Gresham, W. A., Jr., Foster, P. A., Jr., and Kyle, R. J.

REV. OF THE LITERATURE ON TWO-PHASE (GAS-LIQUID) FLUID FLOW IN PIPES (Part 1), Eng. Expt. Station, Georgia Inst. of Tech., WADC-TR-55-422 (June 1955), 157 p.

All available literature on the subject of two-phase (gas-liquid) fluid flow was studied and the significant literature is summarized in this report.

Gas-liquid flow can be classified into at least seven different types of flow in horizontal ducts and five types in vertical ducts. For a given combination of fluids, it is possible to roughly correlate the flow types with the flow rates.

Most of the early workers utilized friction factor-type relations in their abstracts to correlate the pressure drops and flow rates. The first generalized relation was presented by Martinelli and coworkers who correlated the two-phase pressure drop with that of the liquid or gas assumed to flow alone in the duct. Most subsequent investigators have used modifications of this correlation. A few investigators have attempted to solve relations based on the continuity, energy, and momentum equations.

Abstracts of one hundred and eighty (180) references are included.

1603. Griffith, P.

TWO-PHASE FLOW IN PIPES, M.I.T. Summer School, 1958 Special Program in Heat Transfer.

1604. Gross, F.

INVESTIGATION OF THE DIFFUSION OF WATER VAPOUR IN HIGH BOILING POINT LIQUIDS, Z. Angew. Phys., 9, 606-12, (Dec., 1957), In German.

Describes experiments on Shell oil K8 and paraffin oil, both in the presence of the vapour alone and also when an inert gas is present at 20°C. The diffusion coefficients found are rather less than for Frenkel's hole model, but in much better agreement than with calculations based on Eyring's formula.

1605. Gunn, D. J., and Aitken, A. R.

HYDRAULIC CHARACTERISTICS OF TWO PHASE COCURRENT FLOW THROUGH GLASS FIBERS, Can. J. Chem. Engr., 39, 208-14 (1961).

The mechanism of flow of air and water through packed glass fibers was studied. The pressure difference depends on the history of previous gas and liquid flow rates through the bed. The liquid holdup is defined entirely by the gas and liquid flow rates. A measure of the irreversibility of the flow operation is suggested.

1606. Hafford, J. A.

TWO-PHASE FLOW, CF-53-5-112 (May, 1953), 11 p.

Design criteria for the ISHR gas separator and for future two-phase flow problems are summarized.

1607. Haney, P. D.

THEORETICAL PRINCIPLES OF AERATION, J. Am. Water Works Assoc., 46, 353-76 (1954).

A complete discussion of aeration and aeration principles. Several figures endeavor to explain gas absorption and release, many aeration equations are included, and the important influencing factors of gas exchange, such as temp., extent of agitation, film thickness, depth of basin, etc., are discussed. The H_2S-removal theory is given. The size of the air bubble is most important, and its formation is studied. 47 references. (CA-48-6624a)

1608. Hanratty, T. J., and Engen, J. M.

INTERACTION BETWEEN A TURBULENT AIR STREAM AND A MOVING WATER SURFACE, AIChE Jour, 3, 299-304 (1957).

Variables explored in study were liquid flow rate, gas flow rate, and film height; data were correlated in terms of liquid and gas Reynolds no.; thinner films or films having lower Reynolds number were more stable.

1609. Hansen, R. S.

FILM AND SUBSTRATE FLOW IN SURFACE CHANNELS, J. Phys. Chem. 63, 637-8, (Apr. 1959).

The mathematical solution of transfer rate in the transfer of monolayers in surface channels is performed by conventional hydrodynamics.

1610. Harvey, B. F.

NATURAL CIRCULATION VELOCITIES IN A LONG-TUBE VERTICAL EVAPORATOR, Ph.D. Thesis, University of Michigan (1951), 139 p.

1611. Harvey, B. F., and Foust, A. S.

TWO-PHASE ONE-DIMENSIONAL FLOW EQUATIONS AND THEIR APPLICATION TO FLOW IN EVAPORATOR TUBES, Chemical Engineering Progress, Symposium Series 49, No. 5, 91-106 (1953).

A mathematical analysis is presented in which equations of state, the energy balance, momentum balance, and an equation of continuity are combined into a rather unwieldy equation which is solved by a method of isoclines. This gives a relation between the peak temperature attained in a long-tube vertical evaporator and the vapor-head temperature. This difference, elevation of boiling point due to the various heads that increase the pressure in the tube, is correlated very satisfactorily except in those conditions where the data indicate that sonic choking at the end of the tube would exist. The mathematical analysis is tested and found accurately applicable to experimental data on a 20-ft-long, $11\frac{1}{4}$ in.-diameter evaporator tube covering a range of pressures below atmospheric for pure-water boiling.

1612. Hershey, R. L.

THE FLOW OF GAS-LIQUID MIXTURE IN PIPES, Massachusetts Institute of Technology, Ph.D. Thesis (1935).

The purpose of this investigation is to develop and test a method of calculating the mechanical energy velocities occurring in the flow of gas-liquid mixtures in pipes. The type of flow particularly considered is the vertical upward flow of mixtures having a continuous liquid phase. The total loss in the flow of gas-liquid mixture is a compound of two losses, one of which increases with the velocity, one of which decreases. The second is peculiar to this type of flow and is caused by a relative motion of the fluids. This relative motion also introduces a complication in the formulation of a continuity and loss equation which is of a statistical nature and is not susceptible to direct measurement. Most measurements have involved general relations of this velocity and flow variables. In the present investigation, continuity and energy equations have been derived and are expressed in terms of an experimentally determined quantity, namely the gas-liquid volumetric ratio in the pipe. Dependence of this ratio upon the flow variable has been analyzed by the method of dimensional analysis.

1613. Hibben, J. H.

REMOVAL OF DISSOLVED GASES FROM LIQUIDS BY VACUUM SUBLIMATION, J. Res. U.S. National Bur. of Standards, 3, 97-104 (1929).

A method of removing and collecting dissolved gases from liquids is described. It is possible, through the application of the principle of vacuum sublimation, to prepare gas-free liquids for use in the determination of physical constants without appreciable loss of either liquid or dissolved gas. Experimental results are presented which demonstrate the practicability of the method as well as its theoretical limitations.

1614. Hoefer, K.

UNTERSUCHUNG ÜBER DIE STRÖMUNGAVORGÄNGE IN STEIGROHR EINES DRUCKLUFTWASSERHEBERS, Zeitschrift des Vereines deutscher Ingenieure 57, 1174-82 (1913).

This article is a report of an experimental investigation of the performance of the air-lift pump. The performance of the air-lift pump is found to differ greatly from theoretical predictions. The purpose of this investigation is to provide an experimental basis for calculation.

It is found that the velocity of air in the stand pipe is greatly different from the velocity of water, which accounts for the low efficiency of this type of pump. Experimental results are presented in graphical and tabular form.

1615. Holden, J. B., and Rowzee, E. R.

ADIABATIC FLOW OF SATURATED WATER THROUGH HORIZONTAL PIPE, S. M. Thesis, Che. Eng. Dept. M.I.T.

1616. Hoogendoorn, C. J.

GAS-LIQUID FLOW IN HORIZONTAL PIPES, Chem. Eng. Sci. 9, 205-217 (1959).

Investigation of flow through horizontal pipes of 24 to 140 mm diam and pipes of 50 mm having various degrees of roughness, for gas-oil and gas-water flow systems; flow pattern, pressure drop and liquid holdup studied; experimental methods and equipment; results indicate flow patterns occurring with gas-oil flow can be predicted from one diagram and that for gas-water flow same diagram with enlarged wave flow region to be used.

1617. Houghten, L. E., Lincoln, R. L., and Ebin, L.

CRITICAL VELOCITY OF STEAM AND CONDENSATE MIXTURE IN HORIZONTAL, VERTICAL AND INCLINED PIPES, Trans. A.S.H.A.V.E. 30, 153-168 (1924).

Details of experiments made to obtain a thorough understanding and complete knowledge of factors entering into, and effects taking place when steam is sent through a pipe in which there is a counterflow of condensate. Effect of length and size of pipe and type of entrance, upon critical velocity.

1618. Hughes, R. R., Evans, H. D., and Sternling, S. V.

FLASH VAPORIZATION - ANALYSIS OF FLUID MECHANICAL AND MASS-TRANSFER PROBLEMS, Chemical Engineering Progress 49, No. 2, 78-87 (1953).

This paper discusses the general concepts of liquid atomization, drop separation, and flashing efficiency and their relation to the design of the vaporizer, the transfer lines, and the separator. The concepts are developed semi-quantitatively as a guide to further development and design work on these flashing processes.

1619. Hughmark, G. A.

HOLDUP AND PRESSURE DROP WITH GAS-LIQUID FLOW IN A VERTICAL PIPE, Ph.D. Thesis, Louisiana State Univ., (1960), 96 pp.

1620. Huntington, R. L.

TWO-PHASE FLOW IN PIPELINES, Seminar delivered by the author at University of Oklahoma, May 10, 1954.

1621. James, F. E., Jr.

EXPERIMENTAL STUDY OF TWO-PHASE ONE-COMPONENT FLUID FLOW IN CIRCULAR PIPES, Kansas State College of Agriculture and Applied Science, M. S. Thesis (1950), pp. 58.

The purpose of the study was to find a method to calculate the pipe size of equipment for carrying flashing fluids, using a knowledge of two-phase fluid frictional losses.

The proposed method for calculation is based upon a relatively narrow range of water velocities and liquid-to-vapor ratios. The straight lines would be expected to curve upward (pressure drop vertical vs. per cent vapor horizontal) at higher vapor fractions until they become asymptotic to all vapor phase flow lines. A semilogarithmic plot would probably be necessary since the velocity increase would probably be multiples of the liquid velocity rather than fractions thereof. A calculation method of the type proposed has certain advantages over any previously suggested; (1) No trial and error calculations are involved for determining pressure drop over specified length of line. (2) The same friction factor chart is used as for a single phase fluid. (3) The calculations are algebraically simple. The main disadvantages of this method is that a chart estimating the increase in velocity must be experimentally found for each fluid.

1622. James, W., and Silberman, E.

TWO PHASE FLOW STUDIES IN HORIZONTAL PIPES WITH SPECIAL REFERENCE TO BUBBLY MIXTURES, Univ. of Minnesota Technical Paper No. 26, Series B (1958).

1623. Johnson, A. I.

CIRCULATION RATES AND OVER-ALL TEMPERATURE DRIVING FORCES IN A VERTICAL THERMOSYPHON REBOILER, Chem. Eng. Prog. Sym. Ser., 52, No. 18, 37 (1956).

Circulation rates and over-all temperature driving forces were measured by use of a steam-heated vertical thermosyphon reboiler of standard design. The tube bundle contained ninety-six 1-in. 12-BWG carbon steel tubes 8 ft long. The inlet and outlet nozzles measured 6 and 10 in. I.D. The reboiler was operated at heat fluxes up to 16,000 P.c.u./(hr) (sq ft).

Temperature profiles through the central tube of the bundle were observed by means of a thermocouple probe. The profiles indicated that vaporization did not occur until the liquid had passed through approximately one quarter of the tube length.

Circulation rates could be predicted fairly successfully by a modification of Kern's method including the existence of a liquid zone and use of the two-phase pressure-drop correlation of Martinelli and Lockhart for the vaporization zone.

A method is proposed for estimating the over-all temperature driving force (and hence over-all heat transfer coefficients) corresponding to any heat flux value. The method predicts the existence of the liquid zone and utilizes existing correlations for convection heat transfer to estimate the coefficients for the vaporization zone. The observed behavior of water and hydrocarbon support the proposed theory.

The proposed methods for calculating circulation rates and temperature driving forces correlated much of the recent laboratory data of Piret and Isbin satisfactorily.

1624. Kaemmerlen, C. J.

VISUAL DETERMINATION OF THE CRITICAL REGION FOR TWO-PHASE TWO-COMPONENT FLOW, University of Delaware, B. S. Thesis (1947).

This thesis presents a study of two-phase co-current flow in the critical region where the change from laminar to turbulent flow occurs. Visual, photographic, and pressure-drop data are presented for air and water in the critical region in a horizontal ten-foot length of one-inch Pyrex pipe having a converging entrance section and an enlarged exit section.

Methylene blue dye was injected into the water through a nozzle pointing directly downstream. The velocity of the dye stream was made as close as possible to that of the main stream. When the dye stream remained as a single thread, the flow was considered laminar; when the dye stream was broken up completely, the flow was turbulent. The change from one type to the other was taken as the visually determined critical point. Using this method, the study covered the range of air rates from 1.5-26.0 lb/hr and of water rates from 0.321 lb/hr.

It was found that the pressure drop in the gas phase increased as the first power of the gas flow rate at low gas velocities, but as approximately the second power of the gas flow rate at high velocities. In this respect the flow is analogous to the flow of a single phase. The change in slope which is taken to be caused by the transition from viscous to turbulent flow occurred at the visually determined critical point. Also, the visually determined critical point corresponded with the dip region of the superficial friction factor Reynolds number curve.

1625. Kaufman, H.

THERMODYNAMICAL RELATIONS IN TWO COMPONENT TWO PHASE SYSTEMS, Nature, 186, 299 (Apr 23, 1960).

Jacobians are used to obtain in a simple manner some thermodynamic properties of two-component two-phase systems.

1626. Kaye, J., and Rivas, M. A.

EXPERIMENTAL AND ANALYTICAL STUDY OF TWO-COMPONENT, TWO-PHASE FLOW IN EJECTOR WITH CONDENSATION, A. S. M. E., Paper 57-HT-35, for meeting Aug 11-15, 1957. 17 p.

Studies of simple jet pump with 2C-2P flow of air, steam and water, with simultaneous heat transfer and mass transfer processes; it is shown that 2C-2P flow of air, steam, and water is analogous to simpler compressible flows and that normal shocks should occur in this type of flow; simplified flow model for 2C-2P flow used in predicting pressure rise in normal shock in such flow.

1627. Kennard, E. H.

RADIAL MOTION OF WATER SURROUNDING A SPHERE OF GAS IN RELATION TO PRESSURE WAVES, The David W. Taylor Model Basin, USN., DTMB-517 (September 1943), 38 pp.

In the study of explosive pressure waves, the theory of a sphere of gas expanding or contracting under water is needed in two connections - in discussing the motion of the gas globe produced by the explosive itself, and in considering the effect of bubbles in the water upon the propagation of pressure waves. The relevant analytical formulas are collected here and discussed. Their deduction is given in an appendix.

The following topics are treated:

1. the period and form of the radial oscillations of a gas globe, and the pressure and impulse thereby generated in the water;

2. the effect of a pressure wave upon a single gas bubble;

3. the inverse effect of a layer of bubbles in water upon an incident wave of pressure, which is partially to reflect or scatter the incident wave, and to make the transmitted wave weaker but of longer duration;

4. an exact treatment for the analytically simple case of weak waves of pressure incident upon water containing bubbles of relatively small size;

5. scattering by a single bubble.

1628. Kholodovskii, G. E.

NEW METHOD FOR CORRELATING EXPERIMENTAL DATA FOR THE FLOW OF STEAM-WATER MIXTURES IN VERTICAL PIPE, Teploenergetika 4, 68-72 (July 1957).

New method of generalization of experimental data regarding flow of steam-water mixture in vertical tubes; use of dimensional analysis for derivation of new criterion equation.

1629. Kleiman, I. Z.

ON THE PROPAGATION OF STRONG DISCONTINUITIES IN A MULTI-COMPONENT MEDIUM, Applied Mathematics and Mechanics, 22, 268-278 (1958).

Author considers the kinds of discontinuities admitted by ideal (inviscid) compressible flow equations for a multi-phase medium with noninteracting components. This problem is of interest in connection with the mechanics of systems ranging from water-sand mixtures to liquid fuel-air mixtures. Attention is restricted to n-component systems in which intercomponent diffusion is negligible; e.g. multi-component gas mixtures are excluded. Assuming that the pressure is the same within each phase, the equations for the conservation of mass and momentum of each component at a discontinuity are effectively written in terms of the densities, velocities, and mass fractions of each component and the pressure on each side of the discontinuity. Author's analysis of these relations is largely qualitative for strong discontinuities and quantitative for weak shock waves.

In addition to the analogues of shock waves, contact discontinuities, and slip discontinuities of one-component systems, a number of other kinds of discontinuities can exist in n-component mixtures. Author demonstrates the existence and properties of shock waves containing slip discontinuities with respect to some components and of constant-pressure discontinuities with a normal flow of some components. It is shown that as many as 2n different sound velocities may exist for an n-component mixture. For a two-component system explicit expressions for these velocities are obtained in terms of the properties of the mixture upstream from the discontinuity. As the mass fraction of one component is changed from zero to unity, the sound speed varies monotonically. For a mixture of a dense substance with a high sound speed (solid or liquid) and a light substance with a low sound speed (gas), a very small volume concentration of gas will nearly reduce the sound speed of the mixture to that of the gas.

1630. Konstantinov, N. N.

HYDRAULICS OF TWO-PHASE FLOW AND ITS APPLICATION TO DESIGN OF AIRLIFTS, HYDRAULIC GATES, AND CIRCULATION IN VERTICAL WATER-TUBE STEAM BOILERS, Issledovaniye i primeneniye nefteproduktov (Research and Application of Petroleum Products), Nr 2, Gostopekhizdat (Pub. Hse. of Petrol. and Mineral-Fuel Industry) (1950).

1631. Kosterin, S. I.

HYDRAULIC RESISTANCES TO MOVEMENT OF GAS-LIQUID MIXTURES IN HORIZONTAL TUBES, Bulletin de l'academie des Sciences de l'Union des Republiques Sovietiques Socialistes, Classe des sciences techniques 1943, No. 11-12, 37-49 (1943).

Flow of water and air-water mixtures in steel pipes at Reynolds numbers between 1000 and 250,000 was measured at various ratios (r) of "air volume" to "H_2O volume." The ratio (A) of "resistance to flow of mixtures" to "resistance to flow of H_2O" increases with r to 1.3-1.6 at r greater than 1.5; at very high Reynolds numbers, A was smaller. Pulsations of air-water mixtures had a maximum intensity at $r = 3$, and a maximum frequency at $r = 1$. The pulsations decreased at higher rates of flow.

1632. Kosterin, S. I., and Rubanovich, M. N.

EFFECT OF SURFACE TENSION ON THE HYDRAULIC RESISTANCE AND THE STRUCTURE OF THE FLOW OF GAS-LIQUID MIXTURES IN PIPES, Izvestiya Akademii Nauk Soyuza Sovestkikh Sotsialisticheskikh Respublik, Otdelenie Teklnicheskikh Nauk 1949, 1085-93.

Water-air mixtures of various concentrations were pumped through glass pipes at speeds varying from 0.05 to 3 m/sec. The surface tension of water was lowered in some cases by the addition of isoamyl-alcohol. As long as no stable foam was formed, changing the surface tension by as much as a factor of 3 had no effect either on the hydraulic resistance of air-water mixtures or on the nature of the laminar flow through the pipe. Lowering the surface tension increased the degree of dispersion of air in water and caused more foaming. When soap was added, stable forms were formed; and in these cases there was an appreciable increase in the hydraulic resistance of the system, viz., by a factor of 1.5-3, depending on the soap concentration and the ratio of air to water. The effect of such increases in hydraulic resistance were discussed as they applied to the circulation of water in boilers and heating systems.

1633. Kraybill, R. R.

AN INVESTIGATION OF BRIDGING VELOCITIES AND PRESSURE DROP FOR ISOTHERMAL COUNTERCURRENT FLOW OF GAS AND LIQUID IN VERTICAL WETTED WALL TUBES, University of Michigan, Ph.D. Thesis, 217 (1953).

This investigation covered the determination of the bridging point for various countercurrent gas-liquid flow rates in vertical wetted wall glass tubes under approximately isothermal conditions. Bridging is defined as the point at which, due to increasing gas rate and interfacial shear, the liquid film becomes unstable enough to bridge across the tube, creating a discontinuous gas phase with results similar to the familiar flooding of packed towers. Tests were made for effects of tube lengths, tube diameter, fluid systems. Also found were pressure drop correlations effect of gas properties, effect of liquid properties, a new bridging correlation, and the surface film stability.

1634. Kraybill, R. R., and William, B.

TWO-PHASE FLUID FLOW, Sym. Paper, A. I. Ch. E. Meeting, September 14, 1953.

1635. Kutateladze, S. S.

FLOW OF STEAM-LIQUID MIXTURE THROUGH PIPES AND GENERALIZED COORDINATES FOR ITS ANALYSIS, Sovetskoe Kotloturbostroenie, No. 2, 19-26 (1946).

This study offers concepts relative to the mechanism of liquid and vapor motion in boiler tubes resulting in a system of generalized coordinates completely describing the phenomenon in question. The effect of vapor and liquid velocities, pressures, tube diameter, and a number of physical constants are analyzed for the magnitudes of the major characteristics of circulation relative to flow in vertical tubes. A high degree of agreement was obtained between theoretical conclusions and experimental results adequate to embrace the pressure interval up to 180 atmosphere. The experiments with a high-pressure test stand are elaborated upon and analyzed. Certain conclusions, drawn from the mechanism of the process subjected to study, are offered relative to the effect of boiler tube slope.

1636. Kutateladze, S. S.

MOVEMENT OF TWO-PHASE STEAM IN PIPES, Sovetskoe Kotloturbostroenie, No. 6 (1947).

This article outlines several techniques used by the USSR to analyze data on two-phase fluid flow collected over a ten to fifteen year period.

1637. Lang, M.

AIR AND GAS IN STEAM, Kautschuk u. Gummi 8, WT 186-8, 209-10 (1955).

CO_2 may occur in steam by decompn. of Na_2CO_3 formed in treatment of feed H_2O; air may come from autoclaves, etc. Gas in steam gives rise to errors in temp. (T_s) detns. based on manometer readings and satd.-steam tables. Superheating also causes errors. Direct temp. detns. (T_m) are necessary to limit errors to ±1°. Usually steam is superheated 10-20° at the source to insure dry steam at the process. This small amt. of superheating is not objectionable, and has little significance for the heat content. Pressure reduction of satd. steam may give appreciable superheating. If $T_m = T_s$, there is no superheating of gas; if $T_m < T_s$, air or gas is present and T_m is to be used; if $T_m > T_s$ there is superheating and T_s is more significant because the added heat content due to superheating is small. Sample calcns. show the effect of the partial pressure of the air in a vulcanizer on the equil. temp. In the course of a cure, this air can be removed by the condensate through a steam trap by an imperfectly understood process of mixing, adsorption, and absorption.

1638. Lawes, C. P.

A STUDY OF CIRCULATION AND TWO-PHASE FLOW IN NATURAL CIRCULATION, S. B. Thesis, M.I.T., (1959), M. E. Department.

1639. Lerner, B. J., and Grove, C. S., Jr.

CRITICAL CONDITIONS OF TWO-PHASE FLOW IN PACKED COLUMNS, Indus. and Eng. Chem. 43, 216-225 (Jan 1951).

New theory of loading and flooding in packed columns operating with counter-current liquid-gas flow; expression for linear pore velocity of gas in wetted packing, derived in terms of superficial liquid and gas rates; in 2-phase flow systems, for given liquid-gas pair, there exists single critical linear gas pore velocity at which gas flow becomes discontinuous; other results.

1640. Leverett, M. C., and Lewis, W. B.

STEADY FLOW OF GAS-OIL-WATER MIXTURES THROUGH UNCONSOLIDATED SANDS, Petroleum Technology 3, (May 1940)., Am. Inst. Mining Met. Engrs., Tech. Pub. No. 1206, 9 p. (1940).

The relative permeability to water is determined by water saturation alone and is not affected by the introduction of an additional nonaqueous phase. The relative permeability to gas in three-phase flow is slightly less than would correspond to the same gas saturation in two-phase flow. The relative permeability to oil varies in a more complex manner. The isoperms for all components are independent of the viscosity of the oil phase. The pressure of appreciable amounts of all three phases in a flowing steam in equilibrium with the fluid in the pore space is limited to a relatively small region of pore composition.

1641. Lewis, D. J.

THE INSTABILITY OF LIQUID SURFACES WHEN ACCELERATED IN A DIRECTION PERPENDICULAR TO THEIR PLANES II., Proc. Royal Soc. of London, Series A, 202, 81-86 (1950).

An app. for accelerating small quantities of various liquids vertically downwards at accelerations of the order of 50 g. is described. The behavior of small wave-like corrugations initially imposed on the upper liquid surface was observed by high speed shadow photography. The instability observed under a wide variety of exptl. conditions was analyzed; the initial phases agree well with the first order theory. When the disturbance has attained a considerable amplitude, the first order equations cease to apply. Expts. are described with the following surfaces: air-H_2O, air-benzene, H_2O-CCl_4, benzene-H_2O, air-glycerol.

1642. Li, J. C. M.

THERMODYNAMIC FORMULAS FOR TWO PHASE SYSTEMS, J. Chem. Phys. 26, 909-913 (1957).

Bridgman's table of thermodynamic formulae or Shaw's table of Jacobians is extended to a two-phase system of one, two, and three components. The present method will include these tables as special cases and can be generalized to any system in a straightforward manner.

1643. Lottes, P. A.

EXPANSION LOSSES IN TWO-PHASE FLOW, Nuclear Sci. and Eng., 9, 26-31 (Jan. 1961).

Four methods are discussed for predicting the change of static pressure across an abrupt expansion for the flow of liquid vapor mixtures. Design equations are given and recommendations are made for boiling reactor calculations.

1644. McAdams, W. H., and Sherwood, T. K.

THE FLOW OF AIR AND STEAM IN PIPES, Mech. Eng., 48, 1025-1029 (1926).

Equations and curves in units convenient for engineering calculations; check of friction factors appearing in equations of Unwin and Babcock.

1645. McElwee, F. D.

BEHAVIOR OF TWO-PHASE TWO-COMPONENT FLOW IN TUBES, University of California, M. S. Thesis (1949), 62 p.

The idealized case of annular flow of the liquid phase in two-phase, two-component viscous-viscous flow in a vertical tube is analyzed. All forces acting on any fluid element are neglected, have pressure and viscous forces. The relation between flow parameters presented in previous analyses is substantiated, though not proved by this investigation.

The case of air-kerosene mixtures in viscous flow in a vertical tube was investigated experimentally over a wide range of conditions. Only one tube size, a 5 mm. inside diameter, pyrex tube, was used in the study.

Comparison of the results of this investigation and those obtained by Lockhart for the same flow conditions in capillary tubes shows a lack of correlation. This discrepancy renders questionable the neglect of surface and body forces in small tubes in this and previous investigations. Since Lockhart's experiments were performed in capillary tubes (0.0048 ft and 0.0068 ft inside diameter) the possibility is indicated that the justification for neglecting capillary forces may depend upon tube size.

1646. McRae, J. A.

EXPERIMENTS ON THE FLOW OF STEAM THROUGH SMALL PIPES, University of Illinois, B. S. Thesis (1896).

The experiments reported in this thesis were conducted in order to determine the weight per minute and velocity of steam flowing through several sizes and lengths of small pipes, with a given loss of pressure.

1647. Masnovi, R.

LITERATURE SURVEY ON TWO-PHASE FLUID FLOW, Univ. of Pittsburgh, WAPD-TH-360 (1957).

1648. Maung-Myint, M.

A LITERATURE SURVEY ON TWO-PHASE FLOW OF GAS AND LIQUID, B. S. Thesis, MIT (1959).

1649. Mayr, Otto.

RADIOACTIVE METHOD TO DETERMINE THE STATIC QUALITY OF TWO-PHASE FLOW IN A VERTICAL PIPE, A Project at M.I.T. (Filed with other materials about Two-Phase Flow at M.I.T.)

1650. Mermin, N. D.

RPA INSTABILITY AND THE GAS-LIQUID TRANSITION. I., Ann. Phys., 18, 421-453 (1962).

The possibility of a many particle system undergoing a classical gas-liquid phase transition, is shown to be reflected in the structure of the two-particle Green's function in the random phase approximation. When the interaction is sufficiently attractive this Green's function possesses forbidden poles on the imaginary axis of the complex frequency plane. An investigation of the temperature dependent correlation function reveals that the poles appear even in the

classical limit, and that as they appear $(\partial P/\partial V)_T$ vanishes and long range density correlations of the form usually associated with critical fluctuations arise. It is therefore concluded that the poles are symptomatic of the instabilities associated with condensation of the system from a gaseous to a liquid phase.

1651. Mermin, N. D.

RPA INSTABILITY AND THE GAS LIQUID TRANSITION. II. EFFECT OF SHORT RANGE REPULSION, Ann. Phys. 18, 454-479 (1962).

The complex poles of the two-particle correlation function occurring in the random phase approximation for an attractive interaction were interpreted in the classical limit as indications that the approximation had failed due to the huge correlations associated with condensation. The argument, however, is not complete, since the poles occur at arbitrarily high temperatures if the density is great enough. Physically one suspects that strong short-range intermolecular repulsion is responsible for the existence of a critical temperature above which condensation does not occur. Correspondingly, it will be shown that when the RPA is suitably improved to take short range repulsion into account, there will be a critical temperature above which complex poles never occur. In the improved solution below the critical temperature the poles appear as the density increases, but, in contrast to the RPA, disappear again at still higher densities. Thus the poles are confined to a region of the T-V plane having the structure of a classical two-phase region.

1652. Moore, T. V., and Wilde, H. D.

EXPERIMENTAL MEASUREMENT OF SLIPPAGE IN FLOW THROUGH VERTICAL PIPES, Trans. of the American Institute of Mechanical Engineers, 92, 296 (1931).

The purely empirical correlation of the data presented in this paper is valuable because it shows the qualitative relationship between the variables involved. For a given rate of flow of liquid and gas, slip losses are less in smaller pipes, frictional losses, of course, are greater. The most efficient flow string is one that so balances the slip losses and friction losses that a given quantity of oil and gas can be carried with a minimum pressure drop. Slippage is not affected by the viscosity of the liquid flowing. It is, however, dependent on the density and to the lesser extent on the surface tension of the liquid.

1653. Morrow, J. E., Jr.

CHARACTERISTICS OF VERTICAL FLOW OF A GAS-LIQUID MIXTURE, University of Illinois, M. S. Thesis (1941).

The flow characteristic of 3 air-liquid mixtures, namely air-motor oil, air-furnace oil and air-water, were studied as the individual mixtures were pumped through a vertical tube which had an internal diameter of 0.088 ft and was 5.17 ft long. A log-log plot of the volumetric ratio of air to water, ϕ, vs. N^1V_g/d^5g. For each liquid velocity, a straight line relationship was obtained. In case of water the velocities were 43, 60, 100, 130, 150, and 190 lbs/min, for S.A.E. #10 motor oil 42, 60, and 70 lbs/min, and for furnace oil 60, 100 and 130 lbs/min. It was found that the data for a single air-liquid mixture fell on a single line when plotted as ϕ vs. $(N^1V_g/d^5g)W^6$. A separate line obtained for each mixture using the different values of the ϕ. In all cases the air rate was varied from 0.03 to 0.316/min. By the method of Hershey, friction factors were calculated and plotted against the velocity of the mixtures.

1654. Nemet, A. G.

MAXIMUM LIQUID TRANSPORT. FLOW OF GAS LIQUID MIXTURES IN VERTICAL TUBES, Ind. Eng. Chem. 53, 151-4 (1961).

Equations are presented for calcn. of max. liquid flow when gas-liquid mixts. rise in vertical pipes. The max. liquid transport depends on the 4th power of the available pressure drop in long pipes, and the $\frac{3}{2}$ power in short pipes. Pipe diam., material characteristics, frictional losses, and the method of gas introduction also are important factors.

1655. Nowak, E. S., Grosh, R. J.

AN INVESTIGATION OF ENTHALPY DATA FOR WATER AND WATER VAPOR IN THE CRITICAL REGION, ANL-6505 (1961), 64 p.

The available smoothed and experimental data for the enthalpy of water and water vapor in the region of pressures ranging from about 2850 to 4300 psia (200 to 300 kg/cm^2) and for temperatures from 680 to 752°F (360 to 400°C) has been compiled and analyzed. In general, good agreement was found between the smoothed values of enthalpy of various steam tables. However, there are significant deviations near the critical point and in the region of the inflection temperature on isobars of enthalpy versus temperature.

There have been only two independent investigations on the enthalpy of subcooled water and superheated water vapor. To rectify the paucity of data which results from this situation, the authors of this report derived enthalpy values from the available experimental results on the specific heat at constant pressure. The values so derived are in excellent accord with direct measurements of enthalpy. It was also possible to construct an isenthalpic diagram for water and water vapor in the critical region.

1656. Nowak, E. S., and Grosh, R. J.

THE COEFFICIENT OF VOLUME EXPANSION FOR WATER AND WATER VAPOR IN THE CRITICAL REGION, ANL-6404 (1961), 17 p.

This report gives for the first time a tabulation for the coefficient of volume expansion for water and water vapor along eleven isobars in the critical region encompassed by pressures from 3000 to 4000 psia and temperatures from 690 to 750°F. Graphical techniques were employed to derive these values from precise P-V-T data. The over-all error in the derived values of the volume expansion coefficient was estimated to be within five per cent. However, in the region of maximum values for the coefficient of volume expansion along the various isobars, the uncertainty in the derived values is estimated to be between five to thirty per cent.

No attempt has been made in this report to derive other thermodynamic functions for water.

1657. O'Bannon, L. S.

SIMULTANEOUS FLOW OF WATER AND AIR IN PIPES, Transactions of the American Society of Heating and Ventilating Engineers, 30, 157-66 (1924)

Charts are presented showing the simultaneous flow of water and air (both parallel and countercurrent) in a one-inch pipe. A description of the experimental setup is also given.

1658. Oliver, E.

TWO-PHASE VERTICAL FLOW OF STEAM-WATER MIXTURES, S. M. Thesis, Che. Eng., M.I.T. (1959).

1659. Omar, M. H., and Dokoupil, Z.

SOME SUPPLEMENTARY MEASUREMENTS ON THE VAPOUR-LIQUID EQUILIBRIUM OF THE SYSTEM HYDROGEN-NITROGEN AT TEMPERATURES HIGHER THAN THE TRIPLE POINT OF NITROGEN, Physica (Netherlands), 28, 33-43 (1962).

The equilibrium between the liquid and gas phases of mixtures of hydrogen and nitrogen was studied using the flow method. The working pressures were 5, 10, 15, 25, 35 and 45 atm at the temperatures 63.1, 68.1, 72.3 and 74.6°K. A graphical method is described to extrapolate the dew curves to very low pressures. A thermodynamical treatment correlating the dew and boiling points is discussed.

1660. Orga, Temel Halil

SIMULTANEOUS FLOW OF AIR AND WATER IN CLOSED FLUME, State University of Iowa, Ph.D. Thesis (1953).

The investigator formulates the following conclusions from his experiments:

1. Air flowing with the water:

(a) Up to a relative air velocity of about 22 fps distinct capillary waves are formed on the surface of water flowing normally at depths above critical, provided the initial water surface was quite smooth.

(b) When the relative air velocity ranged between 24 and 29 fps discontinuous capillary waves of irregular form were observed on the surface of water flowing at depths near critical, provided the initial surface disturbances originated at the flume boundaries were relatively small.

(c) On the surface of water flowing normally at depths below critical, no capillary wave of any form could be observed before the generation of gravity waves.

(d) The amount of drag moving air exerts on the surface of flowing water is proportional to the square of the relative velocity of the air, and directly proportional to the coefficient of roughness of the water surface and varies also to some degree with the nature of turbulence in surface layers of the flowing rates.

(e) Minimum drag necessary to generate and maintain capillary waves on the surface of water flowing at depths above critical seemed constant and equal to about 320×10^{-5} lb/ft^2, provided the initial water surface was not previously disturbed. The drag coefficient seemed also constant and equal to about 0.006.

(f) For initial water depths near and below the critical, the surface drag and drag coefficient just before the start of gravity waves as computed from equations was not constant, but increased proportionately with initial surface disturbances and with initial water depth.

(g) On the surface of water flowing at any depth, regardless of its initial stages, gravity waves were observed at some point in the flume after the limiting velocities mentioned in (a) and (b) were exceeded. These downstream-moving gravity waves grew in size in the direction of air flow attaining their greatest height at the downstream end of the flume. The length to the point where gravity waves commenced varied depending upon the initial water depth and air discharge.

2. Air flowing against the water:

(a) At a relative air velocity of about 22 fps capillary waves were observed on the surface of water flowing normally at depths above critical. Wave velocity was always less than water velocity, so that the waves moved against the air flow that was causing them.

(b) Capillary waves were not observed on the surface of the water flowing normally at depths around or below critical. It is believed that initial surface disturbances and turbulence in surface layers of water made it impossible to recognize them by visual observations, if indeed they existed at all.

(c) The amount of drag necessary to create capillary waves on the surface of water flowing at depths above critical was about 320×10^{-5} lb/ft^2, so long as the surface of the water was initially quite smooth and free from fluctuation. The drag coefficient corresponding to this surface drag was about 0.006. These values, it may be noted, are the same as for air flowing with water.

(d) On the surface of water flowing at depths above or near critical, gravity waves of quite irregular form and discontinuous nature were observed after a relative air velocity of about 22 fps was exceeded. They moved in the opposite direction to the air flow until the relative air velocity reached approximately 35 fps. After the velocity was exceeded, they were transformed into a very long wave of solitary type which moved in the direction of air flow.

(e) On the surface of water flowing at depths below critical, gravity waves were formed and moved downstream at relative air velocities between 22 and 40 fps into a long standing swell in the downstream end of the flume. At relative air velocities greater than this, the swell moved upstream and became a hydraulic jump. At even greater air velocities, the jump merely moved further upstream without any change in the depth of water below the jump.

3. Also an investigation, with accompanying conclusions, was made upon the effect of air flowing over still water in a flume.

1661. Ostwald, W.

THE QUESTION OF THE NATURE OF THE CRITICAL STATES IN THE TRANSITION LIQUID-GAS, Kolloid-Z. 64, 50-62 (1933).

Consideration of the anomalies noted in the exptl. studies of the transition liquid-gas at the crit. state

and of the mechanism of boiling and condensation leads to the formulation of the transition as liquid ⇄ (liquido-sol ⇄ foam) ⇄ (fog ⇄ aerosol) ⇄ gas. (CA-27-4454-9)

1662. Petrick, M.

TWO-PHASE AIR-WATER FLOW PHENOMENA, ANL-5787 (1958), 88 p.

An experimental two-phase flow study was conducted on a series of Lucite rectangular channels with aspect ratios of 2 to 16 using an air-water system at atmospheric pressure. The objectives of the study were: (1) to determine the effect of sudden changes of flow area on the density of two-phase fluids; (2) to investigate the effect of mass flow rate on the two-phase friction factor multiplier and (3) to develop a sound method of measuring the density of a two-phase fluid in large conduits. The density of the air-water mixture changed during either an expansion or contraction of flow area; however, the magnitude of the change was not great and was readily predicted by a semi-theoretical equation. A sizeable effect of mass flow rate on the two-phase friction factor multiplier was found which was not accounted for in the widely used Martinelli correlation. A traversing technique was developed for measuring the density of a two-phase fluid which also gave a continuous trace of the phase distribution. The method was tried on Lucite mockups of simulated two-phase flow patterns, and excellent agreement was obtained between the measured and calculated voids.

1663. Petrick, M., and Swanson, B. S.

EXPANSION AND CONTRACTION OF AN AIR-WATER MIXTURE IN VERTICAL FLOW, AIChE Jour. 5, 440-445 (1959).

An exptl. 2-phase flow study was made on an air-H_2O system at atm. pressure to obtain information on the effect of expansion and contraction of flow area on the relative velocity of the 2 phases. The relative velocity and, hence, the mean void fraction of the air-H_2O mixt. changed following either an expansion or contraction; however, the magnitude of the change was not great and could be predicted by a semitheoretical equation. The air-H_2O data are also compared with data taken from a steam-H_2O system at 150-600 lb/sq. in. In addn., a photographic study was made of the transition zone, and phase distributions were obtained by the use of a radiation attenuation traversing technique.

1664. Phillips, O. M.

ON THE GENERATION OF WAVES BY TURBULENT WIND, J. Fluid Mech. 2 417-45 (1957).

A theory is initiated for the generation of waves upon a water surface, originally at rest, by a random distribution of normal pressure associated with the onset of a turbulent wind. Correlations between air and water motions are neglected and the water is assumed to be inviscid, so that the motion of the water, starting from rest, is irrotational. It is found that waves develop most rapidly by means of a resonance mechanism which occurs when a component of the surface pressure distribution moves at the same speed as the free surface wave with the same wave-number.

The development of the waves is conveniently considered in two stages, in which the time elapsed is respectively less or greater than the time of development of the pressure fluctuations. An expression is given for the wave spectrum in the initial stage of development (§3.2), and it is shown that the most prominent waves are ripples of wavelength λ_{cr} = 1.7 cm, corresponding to the minimum phase velocity $c = (4gT/\rho)^{1/4}$ and moving in directions $\cos^{-1}(c/U_c)$ to that of the mean wind, where U_c is the "convection velocity" of the surface pressure fluctuations of length scale λ_{cr} or approximately the mean wind speed at a height λ_{cr} above the surface. Observations by Roll (1951) have shown the existence under appropriate conditions, of waves qualitatively similar to those predicted by the theory.

Most of the growth of gravity waves occurs in the second, or principal stage of development, which continues until the waves grow so high that non-linear effects become important. An expression for the wave spectrum is derived (§4.1), from which follows the result

$$\overline{\xi^2} \sim \frac{\overline{p^2} t}{2\sqrt{2}\rho^2 U_c g} ,$$

where $\overline{\xi^2}$ is the mean square surface displacement, $\overline{p^2}$ the mean square turbulent pressure on the water surface, t the elapsed time, U_c the convection speed of the surface pressure fluctuations, and ρ the water density. This prediction is consistent with published oceanographic measurements (§4.3).

It is suggested that this resonance mechanism is more effective than those suggested by Jeffreys (1924, 1925) and Eckart (1953), and may provide the principal means whereby energy is transferred from the wind to the waves.

1665. Phillips, O. M.

THE EQUILIBRIUM RANGE IN THE SPECTRUM OF WIND-GENERATED WAVES, J. Fluid Mech. 4, 426-34 (1958).

Consideration of the structure of wind-generated waves when the duration and fetch of the wind are large suggests that the smaller-scale components of the wave field may be in a condition of statistical equilibrium determined by the requirements for attachment of the crests of the waves. A dimensional analysis, based upon the idea of an equilibrium range in the wave spectrum, shows that for large values of the frequency ω, the spectrum $\Phi(\omega)$ is of the form

$$\Phi(\omega) \sim \alpha g^2 \omega^{-5}$$

where α is an absolute constant. The instantaneous spatial spectrum (k) is proportional to k^{-4} for large wave numbers k, which is consistent with the observed occurrence of sharp crests in a well-developed sea, and the loss of energy from the wave system to turbulence and heat is proportional to $\rho_w u_*^3$, where ρ_w is the water density and u_* the friction velocity of the wind at the surface. This prediction of the form of $\Phi(\omega)$ for large ω with $\alpha = 7.4 \times 10^{-3}$, agrees well with measurements made by Burling (1955).

1666. Pickert, F.

THE THEORY OF THE AIR-LIFT PUMP, Engineering 134, 17-20 (1932).

This article outlines methods for calculating velocities of air and water, the head losses, and the efficiencies of air-lift pump. Performance of pump is determined by specific air consumption (weight of air/weight of water). This value is greatly affected by submergence ratio (depth of immersion/delivery height). Most favorable operation for a given submergence ratio is at minimum specific air consumption.

Overall efficiency $\eta_A \cdot \eta_W$. The efficiency η_W is determined by losses due to acceleration of water and wall friction. The efficiency η_A is determined by the difference between velocities of air and water, or the slip velocity.

1667. Pickrell, W. S.

BEHAVIOR OF TWO-PHASE TWO-COMPONENT FLUID FLOW IN TUBES, University of California, M.S. Thesis (1949) 64 p.

The case of air-kerosene mixtures in viscous flow in a five-millimeter, inside diameter, vertical tube was investigated experimentally.

The data for the annular flow pattern were correlated successfully thereby substantiating the use of the viscous-viscous dimensionless pressure drop, Φ_g, and flow parameter X_{vv}, for the annular pattern. The data for the "slug" type of viscous-viscous flow could not be correlated with these moduli. It was found that the dimensionless pressure drop was a function of the absolute liquid rate, as well as the flow parameter.

1668. Pierce, R. D.

HEAT TRANSFER AND FLUID DYNAMICS IN MERCURY-WATER SPRAY COLUMNS, Ph.D. Thesis, U. of Mich. 186 pp. (1955).

1669. Poettmann, F. H.

THE MULTIPHASE FLOW OF GAS, OIL, AND WATER THROUGH VERTICAL FLOW STRINGS WITH APPLICATION TO THE DESIGN OF GAS-LIFT INSTALLATIONS, Drilling and Production Practice, p. 257 ff (1952).

1670. Poettmann, F. H., and Carpenter, P. G.

THE MULTIPHASE FLOW OF GAS, OIL AND WATER THROUGH VERTICAL FLOW STRINGS, American Petroleum Institute, Paper No. 851-26-I (Mar 1952).

A method for predicting the pressure traverse of flowing oil wells and gas lift wells is described. The method is based on field data from 49 flowing and gas lift wells operating over a wide range of conditions.

The procedure developed permits the calculation of the bottom-hole pressure of flowing oil wells knowing only surface data; and, in the case of gas-lift wells, it is possible to calculate the depth, pressure, and rate at which to inject the gas, the ideal horsepower requirements necessary to lift the oil, and the effect of production rate and tubing size on these quantities.

Data available in the literature on lifting of water, through short lengths of glass tubing are shown to be correlative by use of an equation similar to that for the multiphase flow of oil, water, and gas through vertical tubing.

1671. Poletavkin, P. G., and Shapkin, N. A.

WATER AND STEAM CONTENTS IN SURFACE BOILING OF WATER, Translated from: Teploenergetika 5, No. 4, 54-8, AERE-Lib/Trans-804 (1958) 8 p.

The dependence of water and steam contents on heat flux, flow rate, difference between the temperature of the liquid and its saturation temperature, and pressure in water surface boiling was studied. Equations are presented for calculations of water and steam contents in surface boiling, as well as for tubes heated over their whole peripheries. Water and steam contents and heat exchange in exchangers with high heat flux are calculated for a series of cross sections along the length of the channel.

1672. Portalski, S.

THE MECHANISM OF FLOW IN WETTED WALL COLUMNS, Ph.D. Thesis, Battersea College of Tech., Univ. of London (1960).

1673. Potter, J. H.

THE THROTTLING OF WET STEAM, Combustion, 55-59 (Aug, 1957).

Theory of throttling calorimeter is reviewed and attempt made to represent possible combination of paths by which wet steam may travel through throttling calorimeter; on basis of experimental work of other investigators, (G. Upton and J. Yellott) and two-phase analysis of physical factors, it is shown qualitatively that expansion is completed prior to phase change.

1674. Prall, H. G., Jr.

TWO-PHASE FLOW OF FLUIDS IN COILED PIPE, University of Delaware, M. S. Thesis, June 1949, pp. 65.

The investigation herein reported is concerned with the co-current flow of two fluid phases through a coiled pipe. Although studies have been made at such flow in straight pipe, both horizontal and vertical, little is known of the characteristics of two-phase flow in coiled or curved passages.

The test section of the equipment consisted of 13 turns of type L, $\frac{1}{2}$ inch I.D., soft copper tubing wound in a close-packed helix. Pressure drop data over the length of the test section were obtained in the gas phase by means of manometers.

The rates of flow of the water and air were varied over the widest possible range obtainable with the existing equipment. The air flow was varied from 2.5 lbs/hr to 45 lbs/hr while the water rate varied from 12 lbs/hr to 192 lbs/hr. A preliminary study was made of the air flowing alone in the tube so that comparisons could be made with single phase flow in straight pipes and, also, with two-phase flow in the

curved pipe. The air rates used for this test were similar to those used in the two-phase runs.

The data were correlated on the basis of gas phase friction factors and gas phase Reynolds numbers. At a given Reynolds number, it was found that the friction factor increased with an increase in the amount of water flowing in the tube. This indicated the need for a shape factor in the friction factor relationships to account for asymmetrical flow effects.

A comparison of the data with those obtained by Jenkins and Gazley indicates that the various types of two-phase flow and the transition points for these types of flow occur at substantially the same values of relative interfacial velocity.

1675. Reichart, H. L., Jr.

THE FLOW OF FLUIDS IN TWO PHASE THROUGH A HORIZONTAL PIPE, Massachusetts Institute of Technology, B. S. Thesis (1934).

This paper describes the various types of flow tending the passes of a liquid-gas mixture through a horizontal pipe, and secondly it determines the critical condition of the change of type, and thirdly, it determines the pressure drop through the pipes for those various types of flow.

1676. Richardson, B. L.

SOME PROBLEMS IN HORIZONTAL TWO-PHASE TWO-COMPONENT FLOW, ANL-5949 (Dec. 1958), 147 p.

An experimental investigation was conducted on the flow of air-water mixtures in a number of horizontal rectangular Lucite test sections, whose aspect ratios varied from two to sixteen. These test sections were assembled in various combinations to permit the study of the effect of a sudden change in flow area on the significant flow parameters.

A technique was developed for measuring the volume fraction of each phase, making use of the difference of the attenuation characteristics of the liquid and the vapor for gamma radiation. This technique was evaluated making use of a number of Lucite mock-ups with known void distributions.

Information is presented on the factors influencing the volume fractions, flow patterns and slip ratios in the channels studied. The two-phase pressure drop is compared with existing correlations, and a relationship predicting this pressure drop, in terms of the liquid volume fraction, is derived.

The energy losses associated with an abrupt expansion or contraction were studied. A correlation based on the experimental results is presented to permit the prediction of these losses.

1677. Rogers, J. D.

TWO PHASE FLOW OF HYDROGEN IN HORIZONTAL TUBES, AIChE Jour. 2, 536-538 (1956).

Semirigorous equations are developed for flow of flashing liquids in pipe lines. These relations are applied to the flow of hydrogen, and computed correlations are presented for the pressure drop and vapor fraction. The calculations have been carried out as functions of the parameters: diameter, $\frac{3}{8}$ to 4 in.; mass rate per unit area, 0.0528 to 682 lb/(sq ft)(sec); pressure, 14 to 30 lb/sq in. abs.; vapor fraction 0.005 to 0.65; and heat leak, equivalent to 0 to 0.0224 Btu/(sq ft)(sec) for a $\frac{3}{4}$-in. line.

1678. Ros, N. C. J.

SIMULTANEOUS FLOW OF GAS AND LIQUID AS ENCOUNTERED IN OIL WELLS, Paper presented at the National AIChE Meeting, Tulsa, Oklahoma, (September, 1960).

1679. Santalo, M. A.

TWO-PHASE FLOW, Applied Mechanics Reviews, 11, 523-525 (1958).

A general picture of the present knowledge of co-current flow of a liquid and a gas or vapor is given in this article. A bibliography of 26 references is included.

1680. Scheirig, W.

WATER CIRCULATION IN STEAM BOILERS AND MOTION OF LIQUID-GAS MIXTURE IN TUBES, VDI, Forschungsheft, 365, 13-23 (1934).

1681. Schmidt, Ernest

THEORY OF SIMILARITY AS APPLIED TO THE MOTION OF LIQUID-GAS MIXTURES, Forschung auf dem Gebiete des Ingenieurwesens 4, 1-3 (March-April 1934).

The criteria of dynamic similarity, Reynolds number, and Weber number are applied to liquid-gas flow, by proper definitions of suitable terms.

1682. Schneider, F. N., White, P. D., and Huntington, R. L.

SOME ASPECTS OF SIMULTANEOUS HORIZONTAL, TWO PHASE FLUID FLOW THROUGH PIPELINES, AIME Paper No. 322-G (1953).

1683. Semenov, N. I., and Tochigin, A. A.

ANALYTICAL INVESTIGATION OF A LAMINAR FLOW OF A BIPHASE MIXTURE IN INCLINED TUBES, Inzhenerno-fizicheskiy zhurnal, v. 4, no. 11, 1961, 29-36.

The authors derive exact solutions of the hydrodynamic equations of a laminar flow of a biphase mixture in inclined and horizontal tubes. The equation of continuity and the kinetic equation are given without consideration of the vector components perpendicular to the flow direction. The authors derive expressions for the velocities of gaseous and liquid phases.

1684. Shaw, S. F.

SOME OBSERVATIONS ON PRINCIPLE OF FLOWING OIL WELLS, Trans. A.I.M.E., 80, 220-26 (1950).

1685. Shimose, I.

STATISTICAL THEORY OF PHASE TRANSITION. I. GENERAL THEORY FOR LATTICE GAS, J. Phys. Soc. Japan 9, 451-6 (July-Aug. 1954).

The statistical properties of phase transitions from the point of view of molecular clusters are

interpreted. Results for a lattice gas are expected to be qualitatively correct, though these are approximate from the quantitative point of view. The partition function, the pressure and the density of a lattice gas are calculated in their general forms. Particularly, the discontinuity of the derivative of the isotherm in P - v diagram is derived from the calculation of the partition function.

1686. Shimose, I.

STATISTICAL THEORY OF PHASE TRANSITION, II. NUMERICAL CALCULATION FOR LATTICE GAS, J. Phys. Soc., Japan 9, 457-9 (July-Aug. 1954).

The pressure and the densities (vapour and liquid) at the transition point of a lattice gas (square lattice type) are calculated for some ranges of temperature (or some values of x), using the theory derived in Pt I. Values agree well with the exact values obtained by the matrix method. For small values of x (for example, $x = 0.3$ or $T/T_c = 0.7321$), the values of partition function are given as a function of q. The isotherm obtained from these values has a portion parallel to v-axis (corresponding to P = constant) and at both ends of this portion the derivatives of the isotherm are discontinuous. Furthermore, the system in question is shown qualitatively to have the above properties also for larger values of $x(x<x_c)$.

1687. Shul'gin, D. F.

UNSTEADY MOTION OF A THIN PERMEABLE PROFILE IN A LIQUID, Trudy Sredneaziatskoga Industrail' Institute, No. 66, 61-67 (1956) (In Russian).

Paper examines the unsteady motion of a slightly warped permeable profile. The pressure variation on passage through the porous surface is chosen in the form $\Delta p = av + \lambda$ where a and λ are the experimentally obtained constants characterizing the permeability of the profile, and v is the penetration velocity. In solving the problem, author uses L. I. Sedov's method ("2-dimensional Problems of Hydrodynamics and Aerodynamics," Moscow-Leningrad, Gostekhizdat, 1950, pp. 46-80). Author reduces the solution of the problem to two integral equations of the first type. An accurate solution of this system was found for harmonic oscillations of the profile about the steady forward motion with constant velocity.

1688. Silberman, E., and Ross, J. A.

GENERATION OF AIR-WATER MIXTURES IN CLOSED CONDUITS BY ASPIRATION, AD-54982.

1689. Simpson, H. C., and Silver, R. S.

THEORY OF ONE-DIMENSIONAL, TWO-PHASE HOMOGENEOUS NON-EQUILIBRIUM FLOW, (Presented to the Thermodynamics and Fluid Mechanics Group of the Inst. Mech. Eng. on the 7th Feb. 1962, Session 2, Paper 6).

This paper deals with the flow of a superheated liquid down a straight duct in which frictional forces are neglected. It is first pointed out that there is a fundamental difference between the flow of the fluid flashing from liquid to vapour and that of a single-phase fluid because in the former case, the mean specific volume can change spontaneously with time. As a consequence, a pressure drop will occur when the two-phase fluid flows down the duct even in the absence of frictional forces. The flow of a superheated fluid is then investigated on the basis of the following model. First, nucleation is assumed to occur within the body of a liquid at a rate depending on the properties of the liquid. These nuclei are then assumed to grow and the bubble radius is evaluated as a function of time. These two relations are then combined to provide an expression for the mean specific volume of the vapour-liquid system at any time. Finally, this value is substituted in a momentum equation for flow down a straight duct of constant cross-section to produce a relationship showing the variation of liquid pressure along the duct passing fluid at various mass flow rates. On the basis of this theory, general curves are presented showing the decrease in mass flow rate with duct length for various overall pressure drops, this reduction increasing as nucleation becomes easier. It is also shown that the mass flow rate in a given duct reaches a limiting value as the overall pressure drop increases.

These theoretical curves are then compared with some experimental data on the flow of superheated water through nozzles. Agreement is satisfactory at the higher range of pressure drop, but at low pressure drop the experimental data imply that nozzle diameter influences the flashing. This influence is in a direction contrary to that which would be expected from effects at the nozzle surface and is explained by noting that turbulent fluctuations of pressure certainly occur and these are likely to assist nucleation. Under high pressure drops, turbulent fluctuations become less important. Evaluation of the nucleation parameters shows that the experimental energy of activation for nucleation is very much lower than would be expected for pure water and that the frequency term would indicate that the number of sites for nucleation is low. These results imply that nucleation in impure water occurs at a relatively small number of sites in the liquid which permit the energy of activation to be low. Finally, the theoretical curve of mass flow rate against overall pressure drop for a given nozzle is shown to be in agreement with some experimental data and to produce a limiting value of mass flow rate as the pressure drop increases. However, this limitation is not the same as the sonic velocity, choking effect encountered in the flow of single-phase compressible fluids.

1690. Sobocinski, D. P.

HORIZONTAL CO-CURRENT FLOW OF WATER, GAS-OIL AND AIR, M. S. Thesis, Univ. of Oklahoma (1955).

1691. Sobocinski, D. P., and Huntington, R. L.

CONCURRENT FLOW OF AIR, GAS-OIL AND WATER IN A HORIZONTAL PIPE, A. S. M. E. Paper No. 56-A-60, Also in A. S. M. E. Transaction 80, 252-256 (1958).

Problem of three-phase flow in production of petroleum; design of piping for vertical, horizontal, and inclined multiphase flow has been done largely by

trial; results of study of concurrent flow of oil and gas - field gathering pipelines along with injection of third water phase such as glycol.

1692. Stabnikov, V. N.

THE MOTION OF A CURRENT OF GAS IN A VISCOUS LIQUID, Kim. Mashinostroenie 7, No. 1 6-15 (1938).

The dimensions of the gas bubbles were detd. in relation to the flow in both water and castor oil. The gas entered the liquid in a horizontal and in a vertical direction through circular orifices of varying diams. The size of the bubbles was not proportional to the size of the orifice. The expanding of the bubbles immediately after their escape from the orifice was characteristic, especially with small orifices and high velocities of flow. (CA-34-3967-1)

1693. Stovall, W. B.

TWO PHASE VERTICAL FLOW OF KEROSENE AND AIR, M.S. Thesis, Univ. of Oklahoma (1953).

1694. Struiver, W.

TWO PHASE FLUID FLOW - FLOW THROUGH BENDS AND PRELIMINARY STUDY OF PRESSURE DROP ALONG PIPES, Report No. R. 257, Dominion Physical Laboratory, New Zealand (1955).

The flow characteristics of air-water mixtures passing through 90 deg. and 180 deg. bends are described from photographs. Formulae for the pressure drop along pipes, in two-phase fluid flow, are proposed and some experimental values are given.

1695. Struiver, W.

TWO-PHASE FLUID FLOW LITERATURE REVIEW AND PROGRAMME, Technical Note No. 89, Dominion Laboratory, Dept. of Scientific and Industrial Research, New Zealand (1955).

1696. Styrikovich, M. A.

HYDRAULICS OF GAS-LIQUID SYSTEMS, F-TS-9814/V (1960), 305 p. Prepared by Liaison Office Technical Information Center MCLTD, Wright-Patterson Air Force Base, Ohio.

The most essential laws governing the combined motion of a gas-liquid system are systematically described. The problems considered are: the flow of gas-liquid systems in tubes; motion of discrete bubbles and drops in entraining media; downflow of liquid films; discharge of a gas into a liquid; dynamic two-phase layers; two-phase flow in circular tubes; atomization of liquids by mechanical and pneumatic spray nozzles; drop entrainment by a gas stream and drop separation from the steam; hydrodynamic theory of critical changes in heat transfer during boiling on heating surfaces; and some problems in experimental techniques. The book is designed for workers in the fields of physical-heat engineering, power engineering, hydromechanics, chemical processes, and equipment. 81 references.

1697. Tatuhiro, U.

STUDIES ON THE FLOW OF AIR-WATER MIXTURES, Bull. Jap. Soc. Mech. Eng. 1, 139 (1958).

1698. Tek, M. R.

TOPICS IN MULTIPHASE FLOW, Univ. of Mich. Coll. of Eng. (1961).

1699. Teletov, S. G.

HYDRODYNAMIC EQUATIONS FOR TWO-PHASE LIQUIDS, Dokl. Akad. Nauk S.S.S.R. 4 (1945).

1700. Teletov, S. G.

SUR LE MOUVEMENT LENT SEPARE DES MÉLANGES GAZ-LIQUIDE, Dokl. Akad. Nauk. S.S.S.R. 51, No. 3, 179-82 (January 30, 1946).

Separate slow movement of gas-liquid mixtures; flow of gas mixtures or vapors with liquid in tube has very different character according to discharge, physical properties of compositions, and angle of incline of tube; at low flow velocity, separate movement of gas and liquid is observed in horizontal and inclined tubes; theoretical mathematical study. E. I. 1946, 426.

1701. Ter Linden, A. J.

PHENOMENA ACCOMPANYING THE SIMULTANEOUS FLOW OF GASES AND LIQUIDS THROUGH A PIPE-LINE, Ingenieur (Utrecht) 54, 25-9 (1939).

Under certain circumstances, the current in a pipe with a rough surface seems to flow more easily and rapidly than in a smooth pipe. In the transition from a current condition with negative friction to one with a positive friction, a current is observed in which the friction will equal zero, i.e., the average velocity of the liquid along the wall of the tube has no component in the direction of the current. In tubes placed at an angle, relative velocity of gas in relation to liquid appears to be greater than in vertical tubes. NSA 8, 2407 (May 5, 1954).

Translation available in AEC-tr-1783.

1702. Thompson, W.

ON THE WAVES PRODUCED BY SINGLE IMPULSES IN WATER OF ANY DEPTH OR IN A DISPERSED MEDIUM, Proc. Roy. Soc., vol. 42, p. 80, 1887.

1703. Tolman, R. C.

CONSIDERATION OF THE GIBBS THEORY OF SURFACE TENSION, J. Chem. Phys. 16,758 (1948).

The Gibbs theory of surface tension is discussed. Detailed consideration is given to the structure of transition layers between phases. This provides theoretical information, as to the magnitude of surface tension and as to the location of the surface of tension, which can be used in making applications of the Gibbs theory.

1704. Tolman, R. C.

THE EFFECT OF DROPLET SIZE ON SURFACE TENSION, J. Chem. Phys. 17, 333-337 (1949).

The effect of droplet size on surface tension is given theoretical consideration with the help of results of the Gibbs thermodynamic theory of capillary and of previous results of the author as to the sign and magnitude of superficial densities. It is

concluded that surface tension can be expected to decrease with decrease in droplet size over a wide range of circumstances. In addition, approximate figures are obtained for the rate at which such decreases may be expected. The decreases become significant for very small drops. The results are of interest in view of the important role of surface tension in determining the behavior of small droplets.

1705. Tung, Lu-Ho

DIFFUSION IN TWO-PHASE SYSTEMS, Ph.D. Thesis, University of Illinois (1951) 100 p.

1706. Ueda, T.

STUDIES ON THE FLOW OF AIR-WATER MIXTURES - THE UPWARD FLOW IN A VERTICAL TUBE, JSME Bulletin (Japan Society of Mechanical Engineers), 1, 139-144 (June 1958).

Results are presented for the following three experiments on the upward flow of air-water mixtures in a vertical tube having an inside diameter of 51 mm: (a) Visual observation of the flow patterns, (b) Measurement of the static pressures along the tube. From these results, the volume fraction of air in the tube and the relative velocity of air were calculated. A tentative correlation is presented about the drag coefficient of the force acting between air and water owing to the relative velocity, (c) Measurement of the tube wall temperature under a constant heat rate. The flow rates include the range of 200 to 5000 kg/h for water and 0 to 45 kg/h for air.

It seems that obstacles in tubes have particular effects on the flow of air-water mixtures. Some experiments were also performed to make qualitatively clear the effects of obstacles inserted into the vertical tube.

1707. Ursell, F.

WAVE GENERATION BY WIND, in SURVEYS IN MECHANICS, Batchelor, G. K., ed., Cambridge Univ. Press (1956).

1708. Van Deemter, J. J., and Van Der Laan, E. T.

MOMENTUM AND ENERGY BALANCES FOR DISPERSED TWO-PHASE FLOW, Appl. Sci. Res., Section A, 10, 102-108 (1961).

The equations of motion and the mechanical energy balances for two-phase flow systems are derived by integration over a volume containing a large number of elements of the dispersed phase.

1709. Van Dongen, J. R. J., and Ter Linden, A. J.

APPLICATION OF GAS-LIQUID CYCLONES IN OIL REFINING, Trans. Am. Soc. Mech. Engrs. 80 245-9 (1958).

Reference made to two-phase flow of liquids and vapors in refinery processes; as most final products must be in liquid or vapor form, separation of phases is necessary; problem of separating liquids from vapors efficiently and choice of separation equipment; results of study of cyclone separators on pilot plant scale; applicability in heating, flashing, or cracking processes, etc.

1710. Verber, K.

BREAK-UP OF LIQUID JET, SYMPOSIUM: INTERNAL COMBUSTION ENGINES, Vol I, ONTI (United Sci. and Tech. Pub. Houses), 1936.

1711. Versluys, J.

MATHEMATICAL DEVELOPMENT ON THE THEORY OF FLOWING OIL WELLS, Trans. of the American Institute of Mining and Metallurgical Engineers, 86, 192-208 (1930).

Mathematical analysis of two-phase flow as applied to the theory of flowing oil wells.

Equations are derived for the effect of pressure, the efficiency of a gas-lift, and the effect of gas being soluble on equilibrium of work in the gas-lift. This paper gives the principles of a theory. The constants in the formulas must be ascertained from experiments, which should be performed on the basis of this theory.

1712. Volmer, M.

KINETIK DER PHASENBILDUNG, Vol. IV of Die Chemische Reaktion, edited by K. F. Bonhoeffer, Leipzig, T. Steinkopff. (1939). (CA-33-5276-6) (CA-32-7336-5)

1713. Wade, D. E.

A STUDY OF BUBBLE DYNAMICS AND MASS TRANSFER IN STAGNANT LIQUID SYSTEMS, Ph.D. Thesis, Rice Inst., 145 pp. (1958).

1714. Wahl, M. H.

WETTING WITH SODIUM, NP-5811 (1955).

Certain pretreatments (aqua regia, NaOH, electropolish, and Na_3PO_4) have been shown to enhance wetting of stainless steel by molten Na at low temperatures. Wetting was neither speeded nor retarded by contact with cover gas (98% N_2 - 2%O_2).

1715. Wallis, G. B.

FLOODING VELOCITIES FOR AIR AND WATER IN VERTICAL TUBES, AEEW-R 123 (1961), 17 p.

An investigation of the limiting, or flooding, velocities for countercurrent annular flow of air and water in vertical tubes is reported. The data are correlated in terms of dimensionless groups which are similar to those already in use for describing flooding in packed towers. The relevance of the results to the problem of burnout in boiling equipment is discussed.

1716. Warner, C. F., and Reese, B. A.

INVESTIGATION OF THE FACTORS AFFECTING THE ATTACHMENT OF A LIQUID FILM TO A SOLID SURFACE, Jet. Prop. 27, 877 (1957).

One method of establishing protective liquid film between flowing gas and walls of flow passage is by injection of liquid through slot in passage walls; possible application in cooling of internal surfaces of rocket motors and external surfaces of high velocity missiles.

1717. Wehausen, J. V.

WATER WAVES II, University of California, Institute of Engineering Research, Berkeley, California, Series No. 82, September 1958.

1718. White, P. D.

HORIZONTAL CO-CURRENT TWO-PHASE TWO-COMPONENT FLOW, University of Oklahoma, Ph.D. Thesis (1954), 127 p.

Data are presented for the simultaneous horizontal flow of a vapor and a liquid phase in pipes varying in diameter from 1 in. to 2 in. The data include observations on air and natural gas, each flowing with liquids including water and kerosene, and lubricating oils.

A tentative flow pattern chart is presented which shows the type of flow which would exist under a given set of mass flow rates. This flow pattern chart was prepared for flow in a system near atmospheric pressures. Use of the chart at high pressures is not intended or recommended.

An empirical correlation is presented which allows the two-phase static pressure drop to be predicted if the flow rates, physical properties, and pipe diameter are known. This correlation is limited to those flow patterns which are stable in nature; this specifically excludes slug and stratified flow types. The correlation has not been checked with high pressure data, but it is believed to be valid at high pressures. The correlation is limited to liquids with viscosities of less than 120 centipoise.

Systems that have pressure drops greater than 10% of the downstream static pressure require stepwise solutions. Stepwise solutions are also required if vaporization occurs in the flow system to any great extent, or if considerable temperature change occurs. Kinetic energy changes, where they are important, may be considered separately.

A tentative correlation is presented to predict pressure drops resulting from ripple type flow. Insufficient experimental data are available to validate this correlation but it will serve as a guide in estimating the pressure drop in ripple flow until a better correlation is available, or until sufficient data are available for validation.

A 600-foot reel of 16 mm color motion picture of two-phase flow in a 2-inch plastic pipe has been prepared. All flow types are included in the film and flow rates and appropriate titles are given. A 700-foot reel of 16 mm color motion picture of two-phase flow in a $1\frac{1}{2}$ inch plastic pipe was also prepared and titled. These two reels are on file at the University of Oklahoma, College of Engineering, School of Chemical Engineering, Norman, Oklahoma, and may be obtained upon request.

1719. White, P. D.

HORIZONTAL CO-CURRENT TWO-PHASE FLOW OF FLUIDS IN PIPELINES, The Pet.Eng., D-40, D-46 (August 1955).

Research at the University of Oklahoma provides calculation methods for solving two-phase pressure drops, aids in making economic studies of single lines to handle simultaneously gas-liquid flow; experimental apparatus; chart presented that shows types of flow that would exist under given set of mass flow rates.

1720. Wright, C. Q., III

A STUDY OF TWO-PHASE CONCURRENT FLOW IN A HELIX, University of Delaware, M.S. Thesis (1949), pp. 75.

This thesis presents a study of two-phase concurrent flow in a helical coil. Visual pressure drop and photographic data are presented for air and water flowing through $\frac{1}{2}$ in. copper tubing coiled in the form of a $5\frac{3}{8}$ in. diameter helix containing 13 turns of the test section. The air and water entered at the top of the helix through a special entrance section and left at the bottom through a centrifugal separator. The flow was observed in a glass helix of two turns placed between the test section and the separator.

Flow was considered stratified when a continuous interface existed. When the air stream picked up large slugs of water, causing a sharp increase in the pressure drop the flow was termed in the critical slugging region. The region where the entire periphery was covered with a film of water but the greater mass of liquid remaining in the lower portion of the tube was termed pseudo annular flow because slugs of water still occurred. The region of flow where the tube wall was almost equally covered with the liquid, and no slugs could be observed with the naked eye, was termed true-annular flow. The study covered the ranges of air rates from 2.3 to 46 lbs/hr, and of water rates from 12 to 192 lbs/hr.

It was found that the pressure drop varied as the 1.33 power of the gas rate for stratified flow and as the 1.6 power for annular flow. These values agree fairly well with the data of Gazley and Jenkins for similar flow in a straight pipe. The types of flow can be predicted for any ratio of gas and liquid rates from a plot of a fictitious friction factor versus a Reynolds number.

1721. Yamagata, K., et al.

EFFECT OF AIR INJECTION INTO WATER ON THE HEAT TRANSFER, Trans. of the Society of Mechanical Engineers, Japan, 19, No. 84, 4-9 (1953) (In Japanese - English Abstract).

1722. Yih, C. S.

STABILITY OF PARALLEL LAMINAR FLOW WITH A FREE SURFACE, Proc. Second U. S. Congr. Appl. Mech., New York, ASME, 1955.

1723. Yocum, B. T.

TWO-PHASE FLOW IN WELL-FLOWLINES, Petrol. Engr. 31, B40-2, B44, B46-7 (1959).

The development of equations and coeffs. used in the study of simultaneous flow of oil and gas in well tubing and flowlines.

1724. Zannoni, P. J.

A STUDY OF ENTRANCE SECTIONS FOR TWO-PHASE CONCURRENT FLOW, University of Delaware, B.S. Thesis (1948), 51 p.

The objective of this project was to study by visual observation the conditions at the initiation of two-phase concurrent fluid flow and to select an entrance nozzle which would give the most stable flow conditions and the minimum pressure drop across the entrance section.

In preliminary investigation, 14 mm pyrex glass tube entrance sections were used. By means of visual observations and pressure drop measurements, the two best nozzles were found to be those whose air entrances were at an angle of 6° and 90° with the horizontal. The 6° entrance section was best suited for stratified flow because with this nozzle the greatest range of air-water rates could be obtained. The 90° entrance section gave the greatest range of air-water rates and the minimum pressure drop for annular flow, and is therefore the best nozzle for this type of flow.

In the final investigation, these two nozzles were constructed from one-half inch copper tubing. During the runs with the copper entrance sections, pressure drop measurements were made across the nozzle and at each 12-inch interval along the test section. It was found that the entrance effects vanished at a distance of 36 diameters downstream for the 90° section and 12 diameters downstream for the 6° section.

1725. Zerby, C. D.

DESIGN OF SMOOTHLY FLOWING GAS AND LIQUID MIXTURES, CF-51-10-130 (1951).

The several types of flow mechanisms possible in two-phase flow are defined and their order of occurrence given at a constant liquid flow rate and increasing gas flow rates. The characteristics of two-phase flow, which cause variable conditions in the flow stream, are described. Experimental data are presented which provide a basis for design of a smoothly operating two-phase system. The favorable characteristics of orifice in a two-phase flow stream are described, and the pressure drop equation across an orifice for two-phase flow is described. An example of the proper use of the included data is given.

1726. Zmola, P. C., et al.

TRANSPORT OF GASES THROUGH LIQUID-GAS MIXTURE, Tulane University and Oak Ridge National Laboratory, unpublished.

ADIABATIC FLOW

1727. Adorni, N., et al.

EXPERIMENTAL DATA ON TWO-PHASE ADIABATIC FLOW: LIQUID FILM THICKNESS, PHASE AND VELOCITY DISTRIBUTION, PRESSURE DROPS IN VERTICAL GAS-LIQUID FLOW, Centro Informazioni Studi Esperienze Report R 35, March 1961, Milan, Italy. Special Report No. 7. Work performed under United States-Euratom Joint Research and Development Program. CISE-R-35. 141 p. EURAEC-150

Experimental data on upward two-phase Ar-H_2O adiabatic flow in a vertical cylinder are reported. The temperature is maintained at room temperature, and the pressures studied range up to 22 kg/cm^2. Data on film thicknesses, phase and velocity distributions, and pressure drops are given.

1728. Adorni, N., et al.

FURTHER EXPERIMENTAL DATA ON TWO-PHASE ADIABATIC FLOW: EFFECTS OF THE PHYSICAL PROPERTIES OF THE LIQUID PHASE - PRESSURE OSCILLATIONS - DENSITY MEASUREMENTS, Centro Informazioni Studi Esperienze Report R 41, June 1961, Milan, Italy. CISE-R-41 (Pt. A & B)

1729. Anonymous.

FLOW OF FLASHING MIXTURE OF WATER AND STEAM THROUGH PIPES, Engineering and Boiler House Review 66, 268-269 (September 1951).

The analytical approach to the prediction of the flow characteristics of a two-phase mixture, such as water and steam, is explained, and a comparison of theory with test data is made. Test data and calculated results for a flow through cascade drain lines of 4-inch nominal diameter are tabulated.

1730. Bridge, T. E.

HOW TO DESIGN THE PIPING FOR CONVEYING FLASHING HOT WATER, Heating, Piping and Air Conditioning, 69-73 (March 1949) 92-6 (April 1949), 93-100 (May 1949).

Review of theory and practical application to design of lines for mixtures of steam and water; curves presented from which precalculated data may be obtained; sample problems of pressure drop; theory developed for calculating surge pressures resulting from high velocities in condensate lines; suggestions for designing flash tanks.

1731. Casagrande, I., Cravarolo, L., and Hassid, A.

RESEARCHES ON ADIABATIC TWO-PHASE FLOW, Energia Nucleare (Milan) 9, 148-59 (Mar. 1962).

The possible utilization of steam-water mixtures as reactor coolants requires extensive information on the involved phenomena and particularly on the fluid-dynamics of two-phase flow. The researches performed at CISE on adiabatic vertical two-phase flow are briefly reported and the main results discussed. The experiments were carried out mainly at room temperature and at a pressure of ~22 kg/cm^2 with argon-water mixtures flowing in dispersed regime in a circular vertical conduit, 25 mm ID. The flow rate ranges were: 18 - 205 g/(cm^{2}s) (liquid) and 16 - 95 g/(cm^{2}s) (gas). However experiments were carried out also with other fluids and lower pressures, as well as different geometries. The main quantities measured are: thickness of the liquid film adhering to the conduit wall, phase and velocity distribution, pressure drops, and pressure oscillations.

1732. Santalo, M. A.

STUDY OF ADIABATIC TWO PHASE FLOW IN VERTICAL TUBE (Sc.D. Thesis, M.I.T., Jan. 1958, M. E. Dept.)

1733. Stephenson, D. W.

CHARACTERISTICS OF ADIABATIC FLOW OF FREON-12 THROUGH A RESTRICTOR TUBE EXPANSION DEVICE WITH THE REFRIGERANT ENTERING AT SATURATION CONDITIONS, University of Missouri, M.S. Thesis (1951).

The purpose of this investigation is to study experimentally and analytically the characteristics of substantially adiabatic flow of Freon-12 through a 0.02 inch inside diameter restrictor tube 6 ft long with the refrigerant entering the tube at saturated liquid and at saturated gas conditions.

ANNULUS

1734. Bowes, H.

A BOILING WATER RIG FOR DEMONSTRATION PURPOSES, AERE-M-538 (September 1959), 33 p.

A training rig is described for investigating boiling and non-boiling heat transfer to water flowing vertically upwards in an internally heated annulus. Theory and experimental practice is outlined, together with a practical description of design and construction which incorporates a test length for visual examination of various boiling phenomena.

1735. Collier, J. G., and Lacey, P. M. C.

HEAT TRANSFER TO HIGH PRESSURE SUPERHEATED STEAM IN AN ANNULUS, 1961 International Heat Transfer Conf., Part II, pp. 354-362. New York, ASME, 1961. (Also published in AERE-R-3653).

Equipment is described for measuring the heat transfer characteristics of steam or steam-water mixtures flowing in annuli, at pressures up to 1500 psi. Point heat transfer coefficients are presented for single phase superheated steam at pressures from 20 to 1075 psi. The curve of log $Nu/Pr^{1/3}$ vs log Re was steeper than 0.8, particularly in the low Reynolds number (low pressure) runs but tended to approach the traditional Colburn relationship at high Reynolds number (1.3 to 3.2 x 10^5). With a calming section 18.2 diameters long the entrance effect could be correlated equally well by a factor $(L/D_e)^{-0.1}$ or a factor of the form $(1 + mD_e/L)$, with appropriate coefficients.

1736. Collier, J. G., and Pulling, D. J.

HEAT TRANSFER TO TWO-PHASE GAS-LIQUID SYSTEMS PART II. FURTHER DATA ON STEAM-WATER MIXTURES IN THE LIQUID DISPERSED REGION IN AN ANNULUS, AERE-R-3809 (1962).

In a continuation of experiments reported earlier, measurements have been made of the heat transfer rates from an electrically heated stainless steel tube to a two-phase steam-water mixture flowing upwards in vertical annular shaped channels of various dimensions. Point heat transfer coefficients have been evaluated for a range of values of three independent variables namely, total mass velocity, heat flux, and steam quality (% by wt) at pressures up to 80 psia.

The results have been compared with a number of previously published empirical correlations and in general these correlations (with slight changes in some cases) represent the data sufficiently well for engineering design purposes.

The results have also been compared with current theoretical analyses based on the annular flow model. In this case agreement was not good, the theoretical models predicting coefficients some 50% greater than those experimentally observed. Reasons are suggested for this discrepancy and the need for new experimental approaches emphasized.

1737. Knowles, J. W.

HEAT TRANSFER WITH SURFACE BOILING, MTec-187 (1946), 61 p.

The effect of surface boiling on the heat transfer from a stainless-steel tube to water flowing in an annulus was investigated. The temperature of the cooling water was throughout below the boiling point, and surface temperatures went to about 100°C above the boiling point. Water velocities ranged up to 10 fps and heat fluxes up to 750 w/cm^2. Nondimensional heat-transfer constants about four times larger than for forced convection were obtained. The limitations of stability were studied extensively. Heat-transfer correlation formulas were derived for two ranges of Reynolds no. and two ranges of length/diam. ratios.

1738. Knowles, J. W.

HEAT TRANSFER WITH SURFACE BOILING, Can. J. Research 26A, 268-278 (1948).

Exptl. study of heat transfer from electrically heated stainless steel tubes of from 0.47 to 1.32 cm diam. to downward flowing water in an annular space, with heat flux values up to 720 w per sq cm. The bulk temp. of the water was below its b.p., but the metal surface temp. was up to 100° above. At low water velocities the heat-transfer rate was increased to 4 times the normal value because of surface boiling. As the water temp. was increased at const. heat flux, a breakdown point was reached where high heat fluxes could no longer be maintained. (CA-42-8540g)

1739. McNutt, C. R.

DATA ON BOILING FLOW IN A "C" ANNULUS WITH UNIFORM TUBE POWER . . . , HW-32009 (1954).

1740. Rychkov, A. I., and Khokhlov, V. K.

BOILING HEAT TRANSFER IN AN ANNULUS, Trudy Moskov. Inst. Khim. Mashinostroeniya, 19, 65-78 (1959).

Heat-transfer measurements were carried out in a 515-mm long and 17.5-mm-inside diam. steel tube.

The annulus was formed by inserting steel rods of 8, 12, and 14-mm. diam., resp., into the tube. The tube was heated from the outside with steam, and distd. water was used as the test liquid. The heat-transfer tube was connected to a condenser, which returned the condensate to the bottom of the heat-transfer section. The entering water was elec. preheated to its b.p. The heat flux was detd. by the width of the annulus; decreasing the opening increased the flux. Optimum heat transfer was obtained when the annulus diam. was of the same order as the diam. of the bubbles formed. When the annulus diam. and the heat load both increased, the heat transfer in the annulus and tube were equal.

BINARY MIXTURE AND MULTI-COMPONENT

1741. Balitskii, S. A.

HEAT TRANSFER TO BOILING AQUEOUS SOLUTIONS OF LiBr AND LiCl UNDER VACUUM, Sbornik Trudov. Inst. Teploenerg., Akad. Nauk. Ukrain, SSR No. 14, 97-107 (1958).

Heat transfer was studied by boiling large vols. of aq. solns. of LiBr and LiCl, heated internally with a horizontal brass pipe. At a heat flux q = 3750-24,760 kcal/sq m hr., the heat-transfer coeff. can be calcd. from $\alpha = Cq^n$, where $n \approx 0.63$; α decreases with increasing concn. of solns. At a pressure of 0.05-1.0 atm. the value of α is not affected. The results obtained agree only qual. with the existing equations involving dimensionless ratios. From Referat. Zhur., Khim., 1959, Abstr. No. 46034.

1742. Bonilla, C. F., and Perry, C. W.

HEAT TRANSMISSION TO BOILING BINARY LIQUID MIXTURES, Trans. Am. Inst. Chem. Eng., 37, pp. 685-705 (1941).

Frequently equipment must be designed in which multi-component liquids are to be boiled; present work undertaken to obtain method of interpolation between pure liquids to give boiling heat transfer coefficient for binary mixtures; horizontal surface was used as it constitutes simplest physical and experimental arrangement; pure liquids studied were water, ethanol, n-butanol, and acetone.

1743. Bonilla, C. F., and Eisenberg, A. A.

HEAT TRANSFER TO BOILING STYRENE AND BUTADIENE AND THEIR MIXTURES WITH WATER, Ind. Eng. Chem. 40, 1113-1122 (1948).

Because of the importance of heat transfer to and from water-styrene and water-1,3-butadiene mixtures in GR-S synthetic rubber plants, tests on the boiling of these mixtures were carried out. It was found that in the boiling of mixtures of components that are not mutually soluble the necessary Δt, based on the equilibrium temperature, will be appreciably larger than for either component alone at the same q/A. In the boiling of relatively shallow depths of mixtures of insoluble liquids, considerable superheating of the mixture may be expected, in contrast to the boiling of two-phase mixtures of partially soluble liquids. If the liquid phase of lower density has a lower boiling point, boiling of the denser phase may not occur until high heat transfer rates are reached, as the heat transfer takes place at lower rates by natural convection. At a low rate of boiling the lighter layer will not mix sufficiently with the denser layer to be carried down to the heating surface, and at the boiling rate at which this starts a discontinuity in the Δt value will be observed.

1744. Bruijn, P. J.

ON THE ASYMPTOTIC GROWTH RATE OF VAPOUR BUBBLES IN SUPERHEATED BINARY LIQUID MIXTURES, Physica, 26, No. 5, 326-34 (May 1960).

Growth of vapour bubbles in boiling liquid mixtures is slowed by the difference between the vapour composition and the liquid composition if the constituents of the mixture have different volatilities. As the more volatile component is more rapidly exhausted in the liquid near a vapour bubble than the less volatile component, the growth rate of the bubble depends on the supply of the more volatile component by diffusion. Assuming that the radius R of a vapour bubble increases with the time t as $R = C\sqrt{t}$, the growth rate constant C is calculated as a function of the composition for the binary mixtures water - 1-butanol, water-ethanol and water-acetone boiling under atmospheric pressure. The problem is of special importance as it has empirically been found that a low growth rate often corresponds to a high value of the coefficient of heat transfer.

1745. Cichelli, M. T., and Bonilla, C. F.

HEAT TRANSFER OF LIQUID BOILING UNDER PRESSURE, Trans. AIChE, 41 755-84 (1945).

The temp. difference required to cause boiling from a horizontal Cr-plated surface at medium and high heat-transfer rates, and at pressures ranging in most cases from atm. to near the crit., was measured for H_2O, ethanol, benzene, propane, n-pentane, n-heptane, 50 mol. % water-ethanol, and 33 and 67 mol. % propane-pentane. It was found that the coeff. of heat transfer continues to rise as the pressure is increased, until nucleate boiling ceases to be stable near the crit. pressure, the boiling surface becoming vapor-bound in most cases. An approx. graphical correlation was found for predicting the max. boiling rate possible at any pressure, and another for the temp. difference required to produce the max. rate. The max. rate is found to occur at about $\frac{1}{3}$ of the crit. pressure. Binary mixts. were found to require several times as large a temp. difference to boil at the same rate as the pure components. The principal equations that have been published for predicting film coeffs. of heat transfer in boiling were compared at atm. pressure and over the pressure range covered with the data obtained. The curves and formulas now available apparently enable nucleate boiling film coeffs. to be roughly

estd. for any liquid under any conditions, from a horizontal surface or tube. (CA-40-10692)

1746. Darling, C. B.,

HEAT TRANSFER TO LIQUIDS IN INTERMITTENT FLOW, Petroleum 22, 177-8, 180 (1959).

Water and 50% glycerol solution in intermittent flow in 0.379 in. diam. heated tube gave poorer heat transfer than in steady flow when flow was controlled from downstream of heater; when flow was controlled from upstream of heater, bubbles appeared in liquid and heat transfer was improved by up to 70% over steady flow values.

1747. Davis, D. S.

HEAT TRANSFER FOR AQUEOUS GLYCEROL BOILING IN POOLS, Brit. Chem. Eng. 7, 714 (1962).

A nomogram. (CA-62-14906a)

1748. Filatkin, V.

HEAT EXCHANGE DURING THE BOILING OF AN AMMONIA-WATER SOLUTION, Kohl. Tekh., 34, 23-29 (Oct.-Dec. 1957).

The expts. show that for heat fluxes q $\leqq$ 5000 cal/sq m hr , the heat transfer during the boiling of an aq. NH_3 soln. (I) is detd. principally by free convection. For q $\leqq$ 2500 cal/sq m hr, nucleate boiling exists in the range for which the heat transfer coeff. (W) for I is lower than for 1-component liquids. The lowering of W during nucleate boiling of I is caused by the change in phys. properties and the modification in the structure of the boundary layer at the heating surface. This change in structure is produced by the difference in concn. of the vapor and the liquid phase in the boiling soln. Equations are given for the detn. of W during the boiling of I in the range 1000 $\leqq$ q $\leqq$ 25,000 cal/sq m hr. A nomogram is presented for the calcn. of W in the range of nucleate boiling. From C.Z. 1958, 7045.

1749. Gleim, V. G., et al.

PHENOMENA OCCURRING AT THE PHASE BOUNDARIES OF BOILING SOLUTIONS, Zhur. Prikl. Khim. 31, No. 1 32-37 (January 1957).

The surface tension σ of 1 and of 2 mole % solns. of NaCl, NaOH, Na_2SO_4, Na_2CO_3, and $MgSO_4$ was detd. in the range of 20-90 $\pm$ 0.05°. The difference in σ of these solns. was slight. Hence, the desorption of these salts from the surface of their solns. could not be selective, i.e., the relative proportions of these salts at the surface and in the bulk of the soln. was the same and independent of the temp. The difference $\sigma_{soln.} - \sigma_{H_2O}$ = const. and $\sigma_{soln.} = \sigma'_{soln.} (\partial\sigma_{soln.}/\partial T) (T - T_1) = \sigma'_{soln.} + (\partial\sigma_{H_2O}/\partial T (T - T_1)$, where $(\partial\sigma_{H_2O}/\partial T) (T - T_1)$ is independent of the concn. C and on differentiation becomes $\partial\sigma_{soln.}/\partial C \pm f(T)$ (σ' is σ at some specific temp. T). The temp. coeff. of σ is independent of the electrolyte and the compn. of the soln. and is equal to that of H_2O. The surface activity, however, is a function of the concn., the nature of the solute, and the temp.

1750. Gordon, K. F., et al.

BOILING HEAT TRANSFER BETWEEN IMMISCIBLE LIQUIDS, Intern. J. Heat Mass Transfer 3, 90-93 (Sept. 1961).

An investigation was made of boiling heat-transfer coeffs. between immiscible liquids. Hg and H_2O, MeOH, or EtOH were used. The app. was a 2.5 in. diam. glass tube with Hg heated by an external heating wire and the pool boiling liquid above. The data covered the range ΔT = 7-103°F., q = 1500-110,000 Btu/sq ft hr with h = 200-1800 Btu/sq ft hr °F. Neither a peak flux nor a decline in h was reached.

1751. Grigor'ev, L. N., and Usmanov, A. G.

HEAT EMISSION AT BOILING OF BINARY MIXTURES, Zhur. Tekh. Fiz., 28, 325-32 (1958).

The mechanism of boiling process of binary mixts., EtOH-H_2O, MeOH-H_2O, EtOH-BuOH, acetone-BuOH, differed significantly from that of single-component liquids. The compn. of the boiling mixt. was found to influence the heat transfer. This effect was shown by the dependence of the radius of curvature of vapor-forming centers on concn. of the boiling mixt. An equation was derived for detg. the radius of curvature of vapor-forming centers in boiling binary mixts.: $\rho_0 = 2\sigma/\{[(\eta_2 - \eta_1)/(\gamma_2 - \gamma_1) - \{[(X_2 - X_1)/(\gamma_2 - \gamma_1)] (\partial^2\zeta/\partial X^2)(dx/dT)\}] \Delta t$. Where σ is coeff. of surface tension of the boiling mixt. (kg/m), γ_1 and γ_2 are molar vols., η_1 and η_2 molar entropies, x_1 and x_2 molar concn. based on low-boiling component, ζ Gibb's molar thermodynamic potential, subscripts 1 and 2 designated liquid and vapor, resp., t temp. in °C, T abs. temp. of boiling in °K. The coeffs. of heat transfer at boiling of binary mixts. were significantly lower than those of the pure components. At certain concn. of the mixt. a definite min. of the function $\alpha = f(x_1)$ was observed, where α is the coeff. of heat transfer. A photographic study of the same systems confirmed the relationship given by the equation.

1752. Grigor'ev, L. N., and Usmanov, A. G.

CONDITIONS OF HEAT TRANSFER SIMILARITY IN BOILING OF BINARY MIXTURES, Trudy. Kazan. Khim-Tekhnol. Inst. IM. S.M. Kirova, No. 26, 32-41 (1959).

Bonilla and Perry (CA 35, 72401) tried to generalize the boiling conditions of binary mixts. and H_2O solns. by using the theory of similarity. Their equations fail to differ from those valid for pure liquids. Dimensionless equations are derived by assuming both a single center and a greater no. of such centers of vapor formation and their dynamical interaction. Equations and diagrams for the binary systems EtOH-H_2O, MeOH-H_2O, EtOH-BuOH, and Me_2CO-BuOH are given.

1753. Grigor'ev, L. N., and Usmanov, A. G.

HEAT TRANSFER DURING THE BOILING OF BINARY AZEOTROPIC MIXTURES, Inzhener.-Fiz. Zhur., Akad. Nauk. Belorus. S.S.R., 2, No. 11, 114-18 (1959).

In a previous study an equation was derived which gave the relation between the concn. of a boiling binary mixt. and the radius of curvature of

vapor-forming centers. The validity of this relation was confirmed when the mechanism of the boiling process of binary mixts., such as PhOH-H_2O, H_2O-pyridine, and EtOH-C_6H_6 was investigated. At a predetd. concn. these mixts. are azeotrope-forming, and under this condition $x_2 - x_1 = 0$, where x_1 and x_2 are molar concns, based on the low-boiling component, subscripts 1 and 2 being liquid and vapor, resp. It was found that at this concn. the azeotrope did not differ significantly from the single-component liquids with respect to the coeff. of heat transfer. Graphically, the function $a = f(x_1)$, where a is the coeff. of heat transfer, showed not only a definite min. but also a max.

1754. Huber, D. A., and Hoehne, J. C.

POOL BOILING EXPERIMENT WITH BENZENE-DIPHENYL MIXTURES, Atomics International, TDR No. 5596, September 1960.

1755. Huber, D. A., and Hoehne, J. C.

POOL BOILING INVESTIGATION OF BENZENE, DIPHENYL, AND BENZENE-DIPHENYL MIXTURES UNDER PRESSURE, NAA-SR-6681 (1961), 66 p.

Experimental measurements are reported for the nucleate boiling of benzene, diphenyl, and benzene-diphenyl mixtures. Heat flux is presented as a function of the temperature difference between the heat transfer surface and the coolant saturation temperature. Correlations expressing nucleate boiling are discussed in view of the data. Critical heat fluxes are reported for all the fluids tested and are compared with correlations in the literature. The data were obtained in a pool boiling apparatus at pressures ranging from subatmospheric to 475 psig. System pressure was maintained with nitrogen gas. The test section was a horizontal, 6-inch long, $\frac{3}{8}$-inch OD, type 304 stainless steel tube which was heated by direct current; the tube itself was used as a resistance element. For the pure fluids, the nucleate boiling heat transfer data were correlated reasonably well by use of the Rohsenow, Gilmour, and Levy equations. The values of the critical heat fluxes for the pure fluids were best correlated by the Bernath relationship. However, none of the literature expressions adequately predicted the large increases in critical heat fluxes obtained when small percentages of benzene were added to diphenyl.

1756. Jost, W.

BOILING BEHAVIOR OF MULTICOMPONENT SYSTEMS, Z. Naturforsch., 1, 576-80 (1946).

The possibility of improving or rendering possible otherwise difficult or impossible sepns. by addn. of another component to the system is discussed. Expressions are derived thermodynamically for the ratio of vapor pressures of 2 components in a multicomponent system. Numerical examples showing the validity of the expressions are given for the systems heptane-toluene-aniline and benzene-cyclohexane-aniline. Because entropies of mixing are greater than the ideal values assumed in the derivations, it was necessary to use values for heat of mixing that were smaller than those measured calorimetrically. The practical applications of the addn. of a third component to two-component systems are discussed. (CA-41-5353e).

1757. Katti, P. K., and Rustgi, O. P.

A NOTE ON THE BOILING POINTS OF REGULAR SOLUTIONS, Curr. Sci., (India), 24, 406-7 (1955).

A formula for the boiling-point-concentration curve of binary mixtures is used which depends on effectively four numerical parameters. It is applied to mixtures of benzene and carbon tetrachloride. Values for the parameters are taken from measurements of partial vapour pressures. The calculated curve is in agreement with six values of boiling points obtained by direct measurement.

1758. Lebedev, P. D., and Sorokin, A. F.

RULES FOR HEAT AND MASS TRANSFER IN THE BOILING OF SOLUTIONS, Izv. Vys. Ucheb. Zav. Energ. No. 1, 80-85 (January 1958).

The process of heat transfer, during boiling, of 2-component liquids (solns.), which is complicated by mass transfer due to diffusion processes, was studied. Generalized relations were recommended for heat transfer during the boiling of solns. under conditions of free convection within tubes. From Referat.Zhur., Fiz., 1958, Abstr. No. 20176.

1759. Leppert, G., Hoglund, B. M., and Costello, C. P.

BOILING HEAT TRANSFER TO WATER CONTAINING A VOLATILE ADDITIVE, ASME Paper, Trans. Am. Soc. Mech. Engrs. 80, 1395-1404 (1958).

Aspects of local boiling in forced circulation when the boiling fluid contains small percentages of alcohol are discussed. Particular emphasis is placed on the improvement in smoothness of boiling and in the decrease of average bubble size when the additive is present, as contrasted with boiling distilled water. Experimental results, including photographs, are presented for surface boiling from the outside of a cylindrical stainless steel tube placed normal to the flow. Data are also presented for the subcooled boiling of distilled water, and comparisons are made with correlations from the literature.

1760. Lowery, A. J., Jr., and Westwater, J. W.

HEAT TRANSFER TO BOILING METHANOL - EFFECT OF ADDED AGENTS, Ind. Eng. Chem. 49, 1445-48 (1957).

Effects at 1 atm. were detd. for 3 added agents (Hymine 1622, Span 20, Aerosol OT) on the boiling curve for MeOH. The heat source, a horizontal steam-heated Cu tube (0.25-in. outside diam.) was used as a resistance thermometer. Concns. of the agents were 0-1%; MeOH ΔT was 50-175°F. Adding 0.01% or more of agent changed the boiling curve considerably. (If present, small bits of wood or rubber had similar effects.)

1761. Minchenko, F. P.

BOILING HEAT TRANSFER, Energomashinostroenie, No. 6, 6, 17-22 (1960).

Results are given of a test on heat transfer to boiling water and solns. of Li salts in a large vessel or in a circulation loop; the analysis provides a general conclusion regarding criterion functions, which is compared with well-known dimensionless equations. From Fuel Abstr. Current Titles 1, Abstr. No. 4875 (1960).

1762. Minchenko, F. P., and Firsova, E. V.

HEAT TRANSFER TO WATER AND WATER SOLUTIONS OF LITHIUM SALTS DURING BUBBLE BOILING IN A LARGE VOLUME., Kutateladze, S.S. ed. Voprosy teplootdachi i gidravliki dvukhfaznykh sred; sbornik statey, Moscow, Gosenergoizdat, 117-128 (1961).

Results were obtained for water and solutions of LiBr and LiCl. Heat load q, pressure p and concentration k, were varied. Three different steel tubes were used. Their surfaces were carefully prepared and stabilized in the working conditions before resuming tests. The tube was heated with a low voltage, high intensity current. An additional heater helped to speed up the heating. Three chromel-alumel thermocouples and two mercury thermometers were fitted. The following measurements were taken: Vapor pressure, current and voltage drop ΔU on the working length of the tube; temperature of boiling liquid; temperature of air inside the sealed tube (equal to that of the inner surface). The temperature of the external surface of the tube was obtained as a difference between the temperature of the inner surface and the drop across the tube wall. From the measure data the coefficient of heat transfer was calculated. The values of the coefficient α for water agree with those given by other investigators and obey the law Eq. (3) $\alpha = Af(p)q^n$. A graph of the function f(p) is given separately. The two salt solutions also obeyed the law (3) and Eq. (5) where $A_1 = 0.75$ and 0.8 for solutions of LiCl and LiBr respectively. There are 8 figures, 2 tables and 18 references: 13 Soviet-bloc and 5 non-Soviet-bloc. (Abstracter's note: References illegible on photostat).

1763. Perroud, P., and de la Harpe, A.

HEAT TRANSFER BY LIQUIDS ENTRAINED IN A TURBULENT GAS STREAM, CEA-1422 (1960), 62 p. Also in Compt. rend., 249, 2728-30 (1959).

The introduction of a small volume of liquid into a turbulent gas stream used as cooling agent considerably improves the heat-transfer coefficient of the gas. When the turbulent regime is established in a cylindrical tube, two types of flow are observed, depending on whether the liquid wets or does not wet the wall. In the first case, an annular liquid film on the wall and droplets in suspension in the gas stream are formed. In the second case, a fog of droplets is formed without any liquid film on the wall. Experiments were performed with the following mixtures: water-hydrogen, water-nitrogen, ethanol-nitrogen (wetting liquids) introduced into a stainless-steel tube of 4-mm ID, electrically heated on 320 mm of the length. The gas flow rate (Reynolds number to 50,000) the ratio of liquid flow rate to gas flow rate (to 15), and the pressure (to 10 kg/cm^2), the temperature (to the boiling point) and the heat flux (to 250 w/cm^2) were varied.

1764. Popov, B. G., et al.

HEAT EXCHANGE IN BOILING AQUEOUS SOLUTIONS OF MINERAL SALTS, Izvest. Vyssikh. Ucheb. Zav. Khim. i Khim. Tekh. No. 1., 173-182 (1958).

The results obtained for solns. of Na_2SO_4, Li_2SO_4 Na_2CO_2, $MgCl_2$, and sugar at different concns. are correlated by the relation $\alpha = AqP$ in which α = the heat transfer coeff. in kilocal/sq m hr °C, q = the heat flux in kilocal/sq m hr, A = an empirical const., and p = an exponent, which for most solns. decreases with increasing concns. The heat transfer coeff. in boiling aq. solns. of salts depend on the nature of the substance dissolved, on its concn., and also on the boiling point elevation. An appropriate app. for conducting these expts. is described.

1765. Popov, B. G.

APPROXIMATE DETERMINATION OF THE HEAT TRANSFER COEFFICIENT DURING BOILING OF AQUEOUS SALT SOLUTIONS, Izvest. Vysshikh. Ucheb. Zavedenii, Khim. I. Khim. Tekhnol., 3, 375-8 (1960).

Data of P and others on the boiling of aq. solns. of various salts over a wide range of concns. are satisfactorily generalized by the equation $E_8 = 0.28 K_S^n K_q^{0.75}$, where n = -0.5 or -0.3 for solns. < 20 or $> 20\%$ satd., resp., $E_s = \alpha\Delta T/q$, K_q is the Jakob coeff. [J., Heat Transfer, 1949 (CA 43,6873c)], and $K_T = \tau/\tau^*$ ($\tau^* = \Delta T^*/T^*$; T^* is the b.p. of the satd. soln.; τ is the b.p. of the actual soln.). This equation differs from those proposed earlier by the fact that it does not contain a large no. of phys. consts., the values of which are not always found in the literature.

1766. Robin, V. A.

INVESTIGATION OF THE MECHANISM OF BOILING A MIXTURE OF ALUMINUM BROMIDE AND CHLORIDE, AND A MIXTURE OF ANTIMONY BROMIDE AND CHLORIDE, Soviet Physics-Tech. Phy. 4, 1051-4 (March 1960).

Boiling halide mixtures wet a glass surface, yet their boiling mechanism differs not only from that of non-wetting liquids, but also from that of water. The reasons for this are the lower surface tension of the halide mixtures, and also the continuous change in composition of vapour and liquid during boiling. In a vertical tube the vapour bubbles rise through the boiling halide mixture, rather than sliding along the glass wall, so that the wall is well washed by the transferring liquid.

1767. Roll, J. B.

THE EFFECT OF SURFACE TENSION ON BOILING HEAT TRANSFER, PhD. Thesis, Purdue Univ. (1962).

The static and dynamic surface tension were measured for aqueous solutions of eleven surface active agents for the purpose of studying the effect of surface

tension upon boiling heat transfer. The surfactants were chosen from the Tween, Aerosol, and Hyonic series. The phenomenon of dynamic or nonequilibrium surface tension arises because of the finite time required for a surfactant molecule to become oriented at an interface. It is demonstrated by the existence of an apparent surface tension somewhere between the value for pure solvent and the static or equilibrium value. Dynamic surface tension was investigated by observing the volume and frequency for air bubbles forming from a submerged orifice. In all cases, the dynamic surface tension for solutions of these surface active agents was less than the value for pure water, greater than the static value for the same concentration, and was a smoothly decreasing function of concentration. The static values were measured using a duNouy tensiometer. Values were recorded at temperatures approaching T = 100°C; the value at this temperature was obtained by extrapolation. Results show that the static surface tension at 100°C may have a positive or negative value for $d\sigma/dT$ depending upon the solute-concentration combination chosen. Further, it was shown that although in general the static surface tension decreases with increases in concentration, there are instances where static surface tension increases with increases in concentration. The heat transfer data were taken in three groups. The first group of data was used to construct plots of the steady-state heat transfer coefficient versus the superheat. The Tween series showed results which could be interpreted quite successfully on the basis of a decrease in the critical radius for nucleation. The Hyonic series resulted in a fouling of the surface, perhaps due to some decomposition of polymerization product. The Aerosol series showed a cleansing action which kept the surface free of fouling and may even have increased the micro-roughness such that the heat transfer coefficient increased. The second group of data was obtained by observing the immediate temperature response upon addition of a surface active agent. In this way the time-related surface effects described above were eliminated. Analysis of these data indicated that the value of the surface tension which gave the best correlation with the liquid superheat was an arithmetic average of the static and dynamic values. Calculations based upon mass transfer to the growing bubble demonstrated why this was so.

The final group of data was obtained using high speed photography. In this manner, quantities such as bubble volume, delay time, and growth time could be measured for the various solutions. A model is presented to describe the manner in which surface tension changes these variables. Results from this model show that surface tension is effective because it changes the nucleating properties of the liquid and not because it alters its hydrodynamic character. Results obtained using this model, as well as data from the films, show that the previously accepted concept of the significance of the balance between buoyancy and surface tension forces at bubble "break-off" is in error. The three sets of data all tend to confirm the hypothesis that surface tension is a factor in boiling heat transfer only because it affects the nucleating properties of the liquid. Hydrodynamic effects, such as bubble volume and frequency, are the direct results of the nucleation effects and are not themselves changed significantly by the surface tension.

1768. Rychkov, A. I., and Sterman, L. S.

INVESTIGATION OF HEAT TRANSFER IN BOILING CAUSTIC SOLUTIONS, Khim. prom. (Chemical Industry), 4 (1948).

1769. Rychkov, A. I., and Pospelov, V. K.

HEAT TRANSFER TO BOILING CAUSTIC SODA SOLUTIONS IN THIN FILMS, Khim. Prom., 426-9 (1959).

The heat flux from the hot surface (a vertical, elec.-heated, Ni-plated Cu tube) to H_2O and NaOH solns. was detd. from the amt. of condensate obtained when the resulting vapors were condensed. The app. is illustrated. With H_2O below the b.p., the H_2O layer on the tube is clear and shows small waves at the surface; at the b.p., centers of vaporization are visible on the tube, causing chains of bubbles to form, which float on the surface for a short time, then increase in size and burst. With further increase in the heat flow, a mat of bubbles is formed on the H_2O surface. Similar effects are found with 5 and 25% NaOH solns., but, because of the greater viscosity, the frequency of formation and break-away of bubbles is less, and decreases with increased concn. For H_2O, the coeff. of heat transfer to the boiling film α increases linearly with the heat flux q and increases with increase in the rate of flow of the H_2O, G. For NaOH solns., α decreases with increase in q and NaOH concn. The exptl. results, within 10%, are expressed by $\alpha = Aq^nG^m$ for H_2O, and $\alpha = AG^m/q^n$ for NaOH solns., where α is the av. coeff. of heat transfer (allowing for change of concn. of NaOH solns. during the evapn.), in kcal/sq m hr°, q is the heat flux in kcal/sq m hr, G is the rate of flow of liquid in kg/sq m hr, and A, m, and n are empirical consts. A table gives A, m, and n for H_2O and 5, 10, 15, and 25% NaOH solns.

1770. Rychkov, A. I., and T'soi, W.

CRITICAL BOILING OF SOLUTIONS AND SALT DEPOSITION ON A HEATING SURFACE, Khim. Mashinostroenie, No. 5, 18-22 (1961).

Max. heat fluxes (Q_{cr}) are exptl. detd. for boiling aq. solns. of nonvolatile compds. Q_{cr} depends on the physicochem. properties and particularly on the concn., x (wt. %). Q_{cr} decreases when x increases. For very sol. compds., Q_{cr} reaches a min. Q_{cr}-($\Delta T/T$) is plotted against x for electrolytes and nonelectrolytes, where T = b.p. of the soln. °K, ΔT = b.p. elevation. Salt deposition on the heating surface is studied. For low-soly. compds., a salt layer appears on the heating surface at a heat flux Q_0. Q_0 is plotted against $\Delta x = x^* - x$(x^* = satn. concn.); Q_0 decreases when x increases. When $\Delta x \geq 10\%$ there is no salt deposition.

1771. Sorokin, A. F.

HEAT TRANSFER TO BOILING WATER AND SODIUM HYDROXIDE SOLUTIONS, 1961, Izvest., Vysshikh. Ucheb. Zavedenii, Energet., 4, No. 3, 53-8 (1961).

The coeff. of heat transfer was detd. for the boiling of H_2O and NaOH on a horizontal, stainless steel, heating surface, consisting of a tube of 25 mm inside diam. and 504 mm long. The tube was heated internally with a 1.4-kw elec. heater, controlled by an automatic transformer. The coeff. of heat transfer, α, in kcal/(sq m hr deg) for H_2O was $3.0\,q^{0.7}$, where q = the heat flux in kcal/(sq m hr). For a weakly basic soln. contg. NaOH 116.16, NaCl 186.73, Na_2SO_4 21.4 g/l., d = 1.232, $\alpha = 2.2q^{0.7}$; for a medium-strength alkali contg. NaOH 377.4, NaCl 73.41, Na_2SO_4 10.50 g/l., d = 1.352, $\alpha = 1.32\,q^{0.7}$; and for a strong alkali contg. NaOH 712.0, NaCl 18.50, Na_2SO_4 0.65 g/l., d = 1.465, $\alpha = 2.86q^{0.55}$. The decrease of the exponent of q to 0.55 in the last case is caused undoubtably by the formation of a ppt. on the boiling surface, causing a decrease of the heat flux. The results are in good agreement with expts. with industrial evaporators. The coeff. of heat transfer is independent of pressure.

1772. Sternling, C. V., and Tichacek, L. J.

HEAT TRANSFER COEFFICIENTS FOR BOILING MIXTURES. EXPERIMENTAL DATA FOR BINARY MIXTURES OF LARGE RELATIVE VOLATILITY, Chem. Eng. Sci. 16, 297-337 (1961).

Pool boiling heat transfer coeffs. were measured for the binary mixts. benzene-Ondina No. 17 Oil (I); methyl chloroform-Ondina No. 133 Oil (II); CCl_4 (III)-II; III-dibutylphthalate (IV); iso-PrOH (V)-I: V-IV; V-ethylene glycol (VI); V-glycerol (VII); MeOH (VIII)-VI; VIII-VII; H_2O (IX)-VI; IX-VII; VIII-amyl alc.; and V-X-38 resin. In all systems tested, boiling coeffs. decrease markedly as the low volatility material is added to the light component. This decrease continues with the system IX-VI until there is ~10% IX in the mixt. Addn. of more VI raises the boiling coeff., with the boiling curve for pure VI closely approaching that for pure IX. In systems with wide-boiling range, boiling heat transfer coeffs. are smaller by up to 30-fold than the av. of the coeffs. for the 2 pure components.

1773. Tananaiko, Yu. M , Prkhal, I., and Shteingrob, E. Kh.

HEAT TRANSFER DURING THE BOILING OF LARGE VOLUMES OF SODIUM CHLORIDE SOLUTIONS, Izv. Kievsk. Politekhn. Inst., 28 9-13 (1959).

A study was made of heat transfer during the boiling of aq. solns. of NaCl in a large vol. over a pipe (20.5 mm. diam., 25 mm. long) heated with superheated steam, with a heat flux q of 11,500-25,000 kcal/sq m/hr and a concn. of 10-20%. With increase in the temp. of the soln., the heat-transfer coeff. decreased by 9-25% in comparison to that for H_2O. Exptl. results are correlated by the dimensionless equation: $Nu = 54\,K^{0.6}.\,Pr^{0.3}$ which generalizes exptl. data with a max. deviation of ±15%, where $K = q/(r\gamma d_0 v)$, r is the latent heat of vaporization, γ is d. of the vapor, d_0 is the breaking diam. of a bubble (diam. of bubble when it bursts), and v is the no. of bubbles breaking in a unit of time. From Ref. Zh., Khim. 1961, Abstr. No. 18136.

1774. Thomas, D. G.

NUCLEATE-BOILING STUDIES WITH AQUEOUS THORIUM OXIDE SLURRIES, Chem. Eng. Prog. Symp. Series No. 32, 57, 182-188 (1961).

Nucleate-boiling heat-transfer measurements were made with aqueous thorium oxide slurries containing up to 1000 g. of Th/kg. of H_2O (0.105 volume fraction of solids, 1-3- μavg. diam). Boiling took place from the surface of $\frac{1}{16}$-and $\frac{1}{8}$-in.-diam. platinum tubes submerged in slurry. For the slurries studied, the heat flux at a ΔT of 10°F was about 10^4 Btu/(hr) (sq ft) regardless of slurry concentration. However, the value of the exponent of the (ΔT) term, n, decreased as the volume fraction of solids was increased. The value of n was 3.3 with no thorium oxide present and approached unity at a volume fraction of solids of 0.10.

The maximum heat flux attainable under nucleate-boiling conditions (often called the critical heat flux or burnout heat flux) at slurry concentrations of 200 g of Th/kg of H_2O was about the same as for water. However, at a concentration of 1000 g of Th/kg of H_2O, the average burnout heat flux was 210,000 Btu/(hr)(sq ft) compared with a value of 490,000 Btu/(hr)(sq ft) for water under corresponding conditions.

At a constant heat flux, the temperature difference between the heated tube surface and the fluid saturation temperature increased 5 to 6°F/hr. This result might be explained by a "soft" film that surrounds the heated-metal surface. This film was apparently less than $\frac{1}{32}$ in. thick and was never distinguishable as an adhering film after the tube was removed from the slurry system. No hard cakes were observed on the surface from which boiling took place during any of the tests.

The nucleate-boiling tests were made with aqueous thorium oxide slurries which had non-Newtonian laminar-flow characteristics and which were almost Newtonian under turbulent-flow conditions. No phenomena were observed which could be attributed to the effect of the solid particles on the gross physical properties of the slurry; for example, the non-Newtonian laminar-flow characteristics of the slurry had no discernible effect on the nucleate-boiling heat transfer.

1775. Van Stralen, S. J. D.

HEAT TRANSFER TO BOILING BINARY LIQUID MIXTURES AT ATMOSPHERIC AND SUBATMOSPHERIC PRESSURES, Chemical Engineering Science 5, 290-6 (1956).

The heat flux from an electrically heated horizontal platinum wire to water, to methylethylketone and to an aqueous mixture containing 4.1% wt of methylethylketone was determined throughout the ranges of convection and nucleate boiling, both at atmospheric pressure and at a pressure of 42 cm Hg. A general shift of the curves to lower heat transfer occurred with decreasing pressure, as a consequence of the

increasing average size of vapour bubbles, generated on the heating surface. The maximum in nucleate boiling heat flux to the 4.1% mixture exceeded considerably the corresponding value in water at both pressures investigated. Maximum heat flux in nucleate boiling has been determined systematically as a function of concentration in a range of concentrations with water in excess, for mixtures of water and methylethylketone, acetone and the lower aliphatic alcohols respectively at several subatmospheric pressures. In all mixtures a maximum value of the maximum heat flux occurred at a certain low concentration of organic component, which was approximately independent on pressure. The ratio of these maxima to the maximum value in water at the same pressure decreased with decreasing pressure.

1776. Van Stralen, S. J. D.

HEAT TRANSFER TO BOILING BINARY LIQUID MIXTURES, Brit. Chem. Eng. 4, No. 1, 8-17; No. 2, 78-82 (1959).

Influence of concentration upon maximum nucleate boiling heat flux investigated at sub-atmospheric and atmospheric and higher pressures for aqueous binary mixtures of M E K, acetone and lower aliphatic alcohols; outline of experimental procedures and equipment; results show in all systems investigated maximum value in maximum nucleate boiling heat flux occurred at certain low concentration of most volatile component.

1777. Van Stralen, S. J. D.

HEAT TRANSFER TO BOILING BINARY LIQUID MIXTURES. IV., Brit. Chem. Eng. 7, 90-7 (1962).

In a survey of conditions affecting convection and nucleate boiling regions of the boiling curve, the effects of subcooling and pressure are discussed, together with the behavior of the peak flux in nucleate boiling. The peak flux is detd. for H_2O and, at pressures above 50 atm., for the binary systems H_2O-EtOH, H_2O-PrOH, H_2O-BuOH, H_2O-1-pentanol, and H_2O-MeCOEt. The abs. values and the ratio of the max. peak flux in mixts. to the peak flux in H_2O at the same pressure and equal subcooling decrease gradually with increasing pressures. A discussion is included of the possible practical ulilization of liquid mixts. as cooling media in nuclear power reactors. 32 references. Cf. ibid. 6, 834 (1961);(CA 54, 984b)

1778. Van Wijk, W. R., Vos, A. S., and Van Stralen, S. J. D.

HEAT TRANSFER TO BOILING BINARY LIQUID MIXTURES, Chem. Eng. Sci. 5, 68-80 (1956).

Heat transfer in boiling liquid mixts. of water and MeEt ketone has been measured over the range of convection and nucleate boiling. Higher heat fluxes are found for the mixt. than for either pure component. The same effect was found for mixts. of dioxane-methanol and 2-chloroethanol-diisopropyl ether. In all cases observed the size of the bubbles was a min. at the max. heat flux. Qualitatively the max. heat flux is explained by the dew point of the vapor formed by flash vaporization being somewhat higher than the b.p. of the liquid mass. Thus, the vapor bubble does not grow by volatilization from the surrounding liquid since that liquid, even though superheated with respect to the compn. as a whole, is not superheated with respect to the bubble of vapor formed by flashing.

1779. Van Wijk, W. R., and Van Stralen, S. J. D.

HEAT TRANSFER TO BINARY LIQUID MIXTURES BOILING UNDER PRESSURES FROM 0.1 TO 50 ATMOSPHERES, Dechema Monograph, 32, 94-106 (1959).

The max. flux for nucleate boiling is highest at minimum bubble size. This occurs at $\Delta\tau = \delta - \Delta T = 0$; δ is superheat of liquid above the b.p. (T) of the liquid. ΔT is the difference between the dew point of the vapor bubbles and T, and $\Delta\tau$ is the superheat at the liquid with reference to the dew point. A graphical method on the equil. diagram, based on assuming that δ is const. for each system and pressure, and that ΔT varies only with concn. at small fractions vaporized at the heating surface, correctly predicts the concn. of the more volatile liquid in the mixt. for highest max. flux. Data are plotted for systems of H_2O with: ethanol, 1-pentanol, 1-butanol, 1-propanol, acetone, methylethylketone, and NH_3 at several pressures.

1780. Vos, A. S.

HEAT TRANSFER TO BOILING BINARY LIQUID MIXTURES, Ingenieur (Utrecht) 68, No. 17, C9-13 (1956).

The binary systems studied comprise H_2O and MeOH, EtOH, BuOH, tert-BuOH, $C_5H_{11}OH$, $C_8H_{17}OH$, Me_2CO and MeEtCO, and dioxane-MeOH and 2-chloroethanol-diisopropyl ether. Heat flux as a function of the temp. difference between heating surface and boiling liquid mixts. was detd. throughout the whole range of convection until the max. of nucleate boiling. In some mixts. at certain concn. a considerably higher max. heat flux was obtained than with water, at about the same temp. of the heating surface as for water. Alternatively, in mixts. the same max. heat flux as for water was obtained at a lower surface temp. A max. of 3.5 times the value for water was observed. At the max. of max. heat flux the size of the bubbles leaving the heating surface was considerably smaller. An attempt was made for a preliminary explanation of the phenomenon.

1781. Vos, A. S., and Van Stralen, S. J. D.

HEAT TRANSFER TO BOILING WATER-METHYL ETHYL KETONE MIXTURES, Chem. Eng. Sci., 5, 50-6 (1956).

Heat transfer in mixtures of water and methylethylketone has been measured throughout ranges of convection and nucleate boiling at atmospheric pressure (43); for mixtures of water with acetone, methylethylketone, lower aliphatic alcohols and ethyleneglycol respectively, maximum heat flux in nucleate boiling has been studied as function of concentration.

CRITICAL FLOW

1782. Agostinelli, A., and Salemann, V.

PREDICTION OF FLASHING WATER FLOW THROUGH FINE ANNULAR CLEARANCES, Trans. Am. Soc. Mech. Engrs., 80, 1138-1142 (1958).

Study of flow of flashing mixture of water and steam through smooth annuli; test data obtained with inlet conditions to 600°F and 3000 psi; critical conditions observed experimentally up to these limits; method for prediction of flow and 2-phase pressure drop; applicability to solution of problems relating to pressure breakdown devices encountered in turbomachinery design.

1783. Allen, W. F.

FLOW OF FLASHING MIXTURE OF WATER AND STEAM THROUGH PIPES AND VALVES, Trans. Am. Soc. Mech. Engrs., 73, 257 (1951).

A simple method is presented of designing piping and valves, particularly heater drain piping, to carry a flashing mixture of water and steam. Rational design formulas are derived from the energy, continuity, and dynamic equations on the basis of an assumed uniform mixture at any point in the path of flow. A scheme is suggested for eliminating flashing completely in heater drain systems employing drain coolers.

1784. Benjamin, M. W., and Miller, J. G.

FLOW OF FLASHING MIXTURE OF WATER AND STEAM THROUGH PIPES, Transactions of the American Society of Mechanical Engineers 64, 657-669 (1942).

A flow formula based on a thermodynamical analysis of the problem and test data is developed, and a method for designing piping to carry a flashing mixture outlined.

1785. Da Cruz, A. J. R.

CRITICAL DISCHARGES OF STEAM-WATER MIXTURES, M.S. Thesis, University of Minnesota, Minneapolis (1953).

1786. Faletti, D. W.

TWO-PHASE CRITICAL FLOW OF STEAM-WATER MIXTURES, Ph.D. Thesis, Univ. of Washington (1959).

1787. Fauske, H.

CRITICAL TWO PHASE, STEAM-WATER FLOWS, Proc. 1961 Heat Trans. and Fluid Mech. Inst. p. 79 ff (1961).

Critical two-phase, steam-water flows have been measured over a range of quality from 0.01 to 1.0, total flows from 500 to 4200 lb/sec-ft^2 pressures from 40 to 360 psia, and with pipe diameters of 0.125, 0.269 and 0.5 inches (ID). A theory has been developed for the two-phase critical flow phenomenon, and extensive comparisons of predicted with experimental values show substantial agreement.

1788. Fauske, Hans K.

CONTRIBUTION TO THE THEORY OF TWO-PHASE, ONE-COMPONENT CRITICAL FLOW, N63-11025, ANL-6633 (Oct. 1962).

A study is made of two-phase, one-component critical flow. Theoretical expressions for the specific volume, void fraction, and slip ratio for critical steam-water mixtures are derived. The pressure profiles for runs at critical flow were all characterized by extremely steep pressure gradients near the throat. The pressure gradients are definitely finite and approach absolute maximum values. These values depend only upon critical flow rate and quality. Sonic velocities are not achieved in critical two-phase flow of steam-water mixtures. The "Homogeneous Flow Model" was found to be unsatisfactory for all critical throat pressures and qualities examined. The assumption of no slip between the phases, therefore, can be said to be definitely incorrect. The theory presented is highly valuable in determining the maximum discharge of steam-water mixtures from conduits and breaks in vessels and pipes.

1789. Firey, J. C., and Moulton, R. W.

PRESSURE DROP AND CRITICAL FLOW FOR STEAM-WATER MIXTURES, HW-47681 (Jan. 1957), 25 p.

When a steam-water mixture flows through a pipe, the liquid flows slower than the vapor since the denser liquid is less accelerated by the pressure gradient. This type of flow is termed slip flow. A general solution of the mathematical relations for slip flow appears difficult to accomplish and an improvement or extension of the empirical pressure drop analysis, developed by Martinelli, is proposed. When the flow in a passage no longer increases with a decrease of back pressure, critical flow exists. This effect can be attributed to the inability of any wave of pressure decrease to propagate upstream when flow velocity equals acoustic velocity. At the very high rates of expansion of critical flow, thermodynamic equilibrium is not maintained in steam-water mixtures. The resulting metastable expansion greatly increases the rate of flow over the equilibrium flow. Various degrees of metastability may occur and it does not appear always possible to reliably predict the extent of metastability.

1790. Haubenreich, P. N.

FLOW OF A FLASHING MIXTURE OF WATER AND STEAM AT HIGH PRESSURES, CF-55-5-200 (1955), 94 p.

Unsteady flow of a flashing mixture of water and steam under saturation pressures as high as 1250 psia was studied for valve and pipe designing. Pressure drop and mass flow rate data were analyzed to determine friction factors for pipes. Properties for constant enthalpy expansion are sufficiently accurate for calculating flow rates and pressure drops. Tables of properties of water expanded isenthalpically from saturated liquid at several pressures are included.

1791. Isbin, H. S., Moy, J. E., and Cruz, A. J. R.

TWO-PHASE, STEAM-WATER CRITICAL FLOW, AIChE Journal, 3, 361-365 (1957).

Two-phase critical flow of steam-water mixtures has been investigated over a pressure range from 4 to 43 lb/sq. in. abs. and a quality range from saturated vapor to 1% (weight) vapor. Discharges were measured from $\frac{1}{4}$-, $\frac{1}{2}$-, $\frac{3}{4}$-, and 1-in. pipes and from annuli of intermediate cross sectional areas. The experimental mass flow rates are always greater than the values calculated on the basis of a homogeneous flow model. Several empirical methods for correlating the data were determined, and comparisons are presented of the predictions of several analytical flow models.

1792. Isbin, H. S., and Fauske, H.

CRITICAL TWO-PHASE, STEAM-WATER FLOWS, TID-11061, (1961), 34 p.

Critical two-phase, steam-water flows were measured over a range of quality from 0.01 to 1.0, total flows from 500 to 4200 lb/sec-sq ft, pressures from 40 to 360 psia, and pipe diameters of 0.269, 0.125, and 0.5 in. inside diameter. A theory was developed for the two-phase critical flow phenomenon, and extensive comparisons of predicted with experimental values show substantial agreement.

1793. Isbin, H. S., et al.

TWO-PHASE, STEAM-WATER PRESSURE DROPS FOR CRITICAL FLOWS, Paper No. 10, Symposium (Preprint or Proceedings) on Two-Phase Fluid Flow, Inst. Mech. Engrs., London, England, February 7, 1962.

This paper is concerned with the presentation and analysis of two-phase, steam-water pressure drop data for very high mass flow rates. The relative proportions of the total static pressure drop that are assigned to the momentum and frictional losses change as the flow mixture accelerates to critical flow at the end of the test sections. Models used to interpret the momentum and frictional losses were found to be inadequate.

1794. Ishigai, S., and Sekoguchi, K.

ON THE FLASHING FLOW OF SATURATED WATER, Trans. Japan. Soc. Mech. Engrs., 2, 563-568 (1959).

1795. James, R.

STEAM-WATER CRITICAL FLOW THROUGH PIPES, Preprint of Thermodynamics and Fluid Mechanics Group, The Inst. of Mech. Eng., June (1962).

1796. Linning, D. L.

ADIABATIC FLOW OF EVAPORATING FLUIDS IN PIPES OF UNIFORM BORE, Proceedings of the Institution of Mechanical Engineers, London, (B) 18 No. 2, 64-75 (1952).

A theoretical investigation of the adiabatic flow of evaporating fluids in pipes is supported by experiments with water. It is postulated, on the basis of published data, that an evaporating fluid flow will conform to one of three modes: annular, separated, and frothing. Starting from assumptions usually made on the subject of fluid flow, theory is developed which enables the mean liquid and vapor velocities and also the associated critical outlet conditions to be calculated. A chart is provided relating initial pressure, critical outlet pressure, and mass flow per unit area, over a range of initial pressures from 8 to 100 lbs/sq in. absolute for water.
F.A. 13, No. 3, 120 (1953)

1797. Massena, W. A.

STEAM-WATER CRITICAL FLOW USING THE SEPARATED FLOW MODEL, HW 65739 (June 30, 1960).

A comparison of the critical mass velocity for steam-water mixtures as calculated by the homogeneous flow model and by the separated flow model is presented. Experimental data are included to demonstrate the agreement of results with those predicted by the separated flow model.
(NSA-62-31792)

1798. Moy, J. E.

CRITICAL DISCHARGES OF STEAM-WATER MIXTURES, M.S. Thesis, Univ. of Minnesota (1955).

1799. Muraoka, J.

STEAM-WATER CRITICAL FLOW TEST-DESIGN TEST 1040, HW-69488 (1961).

1800. Nahavandi, A. N., Rashevsky, M. P.

A DIGITAL COMPUTER PROGRAM FOR CRITICAL FLOW DISCHARGE OF TWO-PHASE STEAM-WATER MIXTURES, CVNA-128 (Feb. 1962).

The available theories for the prediction of critical flow discharge of two-phase mixtures are reviewed. The theories discussed are, homogeneous model theory, annular flow theory and Fauske's theory. A FORTRAN program for an IBM-7090 digital computer, for the application of these theories to the flashing flow of steam-water mixtures, is developed. Critical mass flow velocities for a wide range of pressures and steam qualities are calculated and compared. A critical flow discharge chart, based on Fauske's theory for steam-water mixtures, is presented. A simple empirical formula for the prediction of critical flow discharge is proposed. This formula is useful in preparing computer programs involving two-phase critical flow.

1801. Pattie, B. D.

TWO-PHASE FLOW, CRITICAL DISCHARGES AND VOID FRACTIONS, M.S. Thesis, Univ. of Minnesota, (1957).

1802. Ros, N. C. J.

ANALYSIS OF CRITICAL SIMULTANEOUS GAS/LIQUID FLOW THROUGH RESTRICTION AND ITS APPLICATION TO FLOWMETERING, Applied Sci. Research, A 9, 374-88 (1960).

Theoretical analysis of mechanism of simultaneous flow of gas and liquid through restriction at critical speed; study shows that relationship exists between

mass flows of gas and liquid, restriction size, and upstream pressure; comparison of relationship with measurements showed reasonable agreement; it has been concluded that restriction can be used as gas/liquid flow meter with reasonably high accuracy, provided flow is critical one.

1803. Waters, E. D.

METHODS FOR INVESTIGATING CRITICAL DISCHARGE PHENOMENA WITH SATURATED WATER, HW-56946 (1958), 23 p.

Experimental procedures and techniques are described which allow the convenient determination of the point at which critical flow occurs with saturated water in a piping assembly. Values of upstream pressure, temperature, and the maximum discharge flow rate were investigated using these procedures. Some data are presented in examples which illustrate the techniques. The significance of the critical flow phenomenon is discussed when it occurs in the piping of a nuclear reactor. Also discussed is the effectiveness of temperature monitoring elements located in or near the region of critical flow.

1804. Zaloudek, F. R.

THE LOW PRESSURE CRITICAL DISCHARGE OF STEAM-WATER MIXTURES FROM PIPES, HW-68934 Rev (1961), 46 p.

An apparatus was constructed to investigate the critical flow behavior of steam-water mixtures flowing in passages of constant area. Experiments were limited to circular full-bore cross sections of 0.520- and 0.625-inch diameter, and lengths up to 4 feet. Test section exit qualities from 0.4 to 99% and critical mass velocities between 10^2 and 10^3 lb/sec ft^2 were investigated. Corresponding critical pressures ranged from 40 to 110 psia. To facilitate the direct application of the experimental data to the solution of practical problems, the results were correlated by employing the conventional technique of comparing results with theoretical predictions of the homogeneous-flow model. It was found that the correlation could be divided into three distinct parts. At qualities above 20% where an annular or dispersed flow apparently existed, the critical-mass velocity ratio (G_{ob}/G_c) was found to be dependent only on bulk quality of the mixture and relatively independent of the critical pressure and diameter of the test section. In this quality region, the correlation could be expressed by the relation $1 - (G_c/G_{ob}) = 0.556\text{-}0.420x$. At qualities below 20%, a strong dependency of the critical-mass velocity ratio on the critical pressure was detected. A high critical pressure was generally accompanied by a lower G_{ob}/G_c ratio than that accompanying a lower critical pressure. The critical-mass velocity ratio was apparently independent of the test-section diameter. For qualities below 2% the critical-mass velocity ratio increased tremendously with decreasing quality with values as high as 5.8 occurred at approximately 0.5% quality. In comparing the results with those obtained in similar investigations, it was found that critical-mass velocity ratios were considerably greater than the widely used experimental values obtained by Isbin, Moy, and DaCruz, whose results have come into wide use in design and analysis calculations. However, they do compare favorably over a large range of qualities with a recent work by Faletti. The deviation between the present work and that of Isbin, Moy, and DaCruz was attributed, in part, to the latter's method of experimentation.

CRITICAL HEAT FLUX (BURNOUT)

1805. Alad'ev, I. T., Dodonov, L. D., and Udalov, V. S.

CRITICAL HEAT FLUXES FOR WATER FLOWING IN TUBES, J. Nucl. Energy, Part B. Reactor Tech. 1, 181-5 (March 1960).

1806. Alad'ev, I. T., et al.

BOILING CRISIS IN TUBES, International Developments in Heat Transfer. Part II., New York, The American Society of Mechanical Engineers, p. 237-43 (1961).

Experimental data were obtained for critical heat fluxes in stainless-steel tubes heated by low-voltage current. The effects of heat flux distribution around the channel perimeter and along its length, the geometrical dimensions of the channel heated, and the compressibility of the medium in the section preceding the experimental one were determined. The flow was of subcooled water and steam-water mixtures. The critical heat flux increased with increasing velocity and subcooling at all pressures.

1807. Alad'yev, I. T., et al.

CRITICAL BOILING IN TUBES, Teploperedacha, Energ. inst. AN SSSR. Ed. by M. A. Mikheyev., Moscow, Izd-vo AN SSSR, 1962, 124-143.

A good many critical boiling tests have been made in recent years, usually whilst water is being pumped through an electrically heated stainless steel pipe. It is usually considered that the critical heat transfer rate is uniquely determined by the pressure, rate of flow and the enthalpy of the medium at the place of other factors, such as the distribution of heat flow over the perimeter and length of the pipe, the dimensions of the test length and of neighbouring parts of the system and the compressibility of the fluid in neighbouring spaces are filled with compressible substances, whereas if neighbouring spaces are filled with incompressible substances pulsations do not develop. Pulsating conditions are the least favourable and they must often by suppressed. It sometimes does not suffice to fit a resistance between the expansion vessel and the heated pipe. If the internal diameter of the test pipe is reduced from 8 to 3 mm there is some increase in the critical heat transfer rate. The length of the test piece can have various effects depending upon the flow conditions, particularly when pulsation is present. The thickness of the duct walls (0.4 and 2 mm respectively) and the roughness of the inner surface (even 0.12 to 0.15 mm deep transverse grooves) had little influence on the critical heat flow. The effects of increasing the pressure, the rate of flow and the enthalpy of the fluid in increasing the critical heat transfer rate are discussed. Experimental work on determination of critical heat transfer rates during the flow of water and steam/water mixtures in pipes

is briefly reviewed. Although several methods of generalizing experimental results have been proposed in the USSR the empirical formulae are complicated and often contain numerous empirical constants. Reliable generalizations will only be possible when the actual mechanism and physical laws of critical bubble-wise boiling are understood, which is not yet the case. There are 7 figures.

1808. Anderson, J. K., Waters, E. D., and Batch, J. M.

EXPERIMENTAL OBSERVATIONS OF UPSTREAM BOILING BURNOUT, HW 73902 (June 1, 1962).

Boiling burnout conditions are usually postulated and observed to occur at the outlet end of uniformly heated test sections. However, during experiments with flow through a 12-ft cylindrical test section, boiling burnout conditions were sometimes observed to begin at various upstream locations. These conditions were observed at mass velocities of 5.0×10^6 lb/hr-ft^2 and higher, but not at lower mass velocities. Local qualities for upstream burnout were 10 to 30 wt % at a pressure of 1500 psig. Similar results were obtained with both vertical and horizontal test section positioning. In some experiments the heat flux was increased beyond the initial detection of boiling burnout (film boiling), allowing the film boiling condition to spread along the test section. It was found that the temperature excursion which was experienced in going from nucleate to film boiling conditions was greater as the film boiling condition moved upstream to lower quality regions. Heat fluxes with upstream burnout were generally higher than those for downstream burnout with comparable enthalpies. Also, the upstream burnout cases resulted in conditions at the test section outlet which were at much higher heat fluxes than those which might have been expected to produce burnout. (NSA-62-31793)

1809. Audette, R. F.

BURNOUT PROTECTION REQUIREMENTS AND PRELIMINARY BURNOUT PROTECTION SYSTEM DESIGN, NAA-SR-MEMO-4469 (1959), 13 p.

Tests were conducted to determine the time required to develop a rupture (burnout) in an AOMR tubular test section once burnout conditions are established. Preliminary designs of a protection system based on these data are included. (NSA-14-11720)

1810. Babcock and Wilcox Co., Atomic Energy Division.

REACTOR STUDIES-FINAL REPORT, Part I, TID-10117 (1955), 169 p.

. . . Burnout Heat Flux Studies. Available data on light H_2O burnout data in the region of net steam generation are evaluated. Results show that burnout heat flux increases with increased entrance subcooling, burnout heat flux increases with increased mass flow rate, and burnout heat flux decreases with increased pressure at the higher mass flow rates but reaches a maximum at about 1200 psia for lower flow rates. . .

1811. Baumeister, E.

CALCULATED BURNOUT HEAT FLUXES FOR SANTOWAX-R, NAA-SR-MEMO-3860 (1959), 8 p.

Studies were made to determine burnout heat fluxes for Santowax-R at various pressures, bulk temperature, Reynolds numbers, and high boiler compound. Plots of the burnout heat flux for Santowax-R are given. These values were obtained using the lower limit of the Griffith correlation.

1812. Becker, K. M.

BURNOUT CONDITIONS FOR FLOW OF BOILING WATER IN VERTICAL ROD CLUSTERS, Aktiebolaget Atomenergi, AE-74 (1962).

1813. Bell, D. W.

CORRELATION OF BURNOUT HEAT FLUX DATA AT 2000 PSIA, Nuclear Sci and Eng. 7, 245-51 (1960).

A correlation for burnout heat flux was developed for upflow of water in vertical rectangular channels at 2000 psia. While most of the existing burnout correlations predict that for a constant fluid enthalpy at the burnout point, the burnout heat flux increases with an increase in mass velocity, the proposed correlation exhibits at maximum in this function. The mass velocity at which this maximum occurs decreases with increasing fluid enthalpy. The correlation model was developed from graphical inspection of the available data.

1814. Bendler, A. J.

REVIEW OF UNDERWATER BURNOUTS OF 2S ALUMINUM ELECTRICALLY OVERHEATED, CU-11-53-At-dP-Ch.E. (Rev.) (1953), 14 p.

Underwater arcing and melting failures of electrically overheated 2S aluminum, which have occurred during tests at Columbia University, are discussed with reference to phenomena accompanying the failures, in search of evidence indicating the chemical reactivity between high temperature aluminum and water. Discussion of the evidence, which includes macro- and micro-graphs, leads to the conclusion that even at temperatures as high as the melting and arcing points and in the presence of liquid water or steam, aluminum does not react readily with water.

1815. Bennett, A. W.

HEAT TRANSFER TO MIXTURES OF HIGH PRESSURE STEAM AND WATER IN AN ANNULUS. PART II. THE EFFECT OF STEAM QUALITY AND MASS VELOCITY ON THE BURNOUT HEAT FLUX FOR AN INTERNALLY HEATED UNIT AT 1000 PSIA, AERE R-3804 (1961).

1816. Bergles, A. E., and Rohsenow, W. M.

FORCED CONVECTION SURFACE BOILING HEAT TRANSFER AND BURNOUT IN TUBES OF SMALL DIAMETER, Technical Report No. 8767-21, NP-11831 (1962), 149 p.

A basic heat-transfer apparatus was designed and constructed for the study of forced-convection boiling in small channels. The various regions of

forced-convection surface boiling were studied experimentally and analytically. In the region of low wall superheat, the heat flux can be predicted by available correlations for forced convection. Data indicate, however, that these correlations do not properly account for the radial variation of properties for water at high temperature difference. The conventional Dittus and Boelter-McAdams relationship is recommended for design purposes on the basis of its simplicity and conservative predictions.

1817. Berkowitz, L., et al.

RESULTS OF WET STEAM COOLING EXPERIMENTS: PRESSURE DROP, HEAT TRANSFER AND BURNOUT MEASUREMENTS WITH ROUND TUBES, EURAEC-42 (1960), Special Report No. 2 (CAN-1) Work performed under U. S. Euratom Joint Research and Development Program, 248 p. (R-27).

Data obtained with the Piacenza heat transfer facility are presented. The facility and experimental procedure are described. The computer Olivetti Elea 9002 was used for calculation of quantities of interest starting from experimental data. The range of the experiments included geometry, absolute pressure, specific mass flow rate, and quality. Burnout, pressure oscillations, and uncertainties due to singular sources of errors are discussed. Data are presented in tables and graphs.

1818. Bernath, L.

PREDICTION OF HEAT TRANSFER BURNOUT, Chem. Eng. Prog. Sym. Ser, 52 No. 18 (1956).

The output of a nuclear reactor or other equipment in which heat transfer plays a major role frequently is limited by the heat-flux density at which the equipment is operated. Raising the heat-flux density increases the output but also may produce burnout or melting of the element across which heat is flowing. Although the cause of burnout has been understood for some years, to date no general method has been advanced to describe quantitatively the conditions under which burnout occurs. This paper presents a generalized correlation that predicts the burnout condition over a wide range of pressures, velocities, geometrical configurations, and heat-flux densities but is limited to the local boiling regime for range of experimental reproducibility. In addition, the relation between the local burnout heat flux and the over-all operating conditions of the equipment is developed. This permits the direct calculation of the burnout heat load (power) from the inlet flow and temperature conditions and the geometry of the equipment.

1819. Bernath, L.

EXTENSION OF THE METHOD OF BURNOUT PREDICTION, AECU-3901 (1958), 10 p.

The method of prediction of burnout heat flux with local boiling was extended to include geometries from the confined, forced-flow systems of the original method to pool boiling, natural circulation conditions. A new formula for the limiting (ultimate) heat transfer coefficient is presented and is shown to correspond closely to the former expression for comparable geometric configurations. Heat fluxes at burnout predicted by the new formula are compared with experimental values used in the original method and with more recent data. The agreement between predicted and experimental heat fluxes is illustrated. 50% of the data are predicted within 11.5% by the method.

1820. Bernath, L., and Begell, W.

FORCED CONVECTION, LOCAL BOILING HEAT TRANSFER IN NARROW ANNULI, Chemical Engineering Progress Symposium Ser. 55, No. 29, 59-65 (1959).

Heat transfer data in the region of fully developed local boiling have been collected, analyzed, and correlated. The results of this analysis permit the prediction of the wall superheat for the range of the variables studied. A proposed local boiling film concept is shown to agree with experimental observations.

1821. Bernath, L.

A THEORY OF LOCAL BOILING BURNOUT AND ITS APPLICATION TO EXISTING DATA, Chem. Eng. Prog. Sym. Ser., 56, No. 30, 95-116 (1960).

A theory of local-boiling burnout is presented based on an analogy between the microconvective processes in local boiling and the conventional approach to turbulent diffusion processes. This theory describes, in a plausible manner, the physical significance of the mathematical relationships evolved in an empirical method of prediction of the burnout heat flux for water with local boiling over a wide range of experimental conditions. The prediction method is generalized to liquids other than water. Available data are assembled and discussed, and the results of the prediction method are compared with experimental values.

1822. Bertolotti, G., et al.

A FACILITY USED FOR WET STEAM COOLING EXPERIMENTS: PRESSURE DROP, HEAT TRANSFER AND BURNOUT, CISE-64 (1959), 45 p.

A facility has been designed and built to study the behavior of wet steam. In the facility it is possible to measure pressure drop, maximum (burnout) heat fluxes, and heat transfer coefficients in cylindrical ducts of different geometry for steam-water mixture upward flow at various steam concentrations.

1823. Bobrovich, G. I., et al.

CRITICAL HEAT FLUX IN THE BOILING OF BINARY MIXTURES, Zhurnal prikladoy mekhaniki i tekhnicheskoy fiziki, no. 4, 1962, 108-111.

The work of W. R. Wijk et al. (Ref. 2: Chem. Eng. Sci. 1956, vol. 5) is discussed. A detailed description of the experimental apparatus and methods of measuring the critical heat flux in boiling binary mixtures is given. The critical heat flux for a mixture of water and butyl-alcohol reached its maximum at a concentration of 15-20% alcohol, and the absolute value of the flux is of the same order of magnitude as for pure water. The minimum is reached at

a concentration of 2-3% alcohol. A mixture of water and ethyl alcohol gave similar results. An increase of pressure reduces the effect of the alcohol concentration on boiling. The results are plotted as heat flux versus temperature diagrams, with pressure as a parameter. There are 4 figures.

1824. Booth, M.

BEHAVIOR OF WATER MODERATED REACTORS DURING RAPID TRANSIENTS, In Boiling Burnout Progress. (Issue) No. 8., Viscardi, John E., NDA-24 (p. 29) (1956), 51 p.

The latest experimental results on boiling and related phenomena are reported and discussed. Burnout, maximum heat transfer rates, frequency and formation characteristics of bubbles and vapor films, influence of element shape and surface properties, role of impurities, dissolved gases and pH values, temperature and density distributions, pressure drops, instability corrosion, cavitation, and metal-water reactions are among the topics treated.

1825. Borshanskii, V. M., et al.

EFFECT OF THE RATE OF FLOW ON THE CRITICAL DENSITY OF HEAT FLOW DURING THE BOILING OF WATER, Energomashinostroenie 3 No. 2, 10 (February 1957).

1826. Bõswirth, L.

TRANSITION FROM BUBBLE TO FILM EVAPORATION (BURNOUT), Atomkernenergie, vol. 6, No. 3, 93-8 (Mar. 1961).

With the aid of the impulse pressure which the quickly emerging steam exerts on the steam-water interface, a graphical model for the passage from bubble to film evaporation is given. Formulae for the critical heat flux are derived, and the influence of various parameters is discussed. The formulae are valid for all fluids and are, as far as this can be expected, in good accordance with test results. It is shown in particular that the Cichelli-Bonilla law for the pressure dependence of the critical heat flux of organic fluids can be proven from the formulae derived. With simplifying assumptions, a relationship is derived from which the pressure dependence of the critical heat flux can be calculated, to about one third of the critical pressure. (SA 62-7464)

1827. Bowring, R. W., Roberts, H. A., and Scott, R. W.

BURNOUT IN HIGH PRESSURE WATER, AN APPRECIATION OF RECENT AMERICAN CORRELATIONS, AERE-R/R-2493 (1958), 29 p.

The present position of burnout heat flux in water at 2000 psia is critically examined with regard to the requirements of a pressurized water reactor. The equation of Jens and Lottes for subcooled water, Westinghouse equations for the equality region, and recommendations of a committee at the Westinghouse Bettis plant are discussed.

1828. Bragg, S. L., and Smith, I. E.

DIMENSIONAL ANALYSIS OF BURNOUT HEAT TRANSFER, Intern. J. Heat and Mass Transfer, 3: 252-3 (1961).

The burnout heat transfer rate equation is derived and explained. The explanation is given in terms of the frequency of bubble shedding and the instability of two-phase flow. A physical explanation of the form of the equation is that bubbles break away from the surface as soon as the buoyancy forces are greater than the surface tension forces holding them on; and that burn-out occurs when the buoyant acceleration of the bubbles away from the surface is no longer great enough to keep the bubbles clear of their successors.

1829. Buchberg, H., et al.

HEAT TRANSFER, PRESSURE DROP, AND BURNOUT STUDIES WITH AND WITHOUT SURFACE BOILING FOR DEAERATED AND GASSED WATER AT ELEVATED PRESSURES IN A FORCED FLOW SYSTEM, p. 177-191 in HEAT TRANSFER and FLUID MECHANICS INSTITUTE, Preprints of Papers, Stanford University Press, Stanford, Calif. (1951).

1830. Chang, Y. P.

HEAT TRANSFER AND CRITICAL CONDITIONS IN NUCLEATE BOILING OF SUBCOOLED AND FLOWING LIQUIDS, TID-6045 (1960), 45 p.

The heat transfer and the critical conditions in boiling of subcooled liquids with forced convection are considered. Both ordinary liquids ($100 > Pr > 0.5$) and liquid metals ($Pr < 0.1$) are considered as the heat transfer media. By introducing an equivalent thermal diffusivity, a general equation is obtained, valid from simple forced convection to the critical heat flux of nucleate boiling. When the condition approaches that of critical heat flux, the latent heat transport becomes significant. Through the application again of an equivalent thermal diffusivity and of a wave concept, the critical heat flux is determined. Comparing the result with that obtained from the mechanism of bubble agitation yields the critical superheat. Since the critical heat flux is considered as a problem of hydrodynamic stability and is investigated with respect to the local conditions, it does not depend on the orientation, the form and the dimension of the heater, but depends only on the subcooling, the velocity of flow, and the properties of the liquid. Pressure affects the values of the physical properties, and therefore, does not appear as a parameter.

1831. Chang, Y. P.

FINAL REPORT-SECTION 1. AN ANALYSIS OF THE CRITICAL CONDITIONS AND BURNOUT IN BOILING HEAT TRANSFER. PART I. CRITICAL CONDITIONS. PART II. CRITICAL HEAT FLUXES. July 1961. SECTION 2. A CORRELATION OF BOILING HEAT TRANSFER FROM THE NUCLEATION THEORY-INCLUDING EFFECTS OF SYSTEM ACCELERATION AND FORCED CONVECTION, TID-14004 (1961), 120 p.

Certain basic ideas were applied to boiling heat transfer from which several critical conditions were

derived and an equation of the maximum heat flux in nuclear boiling was obtained. The heat transfer was considered as being limited by the maximum rate of bubble generation from a unit area of the heating surface. Heat transfer in nucleate boiling with and without forced convection and subcooling was also studied. With an empirical modification of the nucleation theory as developed by Volmer and Eyring from the Maxwell-Boltzmann distribution law, an equation was obtained for heat transfer in vigorous boiling. Validity of this equation was tested for 18 different systems under different pressures.

1832. Chirkin, V. S., and Yukin, V. P.

CRITICAL CONDITIONS OF HEAT REMOVAL IN A FLOW OF NON BOILING WATER FOR AN ANNULAR SPACE, (Krizis teplos"yema v potoke nekipyashchey vody dlya kol'tsevogo zazora), ZhTF, Nr 7, 1956.

1833. Chirkin, V. S., and Iukin, F. P.

CRITICAL POINT IN HEAT REMOVAL FROM BOILING WATER FLOWING THROUGH AN ANNULAR GAP, Soviet Physics (Technical Physics) 1, 1503-15 (1956).

The results of the experimental determination of the magnitude of the critical heat flow q in cooling by non-boiling water are presented; q corresponds to the formation of a vapor film between the cooled solid surface and the flow of fluid. In the experiments, the magnitude of the critical heat flow was determined by the conditions at the point of critical heat removal, corresponding to the transition for active boiling in the boundary layer of film boiling. Two experimental setups were used, and these are schematically illustrated. Special emphasis is placed on the arrangement of the working area, the design of equipment used to distinguish pressures, and the construction of the heat-emitting element. The methods of measurement and calculation of experimental quantities are described, and possible errors in their determination are evaluated. In the experiments a regulated transformer was used to increase uniformly the voltage and current in the heat-emitting element. At the critical point of heat removal, the heat emitter usually burned out and an open circuit occurred: the desired quantities were measured at that time. The experimental data are presented in the form of graphs and tables, the analysis of which yields empirical relationships determining the dependence of q on the velocity of the non-boiling water at the inlet to the working area (in the range of 1.5 to 15.1 m/sec), on the average value of the temperature of the water at the exit (from 14 to 137°), on the size of the clearance δ between the external tube and the cylindrical heat-emitting element (varying from 0.5 to 5.6 mm), and on the pressure p (ranging from 1 to 22 atm. abs.). The effect of surface roughness on q is studied in detail. The relationship between the critical heat flow q_1 for a rough surface and q_0 for a technically smooth surface takes the form of $q_1 = \phi q_0$, where ϕ is an experimental coefficient, determined by the type of surface and the nature of the fluid. The values of ϕ presented refer to a pipe of 10 mm diameter for width $\delta = 1.45 + 1.50$ mm, with a velocity of water (or mixture) equal to 2.77 + 2.83 m/sec, and at a temperature of 40 to 45°.

1834. Cicchitti, A., et. al.

CRITICAL SURVEY OF THE LITERATURE ON BURNOUT STUDIES WITH WET STEAM, Energia Nucleare (Milan) 6, 637-60, CISE-69 (1959).

Experimental data on burnout in steam-water mixtures are presented. From burnout studies a new correlation of heat flux data is proposed and a comparison between the existing and proposed correlations is made. The first burnout data obtained with the CISE experimental facility are reported.

1835. Cicchitti, A., et al.

TWO-PHASE COOLING EXPERIMENTS PRESSURE DROP, HEAT TRANSFER AND BURNOUT MEASUREMENTS, Energia Nucleare 7, 407-25 (1960).

Results of pressure drop, heat transfer, and burnout tests with wet steam at high pressure are reported. These tests were conducted with the experimental facility built in the thermal power station at Piacenza, Italy, - Data on stability in various flow patterns are included.

1836. Clark, J. A., and Rohsenow, W. M.

LOCAL BOILING HEAT TRANSFER TO WATER AT LOW REYNOLDS NUMBERS AND HIGH PRESSURE, MIT Tech. Rpt. No. 4, NP-4112; DIC-6627 (1952), 59 p.

Local surface coefficients of heat transfer and maximum heat-flux density are presented for degassed, distilled water flowing upwards in a vertical Ni tube at mass velocities in the range 2.6 to 73 lbs/sec/ft^2 (or inlet velocities in the range 0.05 to 1.4 ft/sec), absolute pressures to 2000 psia, and liquid subcooling from 0 to 300°F. Natural convection significantly affected the nonboiling heat-transfer process; the transition from laminar to turbulent flow at the surface occurred at a length Reynolds number (viscosity based on wall temperature) between 60,000 and 100,000. Data in the region of surface boiling are emphasized. The transition was excited by the effects of superimposed free convection which increased the heat-transfer coefficient as much as 600%. The wall temperature was essentially constant for local-boiling heat transfer at lower velocities as a result of vigorous bubble agitation at the heat surface. Maximum (burnout) heat flux under conditions of local boiling with net vapor generation occurred at a bulk quality of approximately 0.80, for a boiling L/D of 52, and was independent of pressure, velocity, and initial subcooling.

1837. Clark, J. A.

HEAT TRANSFER TO WATER WITH SURFACE BOILING, D. Sci. Thesis, Depart. of Mech. Eng., MIT (1953).

1838. Clark, J. A., and Rohsenow, W. M.

LOCAL BOILING HEAT TRANSFER TO WATER AT LOW REYNOLDS NUMBERS AND HIGH PRESSURES, Trans. Am. Soc. Mech. Engrs., 76, 553 (1954).

Local surface coefficients of heat transfer and maximum heat-flux density are presented for degassed, distilled water flowing upward in a vertical L-nickel tube under the following conditions: Mass velocities

in the range 2.6 to 73 lb_m/ft^2 sec (or inlet velocities in the range 0.05 to 1.4 fps), absolute pressures up to 2000 psia, and liquid subcooling between 0 to 300°F. The effects of natural convection on the nonboiling heat-transfer process were found to be significant, causing the transition from laminar to turbulent flow at the surface to occur at length Reynolds number in the range 60,000-100,000. Emphasis is placed on data in the region of surface boiling. The test section dimensions were 0.180 in. ID and 9.4 in. long.

1839. Collier, J. G.

BURNOUT IN LIQUID COOLED REACTORS. 1., Nuclear Power 6, 61-6 (June 1961).

The theoretical hydrodynamic and heat transfer characteristics of a tube in which liquid is being totally evapd. are discussed in detail. The subcooled boiling region, nucleate boiling, transition from nucleate boiling, and the 2-phase forced convective region are discussed. A suggested mechanism for burnout in the 2-phase forced convective region is presented.

1840. Collier, J. G.

BURNOUT IN LIQUID COOLED REACTORS - 2. Nuclear Power, 6, 64-7 (July, 1961).

The theoretical analysis discussed in part one is compared with the results of experiments.

1841. Core, T. C., and Sato, K.

DETERMINATION OF BURNOUT LIMITS OF POLYPHENOL COOLANTS, IDO-28007 (1958).

An experimental investigation was conducted to establish the burnout limits of a polyphenyl mixture (15% diphenyl, 58% ortho-terphenyl, 24% metaterphenyl, and 3% paraterphenyl), diphenyl, Santowax R, and monoisopropylbiphenyl for various pressures, fluid velocities, and fluid temperatures. The preheated liquid was passed through an electrically heated, $\frac{1}{2}$-in.-OD tube (0.020-in. wall) with an unheated rod (0.188-in. diam) inserted concentrically to form an annular passage, with an equivalent hydraulic diameter of 0.272 in. The electrical power input to the tube was increased by increments until the tube was damaged and/or the outside-wall temperatures rose rapidly to a high value (indicating film-boiling). A best-fit correlation was obtained for the critical heat flux of the polyphenyl mixture. An empirical equation was obtained for the critical heat flux, $(Q/A)_c$, of the 48 diphenyl tests: $(Q/A)_c = 454\ \Delta T_{sub}\ V^{0.53} + 116{,}000$ (Btu/ft² hr). The critical heat flux for the ten Santowax R tests was correlated by the following equation: $(Q/A)_c = 552\ \Delta T_{sub}\ V^{2/3} + 152{,}000$ Btu/ft² hr. A burnout correlation was not obtained with monoisopropylbiphenyl for the test conditions covered in this program. (NSA 12-5322).

1842. Costello, C. P., and Adams, J. M.

BURNOUT HEAT FLUXES IN POOL BOILING AT HIGH ACCELERATIONS, p. 255-61 of "International Developments in Heat Transfer. Part II." New York, ASME, (1961).

For a 0.134 inch outer diameter cylindrical heater with acceleration directed normal to its axis, the peak heat flux attainable in nucleate pool boiling increased slightly with acceleration up to $\alpha/g = 10$. For higher values of α/g the data behave according to the following equation: $q''_b \alpha (\alpha/g)^{0.25}$. This is the result predicted semi-analytically for heaters with accelerations directed normally away from the surfaces. It is postulated that a size effect exists and that for cylindrical heaters of larger diameters higher values of α/g are required to attain the result indicated by this equation. Some experimental verification of this postulate was obtained. The shape and slope of the boiling curve of q" versus ΔT_{sat} for $\alpha/g = 1$ persisted up to burnout at least for α/g less than or equal to 44. The effect of acceleration on ΔT_{sat} was extremely small right up to the burnout heat flux. Wide variations in ΔT_{sat} did not appear to effect appreciably the heat flux at which vapor could stabilize on a heater surface.

1843. Costello, C. P., and Adams, J. M.

THE INTERRELATION OF GEOMETRY, ORIENTATION, AND ACCELERATION IN THE PEAK HEAT FLUX PROBLEM, University of Washington, Dept. of Mech. Engr. Report (1962).

1844. DeBortoli, R. A., Roarty, J. D., and Weiss, A.

ADDITIONAL BURNOUT DATA FOR A RECTANGULAR CHANNEL HAVING A COSINE AXIAL HEAT FLUX DISTRIBUTION, WAPD-TH-227 (1956), 11 p.

Single channel and parallel channel burnout data were obtained at 2000 psia for 0.057 in. x 2.116 in. x 27 in. long and 0.055 in. x 2.116 in. x 27 in. long machined stainless steel rectangular channels in the vertical position. These channels had a cosine axial heat flux distribution. Previous data for a cosine heated channel are also included. The results indicate that the burnout heat flux in a rectangular channel having a cosine axial flux distribution may be predicted by the method presented in WAPD-SFR-Rs-444. There is no significant effect on burnout heat flux due to an unheated parallel channel.

1845. DeBortoli, R. A., Dobel, H., and Roarty, J. D.

ATMOSPHERIC PRESSURE FREE CONVECTION BURNOUT TESTS, WAPD-TH-229 (1956), 17 p.

Atmospheric pressure, free convection burnout heat flux is significantly affected by the cold leg water level. The burnout flux varied from about 6,000 Btu/hr-ft² to 30,000 Btu/hr-ft² as the cold leg water level (U-Loop) was raised from about 8 in. below the top of a subassembly to 28 in. above the top of a subassembly. The inlet temperature (80 to 200°F) has a slight effect (15%) on the burnout heat flux; the higher

the inlet temperature, the lower the burnout heat flux. The burnout heat flux for a nonuniformly heated subassembly (maximum channel flux/minimum channel flux = 2 or 4) was a little higher (~15%) than a uniformly heated subassembly. No significant effect of the maximum-to-minimum flux ratio on the burnout flux could be established.

1846. DeBortoli, R. A., et al.

INVESTIGATION OF BURNOUT HEAT FLUX, Nov. 1956, Reactor Heat Transfer Conference, New York, TID-7529 (p-1.1) Nov. 1 and 2, 1956, p. 205-226.

A program is under way at Bettis Plant to measure burnout heat flux at conditions of interest in connection with the design of pressurized water reactors. A facility is in operation to investigate burnout heat flux at pressures up to 2000 psia. The effects on burnout due to reactor fuel element geometry (round tubes, parallel flow rods, rectangular channels), size (slot thickness, length to diameter ratios), position (vertical or inclined), and materials have been investigated. The effects due to a parallel channel, non-uniform axial flux distribution, direction of flow (upflow versus downflow), and nuclear versus electrical heating of test specimens have also been studied. Burnout has been investigated at 830, 1215, and 2000 psia.

A brief discussion of the Bettis burnout test facility and typical results obtained in the course of the above investigations are presented.

1847. DeBortoli, R. A., Roarty, J. D., and Troy, M.

UPFLOW BURNOUT DATA IN VERTICAL RECTANGULAR CHANNELS AT 2000 psia, WAPD-TH-225 (1956), 23 p.

Data are presented with correlations between calculated and observed values shown tabularly and graphically. Bettis burnout design equations are shown to be satisfactory within the range of variables investigated. No significant difference was found in the burnout fluxes for stainless steel and Zircaloy-2. 6 references.

1848. DeBortoli, R. A., and Masnovi, R.

BURNOUT DATA FOR 0.186 IN. I.D. BY 12 INCHES LONG NICKEL TUBE, WAPD-TH-308 (1957), 14 p.

Burnout data for 0.186 in. inside diameter x 0.227 in. outside diameter x 12 in. long Ni tube (L/D = 64.5) installed in a vertical position were obtained with water at 2000 psia. The mass velocities were varied from 0.20×10^6 to 4.20×10^6 lb/hr-ft^2; at inlet temperatures of 400, 500, 550, and 600°F. For the range of variables investigated, most of the measured values of burnout fluxes are from 0 to 50% higher than the values predicted by the equations of WAPD-SFR-Rs-444. Similar tests run on rectangular channels with the same L/D indicate that burnout in rectangular channels is about 5 to 20% higher than burnout in round tubes.

1849. DeBortoli, R. A., and Masnovi, R.

EFFECT OF DISSOLVED HYDROGEN ON BURNOUT FOR WATER FLOWING VERTICALLY UPWARD IN ROUND TUBES AT 2000 psia, WAPD-TH-318 (1957), 9 p.

Tests to determine the effect of dissolved H_2 on burnout for water at 2000 psia flowing vertically upward at an inlet temperature of 500°F were conducted on a nickel tube 0.186 in. inside diameter x 0.0227 in. outside diameter x 12 in. long (L/D = 64.5). The H_2 concentration was varied from 0 to 135 cc/kg. The majority of the testing was done at a mass velocity of 2.0×10^6 lb/hr-ft^2. Three additional runs were made at mass velocities of 1.0×10^6, 0.80×10^6, and 0.55×10^6 lb/hr-ft^2. Hydrogen concentration had no apparent effect on burnout.

1850. DeBortoli, R. A., et al.

FORCED CONVECTION HEAT TRANSFER BURNOUT STUDIES FOR WATER IN RECTANGULAR CHANNELS AND ROUND TUBES AT PRESSURES ABOVE 500 psia, WAPD-188 (1958), 182 p.

A summary of the latest results of the Bettis experimental program and a review and summary of the studies performed by other laboratories are reported. These latest results are the basis for new or revised procedures to be applied to reactor design. A tabulation of all available burnout heat flux data for water under forced circulation conditions and at pressures above 500 psia is presented. This tabulation not only includes all data obtained at Bettis through September 1957, but also all data generally available from other laboratories. These data have been compiled for the convenience of workers in this field. The burnout heat flux, mass velocity, inlet temperature, exit enthalpy, channel geometry, pressure, and other pertinent information are presented for each burnout point. The experimental techniques by which the Bettis burnout data were obtained are described in detail. Descriptions of the Bettis high-pressure loop facilities, test specimens, and method of testing; a detailed sample data reduction calculation; and an analysis of experimental errors are included. The experimental techniques employed by other laboratories have been out-lined. The qualitative effects of mass velocity, inlet temperature, enthalpy at the burnout point, channel geometry, and pressure on burnout heat flux are described. Existing burnout heat flux correlations are discussed, and it is concluded that none provides a completely satisfactory fit of the available data over the entire range of variables covered by the experimental work. Therefore, a new correlation, applicable to pressures near 2000 psia, has been developed and is presented.

1851. de La Harpe, A.

LITERATURE SURVEY OF BURNOUT HEAT FLUXES FOR TWO-PHASE WATER STEAM IN FORCED CONVECTION, CEA-Bib-28 (1961), 42 p.

The known causes of burnout heat flux are reviewed. The main formulas of correlation found in the most recent literature are presented together with their limits of validity. The important discrepancy existing between those different formulas are explained

and the influence on burnout heat fluxes of the different parameters are shown.

1852. Dingee, D. A., et al.

BURNOUT HEAT FLUX IN A RECTANGULAR CHANNEL, BMI-1065 (1956), 14 p.

An experimental study was made of burnout heat flux to water in a rectangular channel 0.087 by 1 in. in cross section and $12\frac{1}{16}$ in. long. Tests were performed at an ambient pressure of 2000 psia and include a range of flow rates from about 0.2 to 0.5 x 10^6 lb per (hr)(ft^2). Quality burnout data were obtained for two inlet subcoolings, 10 and 60°F; in addition, tests with conditions at the outlet from the test section near saturation temperature with no net vapor generated were performed. These tests were in the nature of an experimental check of previous data obtained by WAPD using the same rectangular channels but with an entirely different test technique. It was found that the quality burnout data for 10°F inlet subcooling agree very well with WAPD results. The 60°F inlet subcooling data fall about 10% above the corresponding WAPD data. Battelle tests at zero exit quality and near zero exit subcooling generally terminated in an instability of flow and pressure. The heat fluxes producing this instability agree favorably with WAPD burnout data under similar conditions. It is concluded that differences in the experimental setup do not lead to significantly different results.

1853. Diskind, T., et al.

BASIC STUDIES IN HEAT TRANSFER AND FLUID FLOW, Quarterly Progress Report IX QPR-3-60 for period July 1, 1960 to September 30, 1960, TID-6765, 15 p.

The resistance and temperature coefficients of "E.C." films (copper film covered with MgF_2 film) were measured. The third test section heater (heated portion of each test section consisted of a stainless-steel tube 0.295 in. OD x 0.025 in. wall x 10.5 in. long) was used to determine the critical heat flux density of the heater using the pulse heating technique at conditions of 0.4 ft/sec water velocity, 170°F inlet temperature, and 17 psia. Burn-out occurred at a heat flux of 750,000 Btu/hr/sq ft. Sustained, but not stable, film boiling was achieved in a fourth test section heater using the pulse heating technique. A smooth vapor film was obtained momentarily at relatively low steady-state heat fluxes over a significant portion of the tube surface. In studies on boiling water flow patterns, difficulties are encountered in finding a satisfactory method of thermally insulating the back side of the heating strip to prevent boiling from occurring beneath the strip. (For preceding period see TID-6035.)

1854. Dobel, H. F., Green, S. J., and Zerbe, J. E.

IN-PILE BURNOUT HEAT TRANSFER TESTS AT THE MTR, WAPD-LSR(IM)-2 (1955), 61 p.

In-pile heat transfer burnout tests conducted in a horizontal channel in the MTR are described. The results indicate no difference between electrical and in-pile burnouts. However, the continuance of in-pile testing is recommended for the study of prototype fuel elements.

1855. Dowling, R. C.

DNB REGRESSION LINE FOR A MATRIX OF OVAL TWISTED RIBBONS WITH VERTICAL UPFLOW OF WATER AT 2000 psia, KAPL-RDTR-308 (1958), 27 p.

DNB data for a matrix of oval twisted ribbons were obtained by SAR Reactor Engineering during tests at ANL, Columbia University, and Bettis. The flow of water was upwards at 2000 psia. Results of the Columbia and Bettis tests are presented and a least squares regression line is fitted to the data.

1856. Drew, T. B.

STUDIES OF PEAK BOILING, Trans. N. Y. Acad. Sci. 20, 733-8 (1958).

The mechanism of boiling H_2O, esp. nucleate boiling, is discussed. The general relation between heating wall temp. and local heat flux d is illustrated, and the variation of the peak heat flux with pressure and subcooling shown. The peak flux is in the magnitude of 1 to 3 million Btu/sq ft hr. Approaching the peak heat flux from the normal nucleate boiling region, the mixed regime of nucleate and film boiling takes place.

1857. Dugone, J.

CALCULATION OF DEPARTURE FROM NUCLEATE BOILING CONDITIONS FOR THE SPERT III REACTOR IN THE HIGH PRESSURE REGION, IDO-16774 (1962), 65 p.

Calculations are made to determine the safe steady-state power operating limits of the Spert III reactor from the viewpoint of fuel plate burnout. A computer program is developed for the IBM 704 to aid in these calculations. The Bettis design departure from nucleate boiling (DNB) equation is used in conjunction with the LeTourneau and Grimble method of "hot channel" analysis in the development of the calculations. For cases where DNB occurs in the bulk boiling region, a modified Martinelli-Nelson two-phase flow correlation and some experimental single-phase pressure drop data are employed. DNB for a typical operating condition of 550°F inlet temperature and 2500 psig is computed to check the code. The results of the sample calculation show that at a steady-state power level of 60 Mw (maximum design power) the minimum flow rate required to prevent DNB is approximately 8000 gpm.

1858. Durant, W. S., and Mirshak, S.

ROUGHENING OF HEAT TRANSFER SURFACES AS A METHOD OF INCREASING THE HEAT FLUX AT BURNOUT, DPST-60-284 (1959), 15 p.

The burnout heat flux and friction factors for rough surfaces were measured for vertical tubes cooled by downward flow of water. An increase in the burnout heat flux of as much as 100% over a smooth surface was obtained at the same coolant velocity, temperature, and pressure. A net gain of as much as 80% in heat flux at burnout is possible if the coolant channel is widened to permit the same flow at the

same pumping requirements as a smooth surface. The results of 50 experiments were correlated empirically, and may be expressed by an equation.

1859. Eicheldinger, C.

ANPP NUCLEATE BOILING PROGRAM, Quarterly Progress Report No. 1 for June through August 1960, MND-E-2414, September 1960, 37 p.

Progress during the first quarter of the revised ANPP Nucleate Boiling Program is reported. A literature survey was conducted to determine the present state of the art in the transient-boiling field. Results of the survey indicate that little work of direct value to this program has been or is being performed. Specifications for the heat-transfer test section were completed. Two tubes with flow only on the inside will be used to simulate the inside and outside flow paths for a PM-1 "hot" tube. A preliminary layout of the test section is included. Some effort was spent on preliminary specifications for the transient instrumentation. Measurements of bulk coolant temperatures (inlet and outlet), test-section wall temperatures (three locations) total and differential pressures, test-section power, and coolant flow rate are planned. An analog simulation of the PM-1 core and primary loop was programmed. Flow coast-down and core voids due to boiling will be included in the simulation.

1860. Eicheldinger, C.

ANPP NUCLEATE BOILING PROGRAM, A Quarterly Progress Report, No. 2, for September through November 1960, MND-E-2415, 29 p.

Design of the test section, supports, and installation was completed. A study of the effect of manufacturing tolerances indicated that the maximum deviation between specified and actual heat flux in the critical notched area was 1.5%. The analog simulation study was completed. Curves showing power and flow variations are included. A motor-generator set is to be installed in the Martin Heat Transfer Loop prior to performance of the test program. This unit is to provide improved transient response and is to enable programming of any credible operational power transient. All instrumentation for the program has been ordered. One major component the recording oscillograph, has been received. (For preceding period see MND-E-2414.)

1861. Eicheldinger, C.

ANPP NUCLEATE BOILING PROGRAM, Quarterly Progress Report No. 3, December 1960-February 1961, MND-E-2416, 33 p.

A plan was developed concerning the method of data reduction to be employed when the experimental PM-1 reactor simulation program is initiated. Fabrication of one complete test section assembly was completed. Tests are described for flow calibration, bulk coolant thermocouple response, and wall thermocouple tests. Instrumentation is also discussed.

1862. Emmerson, G. S.

HEAT TRANSMISSION WITH BOILING, Nuclear Eng. 5, 493-99 (Nov. 1960).

A review and discussion are presented of the rapidly growing store of knowledge of boiling heat transfer, with special reference to reactor applications. The regimes of boiling heat transfer are illustrated by the "Boiling Curve," which was obtained from experiments on electrically-heated wire immersed horizontally in a water bath. No correlation has been established to govern the boiling curve over all regimes although separate correlations were developed, theoretically and empirically, for convection, nucleate boiling, and film boiling with varying limitations. For nucleate boiling it seems simple enough to state that the remarkable increase in heat flux is caused by the agitation of the vapor bubbles, and although this is a satisfactory explanation, it has not proved sufficient in itself for the development of a theory. The transition from nucleate boiling to film boiling and burnout takes place by way of the Departure from Nucleate Boiling (DNB) point, and occurs very rapidly. For this reason, the DNB flux is regarded as the burn-out flux for reactor design purposes. The influences of pressure, local bulk subcooling or quality, channel geometry, and mass velocity on burn-out are discussed. Equations are tabulated for burn-out correlations; their range of applications, geometry, and pertinent remarks are given. When the boiling and burn-out mechanisms are more fully understood and expressed mathematically, the proper interpretation of loop test data will be facilitated, and reliable correlation will be made possible.

1863. Epstein, H. M., Chastain, J. W., and Fawcett, S. L.

HEAT TRANSFER AND BURNOUT TO WATER AT HIGH SUBCRITICAL PRESSURES, BMI-1116 (1956), 28 p.

Local surface coefficients of heat transfer and burnout heat fluxes are presented for deionized water flowing upward in a vertical Hastelloy C tube under the following conditions: mass velocity in the range 1.5×10^6 to 3×10^6 lb/(hr)(ft^2) pressure from 1500 to 2750 psia, and Reynolds numbers in the neighborhood of 10^5. The heat-transfer data are correlated with the Colburn equation. The burnout heat-flux data could not be satisfactorily correlated with the Jens and Lottes relation. Burnout results at the $L/D = 80$ showed a strong dependence upon the amount of inlet subcooling. All burnout heat fluxes appeared to be linearly dependent upon mass flow rate.

1864. Fastovskii, V. G., and Artym, R. I.

EXPERIMENTAL INVESTIGATION OF CRITICAL HEAT FLUX FOR BOILING OF BINARY MIXTURES, Teploenergetika 5, No. 8, 74-8 (1958).

The app. consists of a glass vessel surrounded by an elec. heater. The vessel is covered with a lid which has elec. leads, thermocouple leads, a manometer connection, and a condenser attached to it. The heating element is a 0.4-mm-diam. wire, 50 mm in length, immersed horizontally in the glass vessel.

Means are provided for measurement of temp., voltage, and current. Mixts. investigated were H_2O solns. of MeOH, PrOH, iso-PrOH, BuOH, Et Me ketone, and isopentanol. In making a run the soln. is subjected to preliminary boiling and then the heat load is increased up to the crit. load, q_{cr}. The max. heat input is detd. visually and by the instruments. In the majority of solns. contg. water and a small amt. of org. component, the wire burns out at q_{cr}.

1865. Fauske, H. K.

ANALYSIS OF BURNOUT IN TWO-PHASE FLOW, M. S. Thesis, Univ. of Minnesota (1959).

1866. Firstenberg, H., et al.

COMPILATION OF EXPERIMENTAL FORCED CONVECTION QUALITY BURNOUT DATA WITH REYNOLDS NUMBER, NDA-2131-16 (1960), 60 p.

The basic data and calculations are presented in two tables. Table 1 contains the experimental quality burnout data, and Table 2 contains the calculations of Reynolds numbers and enthalpy at the points of burnout. Table 3 provides an index and gives the sources of data.

1867. Foley, D. J., Batch, J. M., and McEwen, L. H.

BOILING BURNOUT AT HIGH PRESSURE IN HORIZONTAL ANNULI, Presented at: Reactor Heat Transfer Conf. New York, Nov. 1 and 2, 1956, TID-7529 Pt. 2 (p. 7) (Nov. 1956).

Boiling burnout test results are described for forced circulation, bulk boiling heat transfer to high purity water in a 0.192 inch horizontal annulus of 1.43 inches inside diameter and 21 foot heated length. A description is provided of the electrically heated experimental facility, used, and of details of test procedure which cover conditions of pressure from 590 to 2010 psia, heat fluxes from 133,000 to 378,000 Btu/hr/sq/ft mass flow rates from 610,000 to 1,700,000 lb/hr/sq/ft, and outlet steam qualities up to 44.4 per cent by weight.

1868. Foure, C., Rosuel, A., and Sourioux, G.

INFLUENCE ON BURNOUT FLUX OF VORTICES INDUCED IN BOILING WATER AT ATMOSPHERIC PRESSURE, Special Report No. 5, EURAEC-146 (1961), 146 p.

Improvement of the heat transfer coefficient by creating vortices in a flow was studied for the case of water at atmospheric pressure and at low flow velocities. The zone explored was between 1000 and 2800 kw/m^2. For the tubular test section, intake velocities were less than 1 m/sec. It was found that there exists a reduced half-pitch limit above which the addition of twisted tape is not favorable. Below this pitch, the same pumping power led to a gain in flux. In the annular test section the gain in flux was considerable. Contrary to the case of the tubular section, the twisted tape y = 9 improved the heat transfer also. At equal pumping power, for y = 3, the increase in burnout flux was 53% .

1869. Galson, A. E.

STEAM SLIP AND BURNOUT IN BULK BOILING SYSTEMS, Atomic Energy Comm., GEAP-1076 (1957), 21 p.

In concurrent flow of two phase mixtures there exists a velocity difference between the vapor and liquid phases. This difference in velocity is known as the slip velocity. The prediction of slip is the subject of Part I. In boiling systems there is some heat transfer rate at which nucleate boiling becomes unstable. At this point the separate bubbles coalesce forming an insulating vapor film on the heat transfer surface resulting in the destruction, or burnout, of the heater. The prediction of the conditions causing burnout is the subject of Part II.

1870. Gambill, W. R., and Greene, N. D.

A STUDY OF BURNOUT HEAT FLUXES ASSOCIATED WITH FORCED CONVECTION, SUBCOOLED, AND BULK NUCLEATE BOILING OF WATER IN SOURCE-VORTEX FLOW, CF-57-10-118 (1957), 15 p. [See also: Chem. Eng. Progr. 54, No. 10, 68-76 (1958)].

A study of nucleate boiling of subcooled water in forced-convection source-vortex flow in small diameter horizontal tubes is described. A measured heat flux of 11,000,000 Btu/hr ft^2 was attained, a value five times greater than any previously reported for comparable conditions.

1871. Gambill, W. R., and Greene, N. D.

BOILING BURNOUT WITH WATER IN VORTEX FLOW, Chem. Eng. Prog., 54, 68-76 (Oct. 1958).

Preliminary study of boiling burnout heat fluxes associated with forced-convection flow of water through small diameter tubes indicates that large heat fluxes are easily obtainable.

1872. Gambill, W. R., and Bundy, R. D.

BURNOUT HEAT FLUXES FOR LOW-PRESSURE WATER IN NATURAL CIRCULATION, ORNL-3026 (1960), 54 p.

Twenty-nine experimental determinations of burnout heat flux were made with water flowing by natural circulation through electrically heated vertical tubes with and without internal twisted tapes and through rectangular cross sections of three aspect ratios. Heated lengths varied from 10 to 33 in., system pressure at the test-section flow exit from 14.7 to 26.3 psia, inlet subcooling from 36 to 170°F, and burnout heat flux from 13,000 to 218,500 Btu/hr/sq ft. Tests were made with both unrestricted and restricted return flow paths. Three correlations were developed for predicting natural-circulation burnout heat fluxes for such conditions. Two are useful for rapid estimation but the third involves a more fundamental assessment of the coolant mass velocity at burnout by a graphical matching of the heat flux that a given flow rate can sustain to the heat flux that will produce that flow rate. For all the data, this approach gave average and maximum deviations of 15 and 38%, respectively. It was found that use of a ratio of unity is adequate for burnout

prediction, and the reasons for this are discussed in detail. The small burnout penalty incurred by a substantial restriction of return flow path, experimentally observed, is in complete accord with the theoretical model.

1873. Gambill, W. R.

RE: THE APPLICATION OF STATISTICAL METHODS OF ANALYSIS FOR PREDICTING BURNOUT HEAT FLUX, Nuclear Science and Engineering 10, 92 (May, 1961).

Letter to the Editor concerning the article by Jacobs and Merrill, (Nuclear Sci. and Eng. 8, 480 (1960).

1874. Gambill, W. R., Bundy, R. D., and Wansbrough, R. W.

HEAT TRANSFER BURNOUT AND PRESSURE DROP FOR WATER IN SWIRL FLOW THROUGH TUBES WITH INTERNAL TWISTED TAPES, AIChE Paper No. 22, ASME-AIChE Ht. Trans. Conf., Buffalo, August 14-17, 1960, Chem. Eng. Progress Symp. Series No. 32, 57, 127-137, ORNL-2911 (1961).

Earlier studies at Oak Ridge National Lab. of vortex-flow burnout of tubes with inlet swirl generators have been extended by relatively comprehensive experimental determinations of swirl-flow heat transfer coefficients, burnout heat fluxes, and friction factors for water flowing through electrically heated aluminum, nickel, and copper tubes containing full-length Inconel twisted tapes. Non-boiling heat transfer coefficients correlate well with both Froude number and the modulus ratio. In some ranges of Reynolds number and tape twist ratio, swirl flow produces ratios of heat transfer coefficient to frictional pumping power as much as twofold larger than straight flow of the same fluid at the same temperature through the same tube. Forty swirl-flow burnout tests have demonstrated the independence of burnout heat flux (as large as 37×10^6 Btu/(hr)(sq ft) on either pressure level or degree of subcooling. At low pressure, burnout heat fluxes with swirl flow are twice as large as with straight flow through an identical tube without a twisted tape at the same over-all pumping power. Advantages of swirl-flow tubular fuel elements for nuclear reactor applications are discussed.

1875. Gambill, W. R.

GENERALIZED PREDICTION OF BURNOUT HEAT FLUX FOR FLOWING, SUBCOOLED, WETTING LIQUIDS, A.I.Ch.E. Preprint 17, New York (1962), 47 p.

A generalized two-term additive prediction method has been developed in which one term represents the boiling contribution to the burnout heat flux in the absence of forced convection and the other the equivalent forced-convection contribution in the absence of boiling. The predictions of this superposition method have been compared with all available experimental data (1263 points) for burnout with flowing, wetting liquids in the absence of significant net vapor generation. The data compared are for seven fluids in axial, swirl, and cross flow in tubular, annular, rectangular, and rod geometries over very broad ranges of flow conditions $-0.05 < V < 174$ fps, $4.2 < P < 3000$ psia, $0 < \Delta t_{sub} < 506°F$, $1 < a < 57{,}000$ g, and $0.1 \times 10^6 < \phi_{bo} < 37.4 \times 10^6$ Btu/hr · ft^2. When the data are excluded which can be shown to be unrepresentative of burnout under the experimental conditions, a selected data field of 815 tests remains. For these data, 95% of the predictions agree with the experimental values within a maximum deviation of 40%. The method is applicable to either correlation or prediction of burnout. Its predictions of burnout for liquid-metal systems are in much better accord with the early experimental results presently being reported than are those of other burnout correlation equations. The additive nature of the correlation allows it to escape the variable "constants" and exponents which tend to characterize most empirical broad-range burnout correlations. The relative importance of any one variable is shown by the additive approach to depend upon the relative contributions of the boiling and convective terms to the total heat flux at burnout.

1876. Gambill, W. R., and Bundy, R. D.

AN EVALUATION OF THE PRESENT STATUS OF SWIRL-FLOW HEAT TRANSFER, 5th National Heat Transfer Conference (1962).

1877. Glahn, Uwe H. von.

AN EMPIRICAL CORRELATION OF CRITICAL BOILING HEAT FLUX IN FORCED FLOW UPWARD THROUGH UNIFORMLY HEATED TUBES, NASA TN D 1285 (1962), 28 p.

Boiling heat-transfer data associated with the maximum critical heat flux (burnout condition) for water, hydrogen, and nitrogen are correlated for forced flow upward through uniformly heated tubes for conditions of net vapor generation. Correlation is achieved through the development of an empirical relation involving an enthalpy ratio and a function consisting of several dimensionless groups containing variables that include mass velocity, tube geometry, and fluid property terms. All fluid property terms are evaluated at the fluid saturation temperature associated with burnout.

1878. Goldman, K., Firstenberg, H., and Lombardi, C.

BURNOUT IN TURBULENT FLOW - A DROPLET DIFFUSION MODEL, J. Heat Transfer 83, 158-62 (1961).

Burnout presents one of the principal limitations in the design of liquid or wet steam-cooled nuclear reactors, rocket nozzles or other high sp.-power equipment. The controlling mechanism for burnout in flowing systems may not be found in bubble behavior, but rather in the eddy diffusion-limited transport of liquid droplets through a steam boundary layer to the heated wall. Two-phase flow regimes are reviewed briefly. A phys. model, based on the concept that droplet diffusion through a steam boundary layer is the limiting mechanism for burnout in turbulent flow, is described. An equation is derived relating burnout to other parameters in fog flow. With simplifying assumptions, an order-of-magnitude agreement between analysis and exptl. burnout data in fog flow is demonstrated.

1879. Green, S. J.

ESTIMATED FILM BOILING HEAT TRANSFER COEFFICIENTS AT BURNOUT, WAPD-TH-132 (1955), 11 p.

The results of heat flux calculations indicate the fuel element temperature excursion during film boiling is not as great as predicted by adiabatic heat transfer calculations. The equations used in the calculations are given and their use is discussed.

1880. Green, S. J.

TRANSIENT BURNOUT AND PRESSURE DROP STUDIES, WAPD-TH-391 (1958), 12 p.

A summary of the status of various phases of the program (temperature measurement, pressure measurement, flow measurement, current, voltage) is presented and discussed.

1881. Green, S. J., Mauer, G. W., and Weiss, A.

BURNOUT AND PRESSURE-DROP STUDIES FOR FORCED-CONVECTION FLOW OF WATER PARALLEL TO ROD BUNDLES, American Society of Mechanical Engineers, Preprint Paper No. 62-HT-43, New York (1962), 12 p.

1882. Griffith, P.

THE CORRELATION OF NUCLEATE BOILING BURNOUT DATA, ASME Paper No. 57-HT-21 (1957), 17 p.

A dimensionless correlation is developed for nucleate-boiling burnout data including the following ranges of variables:

Fluids - Water
Benzene
n - Heptane
n - Pentane
Ethanol
Pressure - 0.0045 to 0.96 of critical pressure
Velocity - 0 to 110 fps
Subcooling - 0 to 280 deg F
Quality - 0 to 70 per cent

The data are drawn from a variety of sources and have been collected on widely varying types of systems. Over 300 points are correlated with 94 per cent of the points included between the ±33 per cent envelope drawn around the best line through the points. The correlation includes only fluid properties and quantities which can be calculated on the assumption of equilibrium conditions at the burnout point.

1883. Griffith, P.

A DIMENSIONAL ANALYSIS OF THE DEPARTURE FROM NUCLEATE BOILING HEAT FLUX IN FORCED CONVECTION, WAPD-TM-210 (1959), 26 p.

As part of the current effort to produce new and improved forced convection departure from nucleate boiling (DNB) heat flux correlations that would be applicable over a wide range of water conditions, a dimensional analysis of DNB was performed. This analysis was performed by non-dimensionalizing the momentum, energy and continuity equations and applying selected boundary conditions. From this treatment, a number of dimensionless groups were formulated, and the DNB heat flux was expressed in terms of

$$\frac{\phi_{DNB}}{h_{fg}\,\rho_g\,V_i} = f\left(\frac{L}{S},\ \frac{V_i S\,\rho_f}{\mu_f},\ \frac{V_i S\,\rho_g}{\mu_g},\ \frac{C\,\mu_f}{k},\ \frac{\sigma}{\rho_f V_i^2 S},\ \frac{k(T_s - T_i)}{h_{fg}\,\rho_g S V_i},\ \frac{\rho_f}{\rho_g},\ \beta\right) .$$

This relationship is applicable to various fluids over a wide range of conditions. By means of a heat balance, the continuity equation and the equation of state, ϕ_{DNB} can then be expressed in terms of local conditions plus the L/S term.

1884. Griffith, P., Schumann, W. A., and Neustal, A. D.

FLOODING AND BURN-OUT IN CLOSED-END VERTICAL TUBES, Paper No. 5, Symposium (Preprint of Proceedings) on Two-Phase Fluid Flow, Inst. Mech. Engrs., London, England, February 7, 1962.

1885. Hesson, G. M., et al.

PRELIMINARY BOILING BURNOUT EXPERIMENTS WITH A 19-ROD BUNDLE GEOMETRY IN AXIAL FLOW, HW-73395 (Apr. 17, 1962).

Boiling burnout heat flux data were obtained with an electrically heated model of a 19-rod bundle nuclear reactor fuel assembly in a cylindrical tube for vertical upward flow of water at 1200 psig. Heat was generated in the test section by d-c electrical resistance heating. Mass flow rates were 0.5, 1.0, 2.0, and 3.0×10^6 lb/hr-ft^2 and exit coolant qualities ranged from 0 to 29 wt % steam. The resultant data are compared with independent data for a 19-rod bundle.

1886. Hoe, R. H., and Senghaus, L. A.

CORRELATION OF SUBCOOLED AND QUALITY BURNOUT DATA FOR CYLINDRICAL TUBES AND RECTANGULAR DUCTS, NDA-31 (1956).

Abstracts of classified papers to be presented at the Reactor Heat Transfer Conference are given, and a correlation study of subcooled and quality burnout data for water in forced circulation through tubes and ducts is included. (NSA 11-13720).

1887. Howell, J. R., and Bell, K. J.

AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF PRESSURE TRANSIENTS ON POOL BOILING BURNOUT, Prepared for A.I.Ch.E., 5th National Heat Transfer Conference, Aug. 5-8 (1962), 24 p.

The effect of 5 to 10 psig/sec pressure decay rates on burnout in the pool boiling of water was studied. Initial saturation conditions at pressures of up to 62.5 psig were allowed to decay to one atmosphere, and the time to burnout of a stainless steel ribbon undergoing constant internal heat generation at near burnout conditions was studied. Heat fluxes ranged up to 5.75×10^5 Btu/hr-ft^2. The results are correlated on the basis of the steady state pressure vs. burnout heat flux curve which had previously

been determined for the system. It is found that the time to burnout is almost invariably longer than would be predicted from the steady state curve and known pressure decay rates.

1888. Huber, D. A.

EXPERIMENTAL SYSTEMS AND PROCEDURES UTILIZED IN STUDYING THE PHENOMENA OF NUCLEATE BOILING AND BURNOUT, NAA-SR-MEMO-4553 (1959), 11 p.

A survey of boiling heat transfer which was conducted at ten laboratories is given. The characteristics of experimental systems, burnout detection procedures, range of experimental conditions, and results obtained are listed for each laboratory.

1889. Hunt, T. W., et al.

AN INVESTIGATION OF SUBCOOLED AND QUALITY BURNOUT IN CIRCULAR CHANNELS, WAPD-LSR(IM)-1 (1955), 45 p.

Burnout heat flux data under conditions of local boiling and bulk boiling at the circular channel exit were obtained with the Bettis Burnout Loop. Subcooled burnout tests were run at 2000 psia. Quality burnout data were obtained for 1000 and 2000 psia. The effect of inclining a channel at an angle of 45° was also investigated. Quality burnout data are reported in graphical and tabular form. No correlation is suggested from the limited tests run that will predict burnout from local conditions when bulk boiling occurs. A description of the Bettis Burnout Loop and method of operation are discussed. The application of quality burnout data to reactor core design is discussed briefly.

1890. Isbin, H. S.

TWO-PHASE HEAT TRANSFER, TWO-PHASE BURNOUT, Final Report, AECU-4305 (1959), 41 p.

A burnout model has been successfully applied to burnout heat flux data reported for the flow of steam-water mixtures in round tubes and channels with uniform and hot patch heating. The model requires the fitting of characteristic constants which can be evaluated from a set of burnout heat flux versus flow rate at a given subcooling and channel geometry. Two phase local heat transfer coefficients were measured for steam-water flows up to pressures of 90 psia, maximum total flow rates of 182,000 lb/hr sq ft, and heat fluxes up to 50,200 Btu/hr sq ft in a horizontal $\frac{1}{4}$-in. brass pipe. The coefficients increased with increasing qualities up to qualities as high as 0.98. In the region of 0.98 to 1.00 the coefficients decreased to values approaching single phase runs. Brief notes are included on the extensive comparisons which have been made of the data with the literature and of other models proposed.

1891. Isbin, H. S., et al.

MODEL FOR CORRELATING TWO-PHASE, STEAM-WATER, BURNOUT HEAT-TRANSFER FLUXES, J. Heat Transfer 83, 149-57 (1961).

A simplified model is suggested for spray-annular flow in round tubes and rectangular channels; this is used for the prediction of max. heat fluxes for steam-water flows. Results reported are comparisons of the predictions with the exptl. measurements at Bettis Atomic Power Lab., for upward flow at 2000 lbs/sq in. abs., for uniform and "hot patch" heat fluxes. The model was successfully applied to both uniform and nonuniform or hot-patch heat-flux tests. Burnout flux vs. flow rate data obtained for uniform heat flux for a given inlet subcooling are sufficient for the evaluation of the characteristic parameters needed in the burnout model. Comparisons of predicted and exptl. values of the burnout heat flux are encouraging. The effect of nonuniformity of heating was correctly predicted by the model, both quant. and qual.

1892. Ivashkevich, A. A.

BURN-OUT HEAT FLOW DURING FORCED CONVECTION OF FLUIDS IN CHANNELS, Atomnaya Energ. 8, 51-3 (1960), English Translation in: Soviet Journal of Atomic Energy 8, 44-7 (1961).

Critical burn-out heat flow q_c is studied at the point where nucleate boiling is replaced by film boiling. Various experimental data are generalized and an equation for determining the q_c was derived.

1893. Ivey, H. J.

PRELIMINARY RESULTS ON THE EFFECT OF ACCELERATION ON CRITICAL HEAT FLUX IN POOL BOILING, AEEW-R99 (1961).

1894. Ivey, H. J., and Morris, D. J.

THE EFFECT OF TEST SECTION PARAMETERS ON SATURATION POOL BOILING BURNOUT AT ATMOSPHERIC PRESSURE, AEEW-R-176 (1962).

1895. Jacket, H. S., Roarty, J. D., and Sonnemann, G.

INVESTIGATION OF THE EFFECT OF A PARALLEL CHANNEL ON FLOW AND BURNOUT FLUX, WAPD-TH-162 (1955), 11 p.

Preliminary parallel channels tests at 2000 psia were run with a vertically mounted heated test section and an unheated by-pass line that had a flow area 30.5 times that of the hot channel. The flow channel dimensions of the machined and corrosion tested Zircaloy-2 test specimen were 0.097 in. x 1 in. x 27 in. long. Tests were run with inlet temperatures of 400,575 and 625°F and initial isothermal hot channel velocities of 6, 8, and 10 ft/sec.

1896. Jacket, H. S., Lackey, J., and Roarty, J. D.

PRELIMINARY INVESTIGATION OF THE EFFECT OF VERTICALLY DOWNWARD FLOW ON BURNOUT AND PRESSURE DROP AT 830 AND 1215 psia WITH A PARALLEL CHANNEL EFFECT, WAPD-TH-223 (1956), 21 p.

Preliminary burnout and pressure drop tests were conducted with water at 830 and 1215 psia with up-flow through a vertically mounted, electrically heated, rectangular flow channel in parallel with an unheated by-pass line. Single channel burnout data were also obtained. For the parallel channel tests, the by-pass had a flow area more than 30 times that of the flow channel. The heated channel was machined of Zircaloy-2 and measured 0.097 in. x 1 in. x 27 in. long. Tests were conducted at 830 psia with inlet subcoolings of approximately 10 and 60°F, and initial inlet velocities of approximately 6, 8, and 10 ft/sec. Tests were conducted at 1215 psia with approximately 60°F inlet subcooling and initial inlet velocities of 8 and 10 ft/sec.

1897. Jacket, H. S., Roarty, J. D., and Weiss, A.

PRELIMINARY INVESTIGATION OF THE EFFECT OF VERTICALLY DOWNWARD FLOW ON BURNOUT FLUX, WAPD-TH-183 (1956), 5 p.

Tests were run at mass velocities of 0.15 to 1.5 x 10^6 lbs/hr-ft^2, inlet subcooling of 10 to 61°F, and a pressure of 2000 psia. The results are plotted and compared with similar up-flow data. No difference in burnout flux due to flow direction is indicated.

1898. Jacket, H. S., Roarty, J. D., and Zerbe, J. E.

INVESTIGATION OF BURNOUT HEAT FLUX IN RECTANGULAR CHANNELS AT 2000 psia, WAPD-T-319 (1956), 28 p. (See also A.S.M.E. Trans. 80, 391-401 (1958).

Burnout heat flux data were obtained under conditions of zero exit quality and bulk boiling at the exit of electrically heated test specimens. These specimens were long, narrow channels with various slot thicknesses, surfaces, materials, and length-to-diameter ratios. Tests were run at 2000 psia and mass velocities from approximately 0.2 x 10^6 to 3 x 10^6 lb/hr-ft^2. The effect of inclining the channel at 45° was also investigated. The rectangular channel burnout results are in reasonable agreement with data previously obtained for round tubes. A design equation is suggested which yields a conservative estimate of the burnout heat flux in the low subcooling and quality regions for the range of variables investigated. A burnout loop and method of operation are described.

1899. Jacobs, R. T., and Merrill, J. A.

THE APPLICATION OF STATISTICAL METHODS OF ANALYSIS FOR PREDICTING BURNOUT HEAT FLUX, Nuclear Sci. and Eng. 8, 480-96 (1960).

A discussion is given concerning a statistical method for predicting burnout heat flux. Pressure, statistical, and fuel element-channel gap effects that are implicit in the analysis are reviewed. It is noted that the method is valid only for cylindrical channels, and that the analysis is applicable to the bulk boiling region. The statistical, rather than physical, nature of the method is noted.

1900. Jacobs, R. T., and Merrill, J. A.

RE: THE APPLICATION OF STATISTICAL METHODS OF ANALYSIS FOR PREDICTING BURNOUT HEAT FLUX - REBUTTAL, Nuclear Science and Engineering 10, 92-3 (1961).

Rebuttal to letter by W. R. Gambill, Nuclear Science and Engineering 10, 92 (1961).

1901. Janssen, E., and Levy, S.

BURNOUT LIMIT CURVES FOR BOILING WATER REACTORS, APED-3892 (1962), 51 p.

Burnout limit curves are recommended for the design of boiling water reactors. The recommended curves cover the following range of conditions: pressure at 600 to 1450 psia, a flow rate of 0.4 to 6.0 x 10^6 lb/hr-ft^2, steam subcooled to 45% by weight, hydraulic diameter from 0.245 to 1.25 in., and a heated length of 29 to 108 in. The basis for the burnout limit curves is discussed and their application to available data is presented.

1902. Janssen, E.

MULTIROD BURNOUT AT LOW PRESSURE, American Society of Mechanical Engineers, Preprint Paper 62-HT-26, New York (1962), 9 p.

The effect of nonuniform heating, nonuniform spacing, and the presence of restrictions on burnout and the behavior of two-phase flow in a rod-type reactor fuel geometry were investigated. Tests were conducted using electrically heated rods and water at 30 psia. The results show that neither local power peaking of 17%, nor displacement of a rod from its normal position by 0.132 in., nor restriction of the flow by a plate-type spacer had any adverse effect on burnout. On the contrary, the presence of the spacer improved the burnout characteristics.

1903. Janssen, E., and Kervinen, J. A.

SUBCOOLED BURNOUT AT HIGH FLOWS, GEAP-3843.

1904. Jens, W. H., and Lottes, P. A.

ANALYSIS OF HEAT TRANSFER, BURNOUT, PRESSURE DROP AND DENSITY DATA FOR HIGH-PRESSURE WATER, ANL-4627 (1951), 69 p.

Heat transfer, pressure drop, and water density data during forced convection and local boiling heat transfer have been correlated. These data were obtained by the University of California at Los Angeles, Massachusetts Institute of Technology, and Purdue University. All data were obtained on electrically heated tubes through which water passed in forced flow. From measurements of the attenuation of X-rays as they passed through the tube and the water, the density of the water was obtained under heat transfer conditions at UCLA.

In forced convection, the data correlated reasonably well with the Colburn equation. Dissolved gas had very little effect on the heat transfer coefficient.

The local boiling data were correlated by means of the following equation:

$$\Delta t_{sat} = \frac{60\left(\frac{q''}{10^6}\right)^{1/4}}{e^{\frac{P}{900}}}$$

The temperature of the heat transfer surface during boiling was independent of the water temperature and velocity was dependent only on the heat flux and the water pressure. Dissolved gas had very little effect on the temperature of the heat transfer surface.

The heat flux that caused burnout was correlated as a function of water temperature, mass rate of flow, and pressure by means of the following type of equation:

$$\left(\frac{q''}{10^6}\right)_{B.O.} = C\left(\frac{G}{10^6}\right)^m (t_{sat} - t_b)^{0.22}$$

The coefficient "C" and the exponent "m" were determined to be functions of water pressure.

The pressure drop during heat transfer with forced convection was reduced to existing correlations. The pressure drop during local and net boiling could not be correlated. The effect of dissolved gas and scale on pressure drop was unpredictable in most cases.

The density data obtained at high pressures using the X-ray measurements indicated that pressure has a very large effect on the density of water during local boiling.

1905. Kalinowski, J. E.

METHOD FOR DETERMINING FUEL ELEMENT SURFACE TEMPERATURE IN THE HOT CHANNEL CONTAINING BULK STEAM: WALLS FILM BLANKETED WITH SUPERHEATED VAPOR, KAPL-M-S3G-RES-72 (1960), 17 p.

An analysis of burnout correlations is presented in which the limiting condition is assumed to be the fuel element temperature in the hot channel as related to the coolant flow through the reactor.

1906. Kazakova, E. A.

THE EFFECT OF PRESSURE ON THE MAXIMUM HEAT FLOW WHILE BOILING WATER IN A LARGE VOLUME, Izvestiia Akad. Nauk S.S.S.R. OTN (Dept. of Technical Sciences of the Academy of Sciences of the U.S.S.R.) 1 (1949).

1907. Kazakova, E. A.

ON THE MAXIMUM HEAT FLUX ON BOILING WATER UNDER HIGH AND SUPERHIGH PRESSURES, Translated from: Doklady Akad. Nauk SSSR 71, 53, (1950), IGRL-T/R 5 (1950), 4 p.

Values of the heat transfer coefficient for boiling H_2O under pressure from 1 to 200 atm. were determined. Experimental techniques are described, our results are plotted.

1908. Kazakova, E. A.

MAXIMUM HEAT TRANSFER TO BOILING WATER AT HIGH PRESSURES, Engrs. Digest, 12, 81-5 (Mar 1951).

Heat transfer from platinum wire heated by alternating current to boiling water; pressures used range from 1-200 atm; illustrated description of high pressure boiler used in experiments; about 43 tests at various pressures were made; results and conclusions.

1909. Kazakova, E. A.

THE INFLUENCE OF PRESSURE ON THE FIRST CRISIS IN BOILING WATER FROM A HORIZONTAL SURFACE, Published in "Problems of Heat Transfer with a Change of Phase," GEI, Moscow, AEC-TR-3405 (p. 86-94) (1953).

1910. Kezios, S. P., and Lo, R. K.

HEAT TRANSFER FROM RODS NORMAL TO SUBCOOLED WATER FLOW FOR NON-BOILING AND SURFACE-BOILING CONDITIONS UP TO AND INCLUDING BURNOUT, ANL-5822 (January 1958), 156 p.

Forced convection heat transfer from an electrically heated Chromax wire oriented normal to a subcooled water flow was experimentally investigated with and without change of phase. Experiments were carried out up to the limit of burnout, and photographic observations were also made. The variables employed in this study range were the velocity from 1 to 6.8 ft/sec, subcooling in the range 140 to 80°F, and heat flux density up to 3.5×10^6 Btu/hr ft^2. Pressures at the test section ranged from 15 to 30 psia. The results and conclusions are discussed.

1911. Kezios, S. P., Kim, T. S., and Rafchiek, F. M.

BURNOUT IN CROSSED ROD MATRICES UNDER FORCED CONVECTION FLOW OF WATER, International Developments in Heat Transfer, Part II, New York, A.S.M.E. (1961), p. 262-9.

The burnout of crossed-rod matrices was experimentally determined under conditions of varying water flow and degree of subcooling. The matrices placed under test were constructed by employing rows of equally spaced parallel rods (uniform transverse pitch) with the axes of the rods forming every third row offset by one-half the transverse pitch. Transverse pitches of 1.5, 2.0, and 3.0 were employed while the longitudinal pitch was held at unity for all matrices. Each matrix was twelve rows deep and an electrically heated element (solid rod) was located in the ninth row. The basic elements forming the matrices were $\frac{1}{8}$ in. diameter rods. Water-flow through the rod bundles was varied in the range of 175 to 575 $lb_m sec^{-1} ft^{-2}$, corresponding to a face velocity in the range of about 2.8 to 9.3 ft/sec, while the degree of subcooling was varied between 70 and 180°F. The results showed the burnout heat flux q''_{BO} to increase with decreasing transverse pitch. A general correlation was obtained for q''_{BO} as a function of mass velocity, degree of subcooling and transverse pitch. Comparisons of the results with those from the single-wire burnout study of Kezios and Lo showed the test

rods in the matrix arrays withstand a higher burnout heat flux at any given mass velocity and degree of subcooling, in the range where such comparison is valid.

1912. Konkov, A. S., and Modnikova, V. V.

AN EXPERIMENTAL STUDY OF THE CONDITIONS OF IMPAIRMENT OF HEAT TRANSFER DURING BOILING IN TUBES, Teploenergetika, 8, 1962, 77-81.

The present work, over a wide range of experimental conditions, showed how heat transfer is impaired when a steam/water mixture flows in vertical tubes. Tests were made at pressures of 20, 50, 100, 150 and 200 atm. The rate of flow (by weight) ranged from 100 to 13200 kg/m^2 sec and the thermal loading from 85 x 10^3 to 3.34 x 10^6 kcal/m^2 hour. The tests were made on tubes of 3 diameters, 4, 8 and 32.2 mm. Steam from a super-critical pressure boiler was passed through the experimental tube made of stainless steel grade 1X18H9T (1Kh18N9T) which was electrically heated. Tests were made in two ways: by supplying to the experimental length water not heated to saturation and causing boiling directly in the experimental section; or by delivering to the experimental section a steam-water mixture of known composition. These different procedures made no difference to the final results. Temperatures of the outside walls of the tube were measured along its length and were initially equal. Beyond a certain steam content the wall temperature rises sharply, reaches a maximum and then diminishes, the maximum temperature jump depending upon the speed, the specific thermal load and pressure. The actual values of the temperature jumps were smaller than in tests with filmwise boiling and ranged from 25 to 300°C. Graphs are plotted of the impairment of heat transfer as a function of rate of flow by weight, for a given pressure. As the rate increases, the impairment diminishes at first fairly steeply and then when the rate is greater than 2000 kg/m^2 per sec it becomes almost constant. At constant rate the impairment increases with diminishing pressure, this increase practically ceasing from about 100 atm. The following explanation of this phenomenon is offered. When a gas-liquid mixture of high gas-content flows in a pipe, there is a thin film of liquid on the internal surface of the pipe. When the kinetic energy of the flow reaches a certain value, the tangential forces on the surface of phase separation become greater than those which hold the film to the tube surface and it breaks away, causing the impairment of the heat transfer. This explanation is used in an attempt to generalize the experimental results and the following criterial expression is given for the impairment of heat transfer.

$$x_{imp} = \left[\frac{q\sqrt{\frac{\sigma}{\gamma' - \gamma''}}}{r\gamma''\nu'}\right]^{-0.125} (Pr_1)^{-0.5}\left(\frac{\mu'}{\mu''}\right)^{-0.2} x \left(\frac{d}{\sqrt{\frac{\sigma}{\gamma' - \gamma''}}}\right)^{+0.2} \left(\frac{500}{Re_1 \frac{\gamma''}{\gamma'} + 350} + 0.35\right),$$

where x_{imp} - the steam content at which impairment of heat transfer takes place; q - the specific thermal loading; r - latent heat of boiling; γ - the specific gravity; μ - viscosity: ν - kinematic viscosity of fluid; Pr_1 - Prandtl's number for liquid; Re_1 - Reynolds number for liquid. The notation ' refers to liquid and the notation " to gas. The equation is recommended for calculation of the steam content at which impairment of heat transfer takes place only for rising flow of steam-water mixture in vertical pipes. There are 7 figures and 1 table.

1913. Kreith, Frank, and Summerfield, Martin

HEAT TRANSFER TO WATER AT HIGH FLUX DENSITIES WITH AND WITHOUT SURFACE BOILING, Transactions of the American Society of Mechanical Engineers, 71, 805-815 (1949).

Surface coefficients of heat transfer have been obtained at rates of heat flux up to 3 Btu/(sq in.)(sec) for water flowing in stainless-steel tubes at mass-flow rates up to 5.4 lb per sec-sq in. The nonboiling forced-convection data were correlated by the Colburn equation $Nu_f = 0.023\ Re_f^{0.8}\ Pr_f^{1/2}$ within ±5 per cent, but, with surface boiling, considerably larger Nu moduli were observed. When surface boiling occurred, the temperature was determined primarily by the pressure, being relatively insensitive to variations in velocity, heat flux, and bulk temperature. The maximum heat flux that could be removed under given conditions was limited by an unsteady-flow phenomenon. Data for pressure drop with and without nonboiling heat transfer are presented and correlated by an empirical viscosity correction factor.

1914. Kutateladze, S. S.

HYDROMECHANICAL MODEL OF THE CRITICAL CONDITION OF HEAT TRANSFER IN BOILING LIQUIDS FOR THE CASE OF FREE CONVECTION, Translated from: J. Tekh. Phys. 20, 1389, AEC-TR-1858 (1950), 5 p.

The amount of heat transmitted to a boiling liquid through the container wall is affected by the formation of a vapor film along the wall, when a certain critical value of the external heat supply is reached. A hydromechanical model of this phenomenon, for the case of free convection, is proposed which gives the critical heat value except for a proportionality factor.

1915. Kutateladze, S. S., and Bobrovich, G. I.

APPLICATION OF THE SIMILARITY METHOD IN GENERALIZING EXPERIMENTAL DATA OBTAINED FOR THE CRITICAL HEAT FLUXES IN A BOILING LIQUID, Atomnaya energiya, 9, 493-494 (1960).

Cooling of surfaces by liquids which form a boiling film or bubbles (which complicate the heat transfer considerably) on the surface has been investigated various times. The present "Letter to the Editor" contributes to this problem. There are two hypotheses which deal with the occurrence of a crisis during bubble-forming boiling. One of them has been formulated by G. N. Kruzhilin. According to this hypothesis, the first critical density of the heat flux is determined by the same criteria as the heat transfer during bubble boiling, i.e., the critical density of the heat flux is described by the function

$$q_{crit}\,\frac{r\gamma''}{\Delta T''(\gamma-\gamma'')\lambda} = f\left[\frac{\nu}{u};\ \frac{c\gamma\Delta T''\sqrt{\sigma(\gamma-\gamma'')}}{(r\gamma'')^2};\ \frac{g\sigma}{\nu^2\gamma(\gamma-\gamma'')^{1/2}}\right]. \quad (1)$$

Kruzhilin has suggested the following empirical formula for calculating q_{crit}

$$q_{crit} = 4700\ \frac{T''^{0,32}\sigma^{0,21}(\gamma-\gamma'')^{0,48}(r\gamma'')^{0,36}\lambda^{0,40}}{\gamma^{0,31}c^{0,08}\mu^{0,14}}. \quad (2)$$

The other hypothesis, which has been suggested by Kutateladze, assumes that the crisis at boiling is qualitatively a separate event. This event is related to the disturbance of the hydrodynamic stability of the two-phase boundary layer, which occurs when a critical rate of steam generation has been reached. This hypothesis makes it possible to obtain a number of formulas by employing the similarity theory. According to the hydrodynamic theory,

$$\frac{q_{crit}}{r\sqrt{g\gamma''\left(1+\frac{\gamma''}{\gamma}\right)}\sqrt[4]{\sigma(\gamma-\gamma'')}} = K = \text{const}, \quad (3)$$

describes the boiling of a non-viscous saturated liquid having a large volume. (2) and (3) satisfy the test results, although one has been obtained empirically and the other theoretically. (2) may be changed into $k = \frac{0.415\ T''^{0.32}}{\gamma^{0.31}\gamma''^{0.14}r^{0.64}c^{0.08}\sigma^{0.04}\mu^{0.14}(1+\gamma''/\gamma)^{0.50}}$.

k has been calculated that way. The numerical results are compiled in a table.

1916. Latzko, D. G. H.

BURNOUT IN LIQUID COOLED POWER REACTORS, Atoomenergie 2, 143-9 (1960) (In Dutch).

After describing the "burnout" phenomenon on liquid-cooled heat-transfer surfaces at high heat fluxes, a survey is given of some published quantitative correlations for the burnout heat flux in vertical channels. It is shown how the knowledge of such correlations is essential in assessing the potential of liquid cooled power reactor designs.

1917. Leppert, G., and Jens, W.

RECENT DEVELOPMENTS IN BOILING RESEARCH, J. Am. Soc. of Naval Eng. 67, 137-55 (Feb. 1955), 437-56 (May 1955).

Emphasis on work related to nuclear reactors, jet engines, and rockets; mechanism of nucleate and stable film boiling; estimation of heat transfer coefficients and surface temperatures for constant heat input systems; case of constant temperature heating; burnout heat flux. Pressure drop; change of static pressure of flowing two-phase fluid (especially water steam system) in one or more closed channels with relatively high heat input; interdependence of pressure drop; flow rate and flow fraction evaporated in high heat flux, constant heat input systems, which can lead to flow instability and burnout in parallel heated channels.

1918. LeTourneau, B. W., and Grimble, R. E.

AN ANALYSIS OF FUEL-PLATE TEMPERATURE RISE DURING A BURNOUT TRANSIENT, p. 133-48 of Reactor Heat Transfer Conference of 1956 held at New York, November 1-2, 1956. John E. Viscardi, comp., TID-7529, Pt. 1, November 1957.

Analytical solutions of the transient heat conduction equation, subject to boundary conditions representing approximately a burnout condition on 1 or both sides of a clad fuel plate, have been obtained in series form. The plate is assumed to have constant thermal properties, and burnout is represented by an instantaneous jump from a known surface temperature to either an adiabatic boundary or a finite film boiling heat transfer coefficient. The solutions have been evaluated numerically and dimensionless plots of fuel-plate temperature versus time after burnout have been constructed for several cases of interest. It is shown that, for typical zirconium-alloy fuel plates, times of the order of 1 sec after burnout may elapse before damaging temperatures are attained in the fuel plate.

1919. Levy, S., et al.

ECCENTRIC ROD BURNOUT AT 1000 lbf/in^2 WITH NET STEAM GENERATION, Int. J. Heat Mass Transfer, 5, 595-614 (1962).

Burnout and pressure-drop tests were performed with an eccentric rod geometry to simulate possible maldistribution of flow in multirod fuel assemblies of boiling-water reactors. Data are presented for a uniformly heated rod, 0.540 in. in dia. and $8\frac{1}{2}$ ft. long, located within a circular pipe of 0.875 in i.d. Test variables include one concentric and three displaced rod geometries, exit steam qualities from 9 to 66 per cent by weight, flow rates from 0.25 to 1.34×10^6 $lb/h\ ft^2$ and system pressures of 1000 lbf/in^2. Test results are as follows:

(1) Burnout heat fluxes with net steam generation are the same for the concentric annulus of 0.1675 in. and the eccentric flow spacing of 0.096 and 0.061 in. Burnout values decrease by 15-36 per cent when the minimum flow annulus is reduced from 0.1675 to 0.033 in.
(2) Single-phase pressure-drop tests exhibit a decrease in friction factor as the eccentricity increases. On the other hand, two-phase pressure losses remain relatively the same at various eccentricities.
(3) An analytical model is postulated to determine the degree of transverse mixing in an eccentric geometry. The model based upon subdividing the flow area into two parallel channels indicates that mixing extends well over half of the flow zone.

1920. Longo, J.

A STATISTICAL INVESTIGATION OF SUBCOOLED BURNOUT WITH UNIFORM AND LOCALLY PEAKED HEAT FLUXES, KAPL-1744 (1957), 45 p.

Subcooled burnout was investigated for both locally peaked and uniform heat flux distributions. The burnout heat flux at the peak of a locally peaked distribution was found to be up to four times greater than the burnout heat flux of a uniform distribution for the same coolant conditions.

1921. Longo, J., Jr.

CONTINUATION OF KAPL (DIG) INVESTIGATION OF BURNOUT, KAPL-M-DIG-TD-2 (1958), 31 p.

A continuation of the KAPL (DIG) investigation of burnout is presented. Graphs are presented of the experimental burnout heat flux versus mass velocity for various ranges of enthalpy and L/S. The experimental burnout heat flux divided by the contribution of two of the independent variables are plotted versus the third independent variable.

1922. Lowdermilk, W. H., and Weiland, W. F

SOME MEASUREMENTS OF BOILING BURNOUT, NACA-RM-E54K10 (1954), 19 p.

Measurements of boiling burn-out heat flux for water flowing upward through an electrically heated tube were obtained for ranges of velocity from 0.1 to 19 fps; pressure from atmospheric to 2000 pounds psi; length-diameter ratios of 25, 37.5, and 50; and inlet subcooling from zero to 400°F. Unsteady flow was obtained for burn-out conditions with a restriction located downstream of the point of burn-out. A compressible fluid plenum chamber located between the restriction and the exit of the test section resulted in steady-flow burn-out with a tenfold increase in the burn-out heat flux.

1923. Lowdermilk, W. H., Lanzo, C. D., and Siegel, B. L.

INVESTIGATION OF BOILING BURNOUT AND FLOW STABILITY FOR WATER FLOWING IN TUBES, NACA-TN-4382 (1958), 51 p.

High heat transfer rates obtainable with forced convection nucleate boiling process are attractive for use in cooling components of rocket motors and nuclear reactors; effects of flow restriction and compressible volume on flow stability; flow region, burnout is determined for wide range of tube geometry and flow rate values; results presented in graphical and tabular form.

1924. Lukomskii, S. M.

INVESTIGATION OF MAXIMUM HEAT FLOW WHEN WATER IS BOILED IN VERTICAL TUBES, IG-Trans-(R)-3 (1951), 6 p.

Previous work on the boiling of liquids in tubes has been confined to volatile substances at high pressures and water at atmospheric and extra high pressures. This experiment covered the whole range of pressures from atmospheric to 223 atmospheric. A description and diagram of the apparatus are given. Heating was carried out in a short tube of insulating material with electrically heated strips let in to its inner surface. The highest value for maximum heat flow occurred at pressures between 30 and 90 atmospheres. The results are shown in a graph alongside those of Kazakova for the boiling of water in bulk, and are similar. F.A. 10, No. 2, 153 (1951).

1925. McAdams, W. H., Addoms, J. N., and Kennel, W. E.

HEAT TRANSFER AT HIGH RATES TO WATER WITH SURFACE BOILING, ANL-4268 (1948), 78 p.

Study of transfer at high density of heat flux from electrically heated surface to water flowing in annuli; object was to determine quantitative relations between density of heat flux, temperature difference, pressure, degree of subcooling, and water velocity; applicability to cooling of rockets, aircraft engines, etc.

1926. McCollon, K. A.

MTR ETR TECHNICAL BRANCHES QUARTERLY REPORT FOR PERIOD ENDING SEPTEMBER 31, 1958, IDO-16505 (1958), 76 p.

. . . Preliminary out-of-pile heat transfer tests have been started in the nucleate boiling region to provide basic heat transfer data in the convective and subcooled boiling regions and in the burnout regions of fuel elements. . .

1927. Macbeth, R. V

BURN-OUT ANALYSIS. PART I. A BURN-OUT CORRELATION FOR WATER IN ROUND AND RECTANGULAR CHANNELS UNIFORMLY HEATED AT VARIOUS PRESSURES WITH FORCED CONVECTION, AEEW-R-117 (1961), 38 p.

The practical objective of research on burn-out is a reliable method giving the maximum safe rating for any water cooled reactor. Experimental work, which began at numerous centers about 10 years ago, was concerned principally with endeavoring to understand the phenomenon as it applies to simple geometries such as round and rectangular channels. This considerable effort has achieved little real success in providing an explanation of burn-out however. While some uncertainty may be due to experimental variations, inadequate analytical effort is considered to be the primary cause of the present confused situation. The result of some work already carried out is described. An initial examination made on a large group of burn-out data is described and the development is reported of a correlation which predicts burn-out heat fluxes to within an R.M.S. error of less than 10% over a wide range of operating conditions including pressure.

1928. McEwen, L. H.

TECHNICAL NOTE ON PROTECTION AGAINST BOILING DAMAGE, HW-28563 (1953).

1929. McEwen, L. H., et al.

HEAT TRANSFER " BEYOND BURNOUT" FOR FORCED-CONVECTION BULK BOILING, HW-47892 (1957), 20 p.

The results of experiments with forced circulation annular flow heat transfer to boiling water at 1500 psia pressure in a horizontal electrically heated test assembly are presented. The experiments comprised measurements of heater rod surface temperatures near and in the region of transition between nucleate and film boiling at heat

fluxes of from 100,000 to 396,000 Btu/hr sq ft and with steam qualities up to 56% by weight. Apparent phase stratification led to heater rod temperatures which produced a smooth transition from the nucleate to the film boiling portions of the boiling curve.

1930. McGill, H. L., and Sibbitt, W. L.

HEAT TRANSFER AND PRESSURE DROP OF WATER FLOWING IN A SMALL TUBE, ANL-4603 (1951), 58 p. (in: Final Technical Report. . . Feb. 16, 1950 to Feb. 15, 1951, Purdue University).

The purpose of this investigation was to study the effects of high-density heat flux on pressure drop and limiting burnout for upward flow of water in an electrically heated test section. The tests were made under the following conditions: inlet water temperature, 85 to 650°F; environment when the sample was diluted with 90% LaF_3. The susceptibility of CmF_3 is in agreement within experimental error of that expected theoretically for a $5f^7$ configuration.

1931. Markels, M., et al.

ANNUAL PROGRESS REPORT OF METHODS TO INCREASE BURNOUT HEAT TRANSFER, NYO-9500 (1960).

Acoustic energy generated by mechanical or electrical signals and its effect on pool boiling of isopropanol were studied. During the course of the investigation, a method was devised to determine the amount of heat-transfer surface wetted by the boiling isopropanol. Plots of heat flux versus temperature difference for each frequency showed that the acoustic energy did not significantly affect the heat flux at burnout, but slightly increased the critical temperature difference. No general effect of frequency variation was found even at the frequencies of the "boiling songs" of isopropanol. The over-all effect of the acoustic energy was to disturb the vapor tending to coat the heat-transfer surface. This was most evident from the absence of film boiling even at temperature differences far above the critical temperature difference. The application of alternating current to the boiling system gives promise of a self-regulating method to increase boiling heat transfer when required, and is the most significant new finding of this investigation. Two pertinent Russian papers were translated and are appended. (NSA 15-23622)

1932. Masnovi, R.

ADDITIONAL 2000 psia VERTICAL UPFLOW BURNOUT DATA FOR 0.053 in. x 1 in. x 12.06 in. LONG RECTANGULAR CHANNELS WITH AN INLET WATER TEMPERATURE OF 500°F, WAPD-TH-306 (1957), 5 p.

Burnout experiments were performed for a 0.05 in. x 1 in. x 12.06 in. long rectangular channel (L/D = 120) with an inlet water temperature of 500°F. The mass flow rate was varied from 0.18×10^6 to 2.10×10^6 lb/hr-ft^2. The results indicate that the inconsistent data for an inlet water temperature of 500°F reported in WAPD-TH-225 can be considered invalid. The data agree, in general, with the other burnout data reported in WAPD-TH-225.

1933. Masnovi, R., and Troy, M.

UPFLOW BURNOUT DATA FOR 0.101 inch x 1 inch x 6 inch VERTICAL RECTANGULAR CHANNELS AT 2000 psia, WAPD-TH-289 (1957), 10 p.

1934. Masnovi, R., and Williams, J. S., Jr.

DEPARTURE FROM NUCLEATE BOILING DATA FOR 0.097 in. by 1 in. by 12.36 in. FINNED RECTANGULAR CHANNEL TEST SECTION, WAPD-TH-458 (1958), 23 p.

Tests were conducted on a standard 12.06 in. long rectangular channel test section that had 0.005 in. equilateral fins parallel to the direction of coolant flow on both sides of the water channel. The tests were performed with vertical upflow of water at 2000 psia at mass velocities from 0.37 to 1.13 x 10^6 lb/hr-ft^2 and inlet coolant temperatures of 300, 400, and 500°F. The results showed that these fins had no effect on the total heat transferred by the specimen at DNB when compared with a conventional 0.097 in. x 1 in. x 12.06 in. unfinned DNB specimen. Thus, the finned specimen DNB flux, when based on a projected heat transfer area, is equal to the DNB flux of a conventional test specimen. Appendix I contains a discussion of fin theory as applied to the reduction of film temperature drop in the forced convection (heating) region of heat transfer. This discussion shows that reactor design improvement by the use of fins depends upon the design criteria (constant flow, constant pressure drop, or constant pumping power) and the relative magnitudes of the local coolant film drop and coolant enthalpy rise from channel inlet to the channel position considered. The Appendix also contains a discussion of fin theory as applied to operation in the nucleate boiling region near DNB. This analysis shows that because of the small differences in wall temperature between an unfinned specimen and a theoretical finned specimen the test results do not confirm, nor deny, the validity of fin theory at flux conditions approaching DNB.

1935. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report for October, 1960. TID 11036, (TID 13088) (1960), 8 p.

The loop was prepared for operation with the first 7-rod test section. Final fabrication and assembly work on this test section was continued. Parts of the second 7-rod test section were redesigned for maximum reliability.

1936. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report for November 1960, TID 13089, 4 p.

Several unsuccessful attempts were made to obtain experimental data with the first 7-rod test section. Subsequent to this the test section was removed from the loop and examined to determine the causes of operating difficulties. The examination revealed

the importance of separate investigation of problem areas in the design of this and future multi-rod test sections. With the successful completion of this program; multi-rod test sections would be constructed of individually proven components and would have a maximum certainty of satisfactory operation. Because of the necessity of further evaluation of the test program, the revised project schedule is not included. The fabrication of a new single rod test section was completed. The machining of a new shroud tube with ceramic segments for 7-rod test sections is progressing well.

1937. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES FOR MONTH OF FEBRUARY 1961, TID 12146, 34 p.

An outline is given of the test program for the development of tube test sections. Analytical work on burnout detector fluctuations are summarized as a statistical approach to interpreting the repetitive occurrence of fluctuations and a method of using the duration of a fluctuation for estimating a maximum possible surface temperature transient.

1938. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report for March, 1061, TID 12598, 11 p.

Several runs to determine "burnout" conditions were made with the spirally wrapped 7-rod test section. Preliminary indications were that at low mass velocities ($\sim 5 \times 10^5$ lb/hr ft^2) and associated high exit steam qualities, the outer 6 rods run considerably hotter that the central rod. At higher mass velocities ($> 9 \times 10^5$ lb/hr ft^2) and the associated lower exit steam qualities, this was not the case. In these latter operating areas, temperature excursions were observed on the central rod while little evidence of overheating was found on the outer rods. In order to accommodate the NDA 19-rod test section, modification of the existing piping at the exit of the test section housing was started. Also included in these piping changes were provisions for running longer test sections with no alterations to existing piping.

1939. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES FOR MONTH OF MAY, 1961, TID 12574, 10 p.

Test operation with the unwrapped 7-rod test section were completed. The final run of the series was an intentional physical burnout. The results of operations for the spirally wrapped and the unwrapped 7-rod test sections are summarized. A single rod test section, supplied to test the key features of a 19-rod test section was received and is presently in operation. Fabrication work for the Columbia 19-rod test section is proceeding. The alterations to the previously unreliable joints around the top flange proved to be successful at currents as high as 12,700 amps during the operation of the unwrapped 7-rod test section.

1940. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES FOR MONTH OF JULY 1961, TID 13711, 17 p.

Final tests including one physical burnout made with the spirally wrapped 7-rod test section are described. Calculations, based on experimental data, to compare the validity of the homogeneous model vs. an improved Martinelli model for calculating two-phase frictional pressure drop in spirally wrapped and unwrapped 7-rod bundles are given.

1941. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report for August 1961, TID 13781, 5 p.

An unsuccessful attempt was made to run the NDA 19-rod test section. The test section failure was caused by a breakdown of the spiral wrapping material. Final assembly on the CU 19-rod test section is nearing completion. The second single-rod test section was run successfully. Thirty-three heat-flux limit points were recorded including one actual physical burnout.

1942. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report for November 1961, TID 14664, 12 p.

A brief account is given of 3 future 19-rod test sections which are planned to extend the range of variables studied with the CU 19-rod test section. Preliminary experimental results are presented for forced convection boiling of water at 1000 psia in a bundle of 19 heated rods. Safe operating areas are mapped out, several instrumented burnout points are given, steady state heat transfer coefficients and wall temperatures are presented, and the intentional physical failure is described.

1943. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Prog. Report for Month of December 1961, TID 14664, 12 p.

Completion of the "hot rod" test section and receipt of materials for the next two 19-rod test sections are reported. An analysis of the two-phase pressure drop data obtained from running the 19-rod test section revealed that the data are similar to that obtained from the spirally wrapped 7-rod test section. It is thought possible to use these results interchangeably.

1944. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Prog. Report for January 1962, TID 14993, 6 p.

Assembly of the hot rod test section is complete. Bench scale tests to predict the performance of the burnout detector while using Inconel X heater tubes indicated the desirability of conducting a short test program including one burnout. Assemblies for this test are being readied. Analytical studies were initiated aimed at relating transient temperature data during burnout or other thermal transients in an electrically heated simulation to similar transients in fuel elements. The approaches include use of exact solutions, use of heat and mass flow analyzer, and use of the Liebman resistor network. In other work, fabrication of the high flux 19-rod test section was initiated, and design of a test section was begun.

1945. Matzner, Bruce.

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report for February 1962, TID-15259, 17 p.

Details of a test in which the hot rod test section was run to physical burnout are given. Data on burnout detector performance using an Inconel heater tube are also given and a proposed simulator investigation of heat transfer in fuel elements is described. Results of flow work on 7-element test sections indicate that the flow was stable during these tests which included heat fluxes of burnout magnitude.

1946. Matzner, Bruce.

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report, March 1962, TID 15619, 29 p.

The High Heat Flux 19-Rod Test Section was prepared for burnout testing. A schedule of future test section development is given. Extreme test section flow stability is demonstrated for burnout testing with 19-Rod Test Sections. A comparison of the transient thermal response of a typical reactor fuel rod and its electrically heated simulations operated is made which shows that the heater tube backup material has an important effect on the minimum time required to reach burnout temperatures during a thermal transient.

1947. Matzner, Bruce

BASIC EXPERIMENTAL STUDIES ON BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report, April 1962, TID 15637, 14 p.

Successful operation of the High Heat Flux 19-Rod Test Section was achieved. The areas of safe operation for this geometry were greatly extended over those demonstrated with the first 19-Rod Test Section. Thirty data points were recorded for 5 mass velocities between 0.5 and 2.0 x 10^6 lb/hr-ft^2 at outer rod heat fluxes as high as 996,000 Btu/hr-ft^2 with exit qualities as high as 35%. About one-third of these points are regarded as reliable instrumented burnout data. Test operations were concluded by an intentional physical burnout which occurred quite close to the instrumented burnout point. A program for future 19-rod test sections is proposed which will assure reasonably complete coverage of all required burnout data. Fabrication of the Solid Tubular Test Section is nearing completion. Fabrication was started on the spool pieces needed to permit the test section housing to handle heater tubes with a heated length of 6 ft.

1948. Matzner, Bruce.

BASIC EXPERIMENTAL STUDIES OF BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, TID 16451 (July 31, 1962).

Work was carried out on the Dissolved Helium Annular Test Section. The subcooled burnout tests are described. Data were collected at 1000 psia for nominal inlet water velocities of 10, 15, and 20 ft/sec subcoolings of 5 to 125% and no helium addition to the coolant. Some preliminary results were obtained at 1000 psia with helium dissolved in the coolant stream and at 500 psia with no helium addition. (NSA 62-33124)

1949. Matzner, Bruce.

BASIC EXPERIMENTAL STUDIES OF BOILING FLUID FLOW AND HEAT TRANSFER AT ELEVATED PRESSURES, Monthly Progress Report, Aug. 1962, TID 16813, 15 p.

Burnout testing of the internally heated annulus test section was continued and 63 additional burnout points were obtained. The data include runs with outlet subcoolings between 4 and 61°F, pressures of 500, 750, and 1000 psia, and velocities between 5 and 24 ft/sec with no helium addition. Data are presented in tables and graphs.

1950. Maurer, G., and Weiss, A.

HIGH HEAT FLUX TESTS AND BURNOUT TEST ON PARALLEL FLOW RODS, WAPD-TH-357 (1957), 12 p.

High heat flux tests with no burnout and a single physical burnout were conducted with vertical upflow of water, at 200°C psia using a test section having nine heated rods of PWR core one blanket size and pitch. These results indicate that the Bettis Thermal Design Procedures of WAPD-SRF-RS-44 are conservative in predicting burnout heat flux for flow outside of parallel rod bundles.

1951. Menegus, R. L.

BURNOUT OF HEATING SURFACES IN WATER, DP-363 (1959), 52 p.

Results are presented of a study of the burnout heat flux as it affects the design and operation of reactors. The available data are analyzed by hand to determine the important variables, and an empirical formula is fitted with the help of a digital computing machine. A method is suggested for continual improvement of the formula as more data are accumulated.

1952. Merte, H., Jr.

REVIEW OF RUSSIAN LITERATURE PERTAINING TO FORCED CONVECTION DNB, WAPD-AD-TH-539 (Del.) (1959), 36 p.

Russian papers dealing with forced-convection direct nucleate boiling are examined in detail. The studies were limited to round tubes. Comparisons are made between Russian and Bettis calculations. A bibliography of Russian papers and books on heat transfer is included.

1953. Metzler, C. V.

EFFECT OF ADDITIVES ON BOILING HEAT TRANSFER AND CRITICAL HEAT FLUX, NAA-SR-MEMO-6946 (1961), 10 p.

A literature review was made of the effect of additives on boiling heat transfer and critical heat flux. Published data show that certain additives can greatly change the rate of boiling heat transfer and the critical heat flux. Additives which were found to increase the critical heat flux of some organic fluids include both high and low volatility materials. For polyphenyl coolants, suggested additives for initial investigation are benzene and other ring type compounds, and surface active agents and other high molecular weight compounds.

1954. Michiyoshi, Itaru, and Matsumoto, Ryuichi.

PREDICTION OF BURNOUT HEAT FLUX OF FORCED CONVECTION, Nippon Genshiryoku, Gakkaishi 4, 224-31 (1962) (In English).

A method for predicting burnout heat flux of forced convective flow of water in a channel is described. The pressure range covered is between atmospheric pressure and 2000 psia, Reynolds number of flow between 7×10^3 and 5×10^5, length to diameter ratio of flow channel between 7 and 160, and various channel geometries. The method calculates the heat flux q_A at point A where the non-boiling forced convection heat-transfer characteristic curve might intersect with the natural convection-bulk characteristic curve if the boiling did not occur. A correlation between the ratio of burnout heat flux q_{BO} to heat flux q_A and Reynolds number is presented for practical purposes.

1955. Milich, W., and King, E. C.

TEST LOOP FOR DETERMINING BURNOUT HEAT FLUX, Nucleonics 16, No. 4, 108-9 (1958).

A description is given of an experimental two-fluid loop in which NaK is the heating medium and which is used to study the maximum nucleate boiling point, or burnout heat flux, of any fluid as a function of pressure, temperature, and velocity and to study film boiling beyond the burnout point. Results of tests made with isopropyl biphenyl are shown.

1956. Miropol'skiy, Z. L., Shitsman, M. Ye.

CRITICAL HEAT FLOWS FOR WATER BOILING IN CHANNELS, Atomnaya energiya, 11, No. 6, 515-521 (1961). English Translation in: Soviet Journal of Atomic Energy 11, 1166-1173 (1962).

Experimental data obtained by several authors are evaluated and analyzed by introducing dimensionless critical parameters. Such parameters may be interrelated by

$$\frac{q_{cr} l_0}{a' r \gamma''} = f\left(\frac{W_0 l_0}{\nu'}, \frac{W_0 l_0}{a'}, \frac{r}{c_p' T_s}, \frac{W_0''}{W_0'}, \frac{\gamma''}{\gamma'}\right) \quad . \qquad (1)$$

γ - specific weight, (kg/m^3), ν - kinematic viscosity (m^2/sec), μ - dynamic viscosity $(kg \cdot sec/m^2)$, σ - surface stress, r - evaporation heat, λ - heat conduction coefficient, a - thermal diffusivity, T_s - saturation temperature, W_0', W_0'' - reduced velocities (m/sec), q - specific thermal flux, q_{cr} - specific critical heat flux, l_0 - characteristic length (m). Analysis of available data shows that channel cross-sectional dimensions have no essential influence on q_{cr} if the internal diameter is more than 4 mm, the width of annular gaps more than 1 - 2 mm, and that of plane gaps more than 1.3 mm. If $x \geq 0$, q_{cr} is a hyperbolic function of the relative length l/d_{equ}. Since this is not a characteristic parameter, the quantity $\sqrt{\sigma/(\gamma' - \gamma'')}$ is chosen as characteristic length l_0. (The singly primed quantities refer to the liquid, the the doubly primed ones to the vapor). The effect of λ' on q_{cr} is negligible. If the parameter $W_0 l_0/\nu'$ exists, $W_0 l_0/a'$ can be omitted. The rate of mass flow, W_g $(kg/m^2 \cdot hr)$ is chosen as the characteristic of flow rate and phase composition of the boiling medium so that, instead of (1)

$$\frac{q_{cr}\mu'}{\sigma \gamma r} = f\left(\frac{W_g \mu'}{\sigma \gamma'}, \frac{r}{c_p' T_s}, \frac{\gamma'}{\gamma''}, \frac{\Delta i}{r}\right) \qquad (2)$$

can be taken as new "criteria system." The first parameter may be defined

$$\frac{W_g \mu'}{\sigma \gamma'} = \left(\frac{F_r^*}{A_r^*}\right)$$

where

$$F_r^* = \frac{W_0^2}{g \sqrt{\dfrac{\gamma' - \gamma''}{\sigma}}}$$

and

$$A_r^* = \frac{g}{\nu^2}\left(\frac{\sigma}{\gamma' - \gamma''}\right)^{3/2}\left(1 - \frac{\gamma''}{\gamma'}\right)^2 \quad . \quad (A)$$

$r/c_p' T_s$ may be regarded as a measure of thermodynamical similarity, $\Delta i/r = x$, is the relative en- of the flow. The actual relations holding within system (2), as determined experimentally and given in the table. These relations are evaluated and discussed for the following special cases: (1) A non-pulsating system with $x > 0$, (2) a pulsating system with $x \geq 0$, and (3) a non-pulsating system with $x < 0$. The result of the last case, for instance, is given by

$$\frac{q_{crit}\mu'}{\sigma \gamma' r} = 0.174\left(\frac{c_p' T_s}{r}\right)^{0.8} K_W^{0.4} \times \left[1 - 0.45x\left(\frac{\gamma'}{\gamma''}\right)^{0.85}\right] \quad . \qquad (6)$$

It is valid if $q_{cr} > q_s$, and the thermal flow is given by

$$q_s = 0{,}023 \frac{\lambda}{d} Pr^{0.4}\left(\frac{W_g d}{\mu g}\right)^{0.8} (t_s - t\pi) \quad . \qquad (7)$$

The relations are illustrated by graphs. There are 4 figures, 1 table, and 14 references: 10 Soviet and 4 non-Soviet. The three references to English-language publications read as follows: H. Jacket, J. Rourty, J. Zerbe, Trans. ASME, 80, 2, 391, 1958;

D. Bell. Nuclear Science and Eng., v. 7, No. 3, 245 (1960); H. Buchberg. Studies in boiling heat transfer Final Report 1951. U. S. Atomic Energy Commission.

1957. Mirshak, S.

HEAT FLUX AT BURNOUT IN STAGNANT WATER, DP-262 (1957), 11 p.

The heat flux required to melt vertical tubes of stainless steel, submerged in stagnant water at atmospheric pressure, was measured as the temperature of the ambient water was varied from 10 to 100°C. The heat flux in Pcu/hr-ft^2 was correlated by

$$(Q/A)_{Burnout} = 204{,}000 + 3900\ \Delta t$$

where Δt is the difference between the normal boiling point and the temperature of the ambient water.

1958. Mirshak, S., Durant, W. S., and Towell, R. H.

HEAT FLUX AT BURNOUT, DP-355 (1959), 16 p.

The heat flux that causes burnout of electrically heated surfaces that are water-cooled by forced convection was determined for both annular and rectangular coolant passages. The data are correlated by $(Q/A)_{Burnout} = 266{,}000\ (1 + 0.0365V)(1 + 0.00914T_S)(1 + 0.0131P)$, where Q/A is the heat flux in pcu/hr (ft^2), V is the water velocity in ft/sec, T_S is the subcooling in degrees C, and P is the pressure in psia. Surface curvature, equivalent diameter, and material of heated surface are shown to have a negligible effect on the heat flux at burnout for the range studied.

1959. Mirshak, S., and Towell, R. H.

HEAT TRANSFER BURNOUT OF A SURFACE CONTACTED BY A SPACER RIB, DP-562 (1961), 22 p.

Measurements showed that the burnout heat flux of surfaces locally insulated by vertical ribs and cooled by downward flowing water was as much as 32% lower than the burnout heat flux of surfaces without ribs. The results of the tests were correlated by an equation that includes the effects of the thermal conductivity and thickness of the heated surface, the width of the rib tip, and the clearance between the rib tip and the heated surface.

1960. Morgan, P. G.

THE EFFECT OF NONUNIFORM HEAT DISTRIBUTION ON STEAM GENERATION IN TUBES, Eng. and Boiler House Rev. 74, 336-8 (1959).

Steam generation from heated surfaces is generally by bubbles of vapor from discrete points on the heated surface, but higher rates of heat flow through the surface of the tube cause a transition to film boiling, in which a thin layer of vapor occupies the space adjacent to the heated surface; this prevents the transfer of heat to the bulk of the liquid and causes failure of the tube if prolonged. In water-tube boilers, the heat supply to the water-vapor mixt. is irregularly distributed around the perimeter. The tubes used in this investigation were of 2 groups, the 1st of 5.65 to 6.03 mm internal diam. and the 2nd of 18.65 cm internal diam., with a const. ratio of length to tube diam. of 25 in all expts. These tubes were of ordinary boiler steel and were made in such a way that the inner and outer perimeters were eccentric; this gave a variation in tube-wall thicknesses. Nonuniform heat flow was provided by passing an elec. current through the tube itself, with greatest heating occurring at the point of max. thickness. Thermocouples attached the wall of the tube were used to measure the temp. changes in the tube assocd. with different regimes of boiling. At low pressures and low flow rates, the transition from bubble to film boiling could be observed visually by the reddening of the outside wall of the tube, but, in general, the thermocouple readings provided the most definite indication of the transition. Tests were carried out at 26, 100, and 180 atm. and with flow rates in the range 200 to 2000 kg/sq m-sec and steam contents from 0 to 100%. Results are shown in graphs. Heating was found to be more uniform in the larger tubes. An empirical equation was developed to det. the influence of nonuniformity of heating around the perimeter. Values calcd. from this equation differ 25-30% from exptl. results.

1961. Morozov, V. G.

AN INVESTIGATION OF THE EFFECT OF THE PHYSICAL PROPERTIES OF A LIQUID ON THE CRITICAL THERMAL FLOWS DURING THE BOILING PROCESS, Energetika, No. 1,73-81 (1961).

The author outlines an investigation carried out for the purpose of studying the heat transmission in boiling and the determination of numerical values of the critical thermal flows. Methanol, n-propanol, 95%-ethanol, water and carbon tetrachloride were investigated. Numerous experiments on these various liquids showed that the maximum critical thermal flows in boiling, on horizontal plates, at a height of from 3 to 10 mm, erected on their edge, and on plates, with their surfaces facing upward, were actually equal. The experimental data obtained are found to coincide well with the summarized criterial equation, suggested in Ref. 3 (Sterman, L. S., ZhTF, tom XXIII, vyp. 2, 1953). The viscosity determinations of methanol, normal propanol and carbon tetrachloride were conducted at the Department of Physics of the Moscow Aeronautics Institute (MAI). It was found that the maximum critical thermal flows were 35 + 40% greater when boiling on a wire with a 1 mm diameter, than when boiling on the plates. The transition to film boiling on the plates, erected horizontally on their wide plane and washed with liquid on all sides, takes place at thermal flows, which are 20 - 25% less than the values obtained on the plates erected with their surfaces upward. There are 5 figures, and 16 references: 12 Soviet-bloc and 4 non-Soviet-bloc. The references to the most recent English-language publications read as follows: Weswater J. W. and Santagelo J. G., Ind. and Eng. Chemistry, No. 8, 1955.

1962. Mostinskii, I. L.

EFFECT OF INITIAL CONDITIONS ON BOILING CRISIS WHEN PERIMETER OF PIPE IS NONUNIFORMLY HEATED, Inzhenerno-Fizicheskii Zhurnal No. 10, 5-10 (1960).

Experimental study to show that in certain cases, state of working medium at entrance to experimental

section has considerable effect on initial stages of boiling crisis; in tubes which are not uniformly heated, greater heat flows are required to produce boiling crisis than in uniformly heated tubes. (English Summary).

1963. Mueller, G. O.

A REVIEW OF ASSESSMENT OF BOILING HEAT TRANSFER AND THE DEPARTURE FROM NUCLEATE BOILING, KAPL-M-GOM-2 (1958), 98 p.

A review and assessment of current status of boiling heat transfer and DNB (departure from nucleate boiling, formerly burnout) covering theories, procedures, and existing correlations were made. Discussion of the basic theories of nucleation and DNB, the factors which influence boiling, an evaluation of the experimental procedures and a comparison of the correlations presently being used in the field of nuclear reactor and power plant design are included. A table of previous boiling heat transfer and DNB data is included in the appendix.

1964. Nukiyama, S.

EXPERIMENTS ON THE DETERMINATION OF THE MAXIMUM AND MINIMUM VALUES OF THE HEAT TRANSFERRED BETWEEN A METAL SURFACE AND BOILING WATER, Translated from: Japan Soc. Mech. Engrs., 37, 367, A.E.R.E.-TRANS. 854 (1934), 21 p.

Q, the quantity of heat transferred to boiling water from the surface of a metal, increases gradually according to the increase in the value of ΔT, the difference between the temperatures of water and metal, but when a certain point is reached, if ΔT increases above this, then Q, on the contrary, decreases. This point is the maximum value of what is referred to in the title hereof as "heat transferred" and, in this paper, the author verifies the existence of a point such as this, experimentally. At atmospheric pressure, the ΔT corresponding to this point does not exceed 20°C to 40°C at a water temperature of 100°C, and in this case Q reaches 30 to 50 cal/cm^{2}sec, that is, 1,080,000 to 1,800,000 kcal/m^{2}hr. If this is expressed as an equivalent evaporation rate at 100°C, it is 2,000 to 3,000 kg/m^{2}hr, which shows a very much greater value for Q than the maximum value hitherto considered to exist. In addition, the minimum value (not the lowest value) for Q, corresponding to this maximum value, and which must exist, has been determined and report is made of the fact that the curve of the relation between these ΔT and Q at regions of high temperature has a relationship with the effectiveness of quenching.

1965. Oppenheimer, E.

THE EFFECT OF SPINNING FLOW ON BOILING BURNOUT IN TUBES, NDA-80-1 (1957), 33 p.

Experiment results are presented from an investigation of the effects of spinning flow on burnout heat flux for water flowing through $\frac{1}{4}$-in. tubes at low pressures and temperatures. Results indicate benefits on the order of 20% improvement of heat flux for short tubes (for equal pumping power) but not as much as had been anticipated. Heat fluxes as high as 8.5 x 10^6 Btu/hr-ft^2 were achieved.

1966. Ornatskiy, A. P.

EFFECT OF LIQUID VELOCITY ON THE MAXIMUM THERMAL LOAD IN FORCED FLOW OF A BOILING LIQUID, Trudy Inst. teploenergetiki AN UkSSR (Trans. of the Thermal Power Engineering Institute of the UkSSR Academy of Sciences) 12 (1950).

1967. Ornatskiy, A. P., and Kichigin, A. M.

CRITICAL THERMAL LOADING AND BOILING OF UNDERHEATED WATER IN SMALL DIAMETER TUBES AT HIGH PRESSURES, Teploenergetika, No. 6, 1962, 44-47.

The tests were made in a closed forced circulation system made of steel 1 x 18H9T (1Kh18N9T); this system was described by the authors in earlier work (ibid. No. 2, 1961). The test piece was a turned copper alloy tube with an internal diameter of 2 mm and wall thickness 0.4 mm with an effective length of 40 mm, heated by direct current and cooled by the circulating water. The general procedure was similar to that described earlier (ibid. No. 2, 1961). The water used was power station condensate, particular care being taken to remove oxygen. The tests were carried out at pressures ranging from 75 to 150 atm with rates of mass flow ranging from 5000 to 30000 kg/m^2 sec and with underheat (difference between the actual steam temperature and its temperature corresponding to saturation at its actual pressure) ranging from 10 to 250°C. Critical boiling was recognized by the fact that the test piece burned out. About 170 tests were made and the results are tabulated. Graphs of critical loading as a function of the amount of underheat are very similar to those obtained previously in the range of 10 to 75 atm. Curves are plotted of critical loading as a function of the amount of underheat and the rate of mass flow at various pressures and of critical loading as a function of pressure and the rate of mass flow for various amounts of underheat. On the basis of the test results presented here and those previously given (ibid. No. 2, 1961) the following empirical formula is recommended for the critical thermal loading q_{cr} as a function of the rate of mass flow w_g, the degree of underheat Δt_{und} at pressure p for underheat greater than 50°C.

$$q_{cr} = 6.60 \times 10^5 \cdot w_g^{0.6} \, \Delta t_{und}^{0.6} \left(\frac{\gamma' - \gamma''}{\gamma'} \right)^{0.9} \text{ kcal/m}^2 \text{ hour}$$

where w_g - rate of flow by weight kg/m^2 sec; Δt_{und} - the difference between the water temperature and the saturation point, °C; γ' - specific gravity of water at the saturation temperature, kg/m^3; γ'' - specific gravity of dry saturated steam, kg/m^3. The factor $(\gamma' - \gamma'')/\gamma'$ allows for the influence of pressure. Graphs show that 90% of points obtained in the experimental work reported in the two articles lie within ±20% of the line represented by this formula. Similar formulae suggested by other authors are discussed and considered to be less accurate than that presented here. There are 5 figures and 1 table.

1968. Perroud, P., De la Harpe, A., and Rebiere, J.

EXPERIMENTAL STUDY OF HEAT TRANSFER COEFFICIENTS, CRITICAL HEAT FLUXES AND PRESSURE DROPS FOR MIXTURES OF STEAM AND WATER FLOWING IN A VERTICAL TUBE, CEA-1853 (1960), 76 p.

Two stainless steel tubes were used (5 and 10 mm, lengths 400 and 800 mm respectively), heated electrically (50 Hz). The mixture flows from top to bottom. The work was carried out mainly on mixtures of high concentration ($x>0.1$), at pressures between 50 and 60 kg/cm^2, flowing as a liquid film on the walls of the tube with droplets suspended in the central current of steam. By analysis of the heat transfer laws the exchange mechanisms were established, and the conditions under which the critical heat flux may be exceeded without danger of actual burnout were determined. High output concentrations ($x_s>0.9$) may be obtained. An attempt was made to find to what extent existing correlation formulas can be used to account for the phenomena observed. It is shown that these dealing with exchange coeffs. can only be applied in a first approximation in cases where exchange by convection is preponderant, and only below the critical flux. The formulas proposed by WAPD and CISE do not give a satisfactory estimation of the critical heat fluxes, and the essential reasons for this inadequacy are explained. Lastly, the Martinelli and Nelson method may be used to an approximation of 30% for the calculation of charge losses.

1969. Petukhov, B. S., Doctor of Technical Sciences, Professor Kovalev, Engineer.

A PROCEDURE AND CERTAIN RESULTS OF MEASUREMENT OF CRITICAL LOADS ON TRANSITION FROM FILMWISE TO BUBBLE BOILING, Teploenergetika, No. 5, 65-70 (1962).

This article analyses available methods of making tests on the critical condition of change from film boiling with evolution of bubbles and suggests a new one. Accurate knowledge is required to ensure stable operation of modern boilers and atomic reactors in which film boiling is possible. Experimental results obtained by the usual electrical heating methods are unreliable. Accordingly, special tests were made using distilled water at atmospheric pressure under conditions of free convection. The heating surfaces were horizontal electrically heated tubes and wires. Film boiling was ensured by preliminary heating of the specimens in the vapour phase. Special care was taken to ensure uniformity of heating over the length of the specimen: equations are derived for this temperature distribution. The experimental equipment with electrically heated specimens is described. Specimens heated to a temperature of 350 to 400°C were immersed in boiling water and the current through them was gradually reduced until the second critical point was reached, when the film broke away from the specimen. The results show that increasing the specimen diameter reduces the second critical heat loading and that the material of which the specimen is made has little effect on the results. It is shown how to use the test results to calculate the loading at which there is equilibrium between bubble- and film-boiling. There are 4 figures and 1 table.

1970. Pexton, A. F.

A REVIEW OF DATA ON BURNOUT HEAT FLUX FOR STEAM-WATER MIXTURES IN UNIFORMLY HEATED CHANNELS, DEG-Report-203 (1961), 32 p.

A discussion is given of the available methods of predicting burnout heat flux in systems containing flowing mixtures of steam and water. The reliability of the methods when applied to experimental information obtained from uniformly heated round tubes, rectangular channels, and annular passages is reviewed, and the variables which influence two-phase burnout are considered with a view to explaining observed trends. It is concluded that a direct experimental study is required before confident prediction of burnout heat flux in divided fuel elements of the rod cluster type will become possible, and that sufficient information does not exist for general extrapolation of results obtained from simple geometries to such a case. Until further data become available it is suggested that a simple correlation, based only on the major variable, exit quality, should be used to calculate burnout heat flux in rod-cluster fuel elements cooled by steam-water mixtures at pressures of 1000 psia.

1971. Polozhii, S. V.

LIQUID BOILING WITH HEAT SUPPLY THROUGH THE WALL, Translated from: Izvest. Tomsk. Politekh. Inst. im. S. M. Kirova 80, 24-40, AERE LIB/TRANS 814 (1955), 22 p.

The basic contradiction in the process of vapor formation with supply of heat through a wall is the limited possibility of increasing the intensity of the process. Increase of heat flux is possible so long as purely "nucleate" boiling continues. Quantitative changes in this process lead to a sharp reduction of the coefficient of heat-transfer which raises the temperature of the wall and reduces the admissible heat flux. The present trend of the steam-powered cycle, to use very high pressures, may meet with the obstacle related to low heat fluxes that are permissible with very high pressures, limitation being caused by change to film boiling at a low degree of superheating.

1972. Povarnin, P. I.

GENERALIZATION OF DATA ON CRITICAL HEAT FLUX IN FORCED FLOW OF UNDERHEATED WATER IN TUBES (USSR) Teploperedacha (Heat Transfer) Moxkva, Izd-vo AN SSSR, 1962, 111-115.

A previously obtained empirical correlation for the critical heat flux (burnout) in the nucleate boiling of water flowing through tubes at a large difference between boiling point and tube wall temperature ($\Delta t>20$°C) has been analyzed by the method of G. N. Kruzhilin to derive analytical expressions for the heat flux in terms of flow parameters and fluid properties. Curves calculated from three dimensionless groups are compared with values for the corresponding empirical coefficients. The expression derived for the critical heat flux was plotted versus the flow velocity and the curve compared with experimental points obtained in six Soviet studies with water at 100 to 200 atm and 583°K.

1973. Povarnin, P. I.

CRITICAL HEAT FLUX IN THE FLOW OF 96% ETHANOL AT TEMPERATURES BELOW THE BOILING POINT (USSR), Teploenergetika, v. 9, No. 12, Dec. 1962, 57-63.

Heat transfer during forced flow with change of phase has been studied in a previously described closed loop test assembly consisting of a circulation pump, a manostat, preheating and cooling facilities, and a test section with stainless steel or bronze tubes with an inner diameter of 2 to 3.5 mm, a wall thickness of 0.2 to 0.3 mm and a length of 40 to 220 mm. The heat flux, flow velocity, inlet and outlet liquid temperatures, and outer and inner wall temperatures were determined in 163 test runs conducted at 2 to 60 atm, liquid temperatures of 0 to 220°C, and flow velocities of 0.5 to 50 m/sec. The results show that at 20 atm, in 23% of the test runs critical heat fluxes were attained without decomposition of ethanol and at 40 atm, in only 12%; at 60 atm all tests were accompanied by decomposition of ethanol and carbon deposition on the tube wall. Ethanol decomposition and carbon formation prior to the attainment of critical heat-flux densities were manifested by a plateau on the heat-flux - temperature curve. The length and diameter of the tubes were found not to affect the critical heat flux over the range l/d 28 to 90. Expressions derived by the G. N. Kruzhilin method for determining the critical heat flux correlated 60% of the experimental data within ±20% and 40% within ±40%.

1974. Pursel, C. A.

TUBE BURN-OUT AS A LIMIT TO IN-PILE BOILING, HW-32820 (1954).

1975. Raymond, M. W., and Reynolds, J. M.

DESCRIPTION OF BOILING PROJECT BURNOUT DETECTOR, Technical Report 11, NP-6477 (1957), 16 p.

The boiling heat transfer project utilizes water at a maximum pressure of 2000 psia flowing through a 0.18 in. ID Ni tube with a 0.015 in. wall. Power is supplied by a 70 kw, 2000 amp generator system and is absorbed by a 9 in. length of the Ni tube. In this system, calculations indicate that approximately 6 millisecs are available between the time at which the burnout ΔT is exceeded and the time at which "serious" overtemperature will occur. Power must essentially be reduced to 0 in this time. "Serious" overtemperature in this case is somewhat lower than that which would rupture the test section because of the importance of an unaltered tube surface condition to ensure the consistency of subsequent data to be taken with the same tube. It is estimated that, in this particular configuration, a 50° overtemperature is tolerable at peak test conditions. It is on this temperature rise that the 6 millisec requirement is predicated.

1976. Rengholt, Ulf.

BOILING HEAT TRANSFER, Tek. Tidskr. 89, 285-90 (1959).

A review of the literature on types of boiling, heat-transfer mechanisms, bubble formation, formulas for heat-transfer coeffs. for surface boiling, boiling burn-out, and the autocatalytic effect.

1977. Reynolds, J. M.

BURNOUT IN FORCED CONVECTION NUCLEATED BOILING OF WATER, NP-6476 (1957), 18 p.

Data are presented for burnout in forced convection nucleate boiling of water at pressures above 500 psia. A dimensionless correlation is devised for the M.I.T. data which is found to be valid for certain recent data reported by Argonne National Laboratory.

1978. Rickard, C. L.

BOILING BURNOUT NEWSLETTER No. 1, BNL-2097 (1954), 8 p.

Preliminary subcooled local boiling burnout and quality burnout data for round Ni tubes in vertical inclined (45°) position and subcooled local boiling burnout data in vertical Ni rectangular channels (1 in. x 0.060 and 0.050 in. spacings) are tabulated. The subcooled burnout data obtained are in close agreement with the ANL correlation for both vertical and inclined channels. Inclining the channel at 45° seems to have very little effect on the burnout point in the subcooled and the quality range tested.

1979. Rickard, C. L.

BOILING BURNOUT NEWSLETTER No. 3, BNL-2221 (1955), 3 p.

Brief data are presented on subcooled boiling burnout in a vertical Zircaloy-2 channel at exit water pressure of 2000 psia.

1980. Roarty, J. D., and Sher, N. C.

PRELIMINARY DETERMINATION OF FORCED CONVECTION HEAT TRANSFER COEFFICIENTS FOR RECTANGULAR CHANNELS AT 2000 psia, WAPD-TH-217 (1956), 10 p.

During each of the pressure drop tests described in WAPD-TH-204, "Boiling Pressure Drop in Rectangular Channels," a series of thermocouple readings were recorded which represented temperature conditions near the outside wall of the rectangular test sections. These data, which can be interpreted in terms of heat transfer coefficients, were obtained under the test conditions reported in WAPD-TH-204. While it is planned to improve the technique herein described, the preliminary data reported may be qualitatively interpreted as minimum confirmation of the Dittus-Boelter and Jens and Lottes equations for predicting non-boiling and boiling heat transfer coefficients, respectively, in rectangular channels at 2000 psia.

1981. Rohsenow, W. M., and Clark, J. A.

TECHNICAL REPORT NO. 4 ON LOCAL BOILING HEAT TRANSFER TO WATER AT LOW REYNOLDS NUMBERS AND HIGH PRESSURE, NP-4112 (July 1952), 59 p.

Local surface coefficients of heat transfer and maximum heat-flux density are presented for degassed, distilled water flowing upwards in a vertical Ni tube at mass velocities in the range 2.6 to 73 lbs/sec/ft^2 (or inlet velocities in the range 0.05 to 1.4 ft/sec), absolute pressures to 2000 psia, and liquid subcooling from 0 to 300°F. Natural convection significantly affected the nonboiling heat-transfer process; the transition from laminar to turbulent flow at the surface occurred at a length Reynolds number (viscosity based on wall temperature) between 60,000 and 100,000. Data in the region of surface boiling are emphasized. The transition was excited by the effects of superimposed free convection which increased the heat-transfer coefficient as much as 600%. The wall temperature was essentially constant for local-boiling heat transfer at lower velocities as a result of vigorous bubble agitation at the heat surface. Maximum (burnout) heat flux under conditions of local boiling with net vapor generation occurred at a bulk quality of approximately 0.80, for a boiling L/D of 52, and was independent of pressure, velocity, and initial subcooling.

1982. Rohsenow, W. M., and Griffith, Peter.

CORRELATIONS OF MAXIMUM HEAT FLUX DATA FOR BOILING OF SATURATED LIQUIDS, NP 5738 (March 1, 1955), 8 p.

Data for the boiling of single component liquids show in the region of transition from nucleate boiling to vapor film boiling the existence of a maximum heat flux as the wall temperature is raised. An attempt is made to eliminate some and predict a quantitative effect for other of the variables which appear in a correlation by J. N. Addams.

1983. Romie, F. E.

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF ULTRASONIC VIBRATIONS ON BURNOUT HEAT FLUX WITH BOILING WATER, Quarterly Technical Progress Report, ATL-A-113 (EURAEC-104 (October-December 1960), 4 p.

The effects of an ultrasonic field on the maximum nucleate heat flux that can be sustained by boiling water in a flow system are being investigated. Design and procurement of apparatus is underway.

1984. Romie, F. E.

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF ULTRASONIC VIBRATIONS ON BURNOUT HEAT FLUX WITH BOILING WATER, Quarterly Technical Progress Report, ATL-A-118 (Jan-Mar 1961), 7 p.

In this investigation, the effect of an ultrasonic field on the maximum nucleate heat flux (burnout) that can be sustained by boiling water in a flow system will be determined. The water will flow in the direction of sound propagation within an annular flow channel bounded on the outside by a glass tube and on the inside by a 0.25-in. OD heating element. The design of the test section and flow system is given.

1985. Romie, F. E.

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF ULTRASONIC VIBRATIONS ON BURNOUT HEAT FLUX WITH BOILING WATER, Quarterly Technical Progress Report No. 3, ATL-A-122 (EURAEC-157) (April-June 1961), 7 p.

The heat-transfer loop was completed and is in operation. Difficulty was experienced in obtaining a sufficiently strong connection between the burnout-detector voltage tap and the heating element. This problem and its potential solution are described. The lack of means of obtaining controlled burnout prevented collection of data on the burnout effects of the ultrasonic field.

1986. Romie, F. E., and Aronson, C. A.

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF ULTRASONIC VIBRATION ON BURNOUT HEAT FLUX WITH BOILING WATER, Final Summary Report, ATL-A-123 (EURAEC-217) (Oct 3, 1960-July 31, 1961), 23 p.

Experimental results were obtained on the effect of an ultrasonic field on the burnout heat flux for water flowing, at atmospheric pressure, through an annular flow channel formed by a $\frac{1}{4}$-in.-diameter electrically heated tube and a concentric glass tube of $\frac{3}{4}$-in. ID. The active length of the central heating element was $5\frac{1}{2}$ in. The ultrasonic transducer, which was operated at 25,000 cps and a maximum electrical input of 300 watts, was located at the inlet end of the flow channel. The ultrasonic waves were propagated in the water in the direction of flow and thus parallel to the surface of the heating element. Burnout conditions covered channel inlet flows from 1.61 to 6.25 ft/sec and subcooling from 16 to 28°F. No effect of the ultrasonic field on the burnout heat flux or on the visible boiling phenomena at burnout conditions was detectable. During boiling at heat fluxes well below burnout, the effect of the ultrasonic field was a reduction in the diameter of the envelope of bubble activity surrounding the heating element. Visual inspection appeared to show that this reduction was associated with a smaller average bubble size and a greater frequency of bubble formation. However, all evidence of the presence of the ultrasonic field vanished as the flow velocity increased or as the heat flux increased to the burnout level.

1987. Ryan, S. A., Wagner, C. A., and Longo, J., Jr.

COMPILATION OF EXPERIMENTAL BURNOUT DATA AS OF MARCH 1958, KAPL-M-D1G-TD-4(PT-1) 89 p.

The results of investigations of departure from nucleate boiling (burnout) as of March 1958 are given. Only those results thought pertinent to the design of nuclear reactors are included. It is intended that this compilation can be of aid to reactor designers in predicting burnout conditions for a particular design. This is especially important since existing correlations are empirical and should be used only in the range of variables from which they were derived.

1988. Rybin, R. A.

CRITICAL THERMAL LOADS IN A SATURATED LIQUID BOILING IN TUBES, Atomnaya energiya, v. 13, No. 4, 1962, 377-380.

A comparison between experimental and theoretical data on the nature of the boiling crisis indicates that the former can be sufficiently generalized, within the limits of error, by taking only hydrodynamic factors into account. Such a method of generalization is discussed here. The criterion for a generalization of the critical thermal loads which correspond to the boiling of non-viscous liquids is

$$K = q_{cr}/r\sqrt{g\gamma''}\sqrt[4]{\sigma(\gamma' - \gamma'')} = \text{const},$$

where q_{cr} is the critical flow of heat. As the relation

$$Ar = \gamma'\sigma^{3/2}/g\mu^2\sqrt{(\gamma' - \gamma'')}$$

is assumed to be valid in second approximation, the following system of fundamental criteria is obtained:

$$K = f\left(W_0\sqrt[4]{\frac{\gamma' - \gamma''}{g^2\sigma}} \;;\; \frac{\Delta i}{r} \;;\; \frac{\gamma''}{\gamma'} \;;\; W_0\sqrt[4]{\frac{\gamma' - \gamma''}{g^2\sigma}} = K_W \;;\; \frac{\gamma'\sigma^{3/2}}{g\mu^3(\gamma' - \gamma'')^{1/2}} \;;\; d\sqrt{\frac{\gamma' - \gamma''}{\sigma}}\right), \quad (1)$$

$$d\sqrt{\frac{\gamma' - \gamma''}{\sigma}} = K_d \quad .$$

(cf. S. S. Kutateladze, M. A. Styrikovich. Gidravlika gazozhidkostnykh sistem - Hydraulics of gas-liquid systems - M., Gosenergoizdat, 1959.) If $x = \Delta i/r$ is the vapor content by weight, K can be put equal to

$$f(W_0\sqrt[4]{(\gamma' - \gamma'')/g^2\sigma} \;;\; \beta) \quad (2)$$

after having introduced $\beta = [1 + \gamma''(1 - x)/\gamma' x]^{-1}$. These relations hold for pressures of 100-200 atm in water-steam mixtures and for tube diameters of d = 6-10 mm, in which case q_{cr} is independent of d. Differences between experimental data obtained under equal conditions are attributed to the occurrence of pulsations in steam-generating circuits. How the length of tube within which there is surface boiling influences the flow in the length of tube in which the crisis sets in is discussed in detail. The effect of an inaccurate determination of the vapor content, and the effect of the transition from bubble boiling to film boiling, are also discussed. (Abstracter's note: Most of the quantities used here are not defined, and obviously are taken from Soviet books. The 18 references are all Soviet.)

1989. Sato, K.

DETERMINATION OF BURNOUT LIMITS OF POLYPHENYL COOLANTS, AGC-AE-32 (1957), 67 p.

An experimental investigation was conducted to establish the burnout limit of liquid diphenyl for various flow conditions. Burnout limits were determined by failure of an electrically heated tube within which the diphenyl flow was controlled. The tube was an annular flow passage with a hydraulic diameter of 0.272 in. A total of 23 tests were conducted over the following range of parameters: system pressure, 197 to 406 psia; Liquid bulk temperature, 572 to 737°F; Liquid bulk velocity, 4.8 to 17.3 ft/sec; Subcooling, 77 to 328°F; and Heat flux, 227,000 to 890,000 Btu/hr sq ft.

1990. Sato, K.

POLYPHENYL-COOLANT BURNOUT STUDIES, Monthly Progress Report No. 8 for June 16 through July 15, 1957. IDO-28002 (1957), 22 p.

Studies were conducted to determine whether polyphenyl compounds, such as Santowax-R, or other terphenyl compounds, are suitable as heat-transfer fluids in organic-moderated reactors. The maximum allowable heat flux to the fluid will be established experimentally by determining the heat-flux rate at the beginning of film-boiling for various pressures, fluid velocities, and fluid temperatures.

1991. Sato, K.

POLYPHENYL-COOLANT BURNOUT STUDIES, Monthly Progress Report No. 9 for July 16 through August 15, 1957. IDO-28003 (1957), 30 p.

Polyphenyl compounds were tested to determine whether they are suitable for use as heat-transfer fluids in organic-moderated reactors. The maximum allowable heat flux to the fluid will be established experimentally by determining the heat-flux rate at the beginning of film boiling for various pressures, fluid velocities, and fluid temperatures.

1992. Sato, K.

POLYPHENYL-COOLANT BURNOUT STUDIES, Monthly Progress Report No. 10 for August 16 through September 15, 1957. IDO-28004 (1957), 26 p.

The objective of this program is to determine whether polyphenyl compounds, such as Santowax-R or other terphenyl compounds, are suitable as heat-transfer fluids in organic-moderated reactors. The maximum allowable heat flux to the fluid will be established experimentally by determining the heat-flux rate, at the beginning of film boiling, for various pressures, fluid velocities, and fluid temperatures.

1993. Sato, K.

POLYPHENYL-COOLANT BURNOUT STUDIES, Monthly Progress Report No. 11 for September 16 through October 15, 1957. IDO-28005 (1957), 17 p.

The objective of this program is to determine whether polyphenyl compounds, such as Santowax-R or other terphenyl compounds, are suitable for use as heat-transfer fluids in organic-moderated reactors. The maximum-allowable heat flux to the fluid will be established experimentally by determining the heat-flux rate at the beginning of film-boiling for various pressures, fluid velocities, and fluid temperatures.

1994. Sato, K.

POLYPHENYL-COOLANT BURNOUT STUDIES, Monthly Progress Report No. 12 for October 16 to November 15, 1957. IDO-28006 (1957), 68 p.

The objective of this program is to determine whether polyphenyl compounds such as Santowax-R, or other terphenyl compounds, are suitable for use

as heat-transfer fluids in organic-moderated reactors. The maximum allowable heat flux to the fluid will be established experimentally by determining the heat-flux rate at the beginning of film-boiling for various pressures, fluid velocities, and fluid temperatures.

1995. Sato, T., et al.

EXPERIMENTAL STUDIES OF THE BURNOUT UNDER THE BOILING (1st Report, Transient phenomena to meltdown) Trans. Japan Soc. Mech. Engrs, 27, No. 177, 722 (1961).

1996. Scherrer, V. E., McLean, E. A., and Faneuff, C. E.

STUDY OF BOILING PROCESS, pp 4-28 of Boiling Burnout Progress (1956), 51 p.

The latest experimental results on boiling and related phenomena are reported and discussed. Burnout, maximum heat transfer rates, frequency and formation characteristics of bubbles and vapor films, influence of element shape and surface properties, role of impurities, dissolved gases and pH values, temperature and density distributions, pressure drops, instability, corrosion, cavitation, and metal-water reactions are among the topics treated.

1997. Shimazaki, T. T., Huber, D. A., and Adler, K. L.

HEAT TRANSFER IN ORGANIC-COOLED REACTORS, NAA-SR-Memo-7157 (June 29, 1962).

The heat transfer aspects of organic-cooled power reactors are discussed. Typical organic reactor coolants are described. Data on convective heat transfer, boiling heat transfer, and critical heat flux of some organic coolants are presented. Convective heat transfer coefficients and, if the volatilities of the various compounds in the coolant are not too different, boiling heat transfer rates are found to be predictable from generalized correlations. The critical heat flux of a polyphenyl mixture is found to increase with addition of high boilers. Heat transfer limitations due to pyrolytic and radiolytic decomposition effects are discussed. Thermal, heat transfer, and hydraulic data for a 300 Mwe organic moderated and cooled power reactor are given. The possibility of improving organic coolant heat transfer by use of additives and by other means is indicated. (NSA 62-33121)

1998. Silvestri, M., et al.

A CRITICAL SURVEY OF THE LITERATURE ON BURNOUT STUDIES WITH WET STEAM, Energia Nucleare, 6, 637-660 (1959).

Experimental data; new correlation of burnout heat flux data proposed and comparison between existing correlations and proposed correlation is made; first burnout heat flux data obtained with experimental facility CISE-Edisonvolta are reported. Over 40 refs.

1999. Silvestri, M.

TWO-PHASE (STEAM AND WATER) FLOW AND HEAT TRANSFER, p. 341-53 of "International Developments in Heat Transfer, Part II." New York, ASME, 1961.

Flow dynamics and heat transfer in steam-water systems were studied. Critical (or burnout) heat fluxes were determined for different conditions of heat input. The burnout heat flux showed a maximum, whose value depended on flow rate and quality, in addition to geometry and pressure. The maximum was reached when the inlet mixture linear velocity had a definite value, which was strongly dependent only on pressure.

2000. Singh, S. P.

BURNOUT IN STEAM-WATER FLOW AT 2000 psia, M. Sc. Thesis, University of Minnesota (1958).

2001. Smolin, V. N., Polyakov, V. K., and Yesikov, V. I.

HEAT TRANSFER CRISIS OF A STEAM-GENERATING TUBE, Atomnaya energiya, v. 13, No. 4 (1962), 360-364.

The heat transfer crisis was investigated using a vertical tube made of 1X18H9T (1Kh18N9T) stainless steel, 1 mm thick and of 10 mm diameter. The tube was filled with chemically desalted water and was connected into a circulation. The rate of flow W_g, amounting to 850-7000 $kg/m^2 \cdot sec$, was regulated by a valve 20 m away from the experimental portion. The water was heated electrically. At a pressure of 150 at, the thermal load q amounted to $(0.46 - 1.65) \cdot 10^6$ $kcal/m^2 \cdot hr$. The temperature distribution along the experimental tube was measured with chromel-copel thermocouples. The temperature of the water at the inlet to the heater, and the temperature of the water-steam mixture at the outlet of the tube, were measured with resistance thermometers. These were connected to appropriate secondary instruments for determining the moment at which the crisis set in and for cutting off the supply of heat if the temperature of the tube wall then exceeded 600°C. Under a fixed thermal load the flow rate was varied and the experiment broken off at whatever flow rate caused the temperature jump on the tube wall to reach 10-15°C at the moment of crisis. The dependence of the steam content on the critical rate of flow was measured for different values of q. The resulting family of curves showed a minimum between 2000 and 3000 $kg/m^2 \cdot sec$. As q increased, the curves flattened and lay deeper, the minimum being shifted towards higher values of W_g. The abrupt fluctuations in the wall temperature, indicating the approach of the crisis, were plotted under various boiling conditions. The trend of these graphs reveals the course of heat transfer in each individual case and makes it possible to draw general conclusions as to the development of the crisis; for example, the existence of a limit of W_g is thereby confirmed. When W_g^{lim} is reached, the effect of the flow rate on the critical thermal load is reversed. When $W_g < W_g^{lim}$, the effects of translational motion outweigh those of the rotational motion, and when $W_g > W_g^{lim}$ the opposite is true. The critical thermal load is found from two equations of the form $y = ax^m z^n$, the range of application being given by

$$K_{lim} = \frac{1 - x}{W_g} = 0.345 \cdot 10^{-3} \quad .$$

If

$$\frac{1 - x}{W_g} > K_{lim} \quad ,$$

then

$$q_{cr} = 9.1 \cdot 10^8 \frac{(1 - x)^{3.2}}{W_g^{0.8}} \text{ kcal/m}^2 \cdot \text{hr} \quad ,$$

and if

$$\frac{1 - x}{W_g} \leq K_{lim} \quad ,$$

then

$$q_{cr} = 1.10^4 (1 - \beta)^{1.11} \cdot W_g^{0.7} \text{ kcal/m}^2 \cdot \text{hr},$$

where β is the steam content per unit volume. The two formulas hold for pressures of 150 at in tubes of 8 mm bore within the range of flow rates under consideration and with a steam content of not more than 50% by weight. The error of the formulas is ±30%. There are 4 figures.

2002. Sofer, G. A.

FOG COOLANT TECHNOLOGY AND ITS APPLICATION TO NUCLEAR REACTORS, Preprint paper No. 93, New York, Engineers Joint Council (1962).

Fog flow is a term applied to two-phase flow under conditions which cause a large part of the liquid phase to be in a dispersed state within the vapor. The present status of fog cooling technology is summarized with emphasis on the following areas: regions of fog flow stability, pressure drop in fog flow, mean coolant density, critical heat flux data, heat transfer coefficients, mixing and separation devices, and corrosion and erosion. A table shows possible application of fog cooling to various types of reactors. A most attractive application of the coolant is foreseen for D_2O-moderated reactors. (NSA 62-31801)

2003. Sonnemann, G.

CORRELATION OF BURNOUT DATA, WAPD-TH-160 (1956), 15 p.

A burn-out correlation, which takes into account the additional parameters of inlet subcooling and channel length and diameter is described. It does not consider directly the bulk fluid properties at the burnout point. This correlation predicts that the burnout flux increases with increased inlet subcooling and decreases with increased channel length. This is in general agreement with the trends shown by the experimental data. 10 references.

2004. Sonnemann, G.

A METHOD OF CORRELATING BURNOUT HEAT FLUX DATA, Nuclear Sci. and Eng. 5, 242-7 (1959).

A burnout correlation, which takes into account parameters of inlet subcooling and channel length and diameter is described. It does not consider directly the bulk fluid properties at the burnout point. This correlation predicts that the burnout flux increases with increased inlet subcooling and decreases with increased channel length. This is in general agreement with the trends shown by the experimental data.

2005. Stein, R. P.

FLOW INSTABILITY BURNOUT IN A SIMULATED REACTOR FUEL CHANNEL, Presented during Hydrodynamic Instability and Two-phase Pressure Drop Session of Natural Heat Transfer Conference, Storrs, Connecticut (August 1959).

2006. Sterman, L. S.

THE THEORY OF HEAT TRANSFER IN THE BOILING OF A LIQUID, Zhur. Tekh. Fiz., 23, 341-51 (1953).

The differential equations describing the heat transfer by convection during the boiling process, and the equations defining the conditions for the transfer of heat during boiling from the laminar transition layer to the turbulent core, are deduced. A functional relation between the similarity criteria for the case of heat interchange during the boiling process is established. The experimental data for the determination of the critical heat flow values during boiling in a large volume, and some data regarding the interchange of heat during the boiling process in pipes, are represented in the form of defined characteristic relations.

2007. Sterman, L. S., and Styrushin, N. G.

AN INVESTIGATION INTO THE INFLUENCE OF SPEED CIRCULATION ON THE VALUES OF CRITICAL HEAT FLOWS FOR LIQUID BOILING IN TUBES, Translated from: Zhur. Tekh. Eng. 22, 446-54 IGRL-T/W-40 (1952), 11 p.

The results of investigations into the determination of the dependence of critical heat flux Q_{cr} and heat flow Q_{min}, at which the change from film to nucleate boiling takes place, on speed of circulation are presented. The investigation was carried out with isopropyl spirit. This liquid was chosen because the values of critical heat flow for isopropyl spirit are comparatively small, and therefore it could be expected that the range of speeds which could be obtained on the existing experimental installation (up to 6-7 m/sec) would prove sufficient for the determination of the rule governing the variation of Q_{cr} and Q_{min} according to W_0. All the experiments were carried out on a tube with an internal diameter of 16 mm made from E YA-1 T stainless steel. The length of the experimental part of the tube was 100 mm, and the length of the stabilizing section of the tube before the experimental part was about 500 mm. The heating of the experimental part was about 500 mm.

2008. Sterman, L. S., Stiushin, N. G., and Morozov, V. G.

AN INVESTIGATION OF THE DEPENDENCE OF CRITICAL HEAT FLOW ON THE RATE OF CIRCULATION, Zhur. Tekh. Fiz., 26, 2323 (1957), English Translation in: Soviet Physics-Technical Physics 1, 2250-54 (1957).

The thermal flux at which the reverse transition from film to bubble boiling is observed was detd. as a function of the circulation velocity for EtOH at

2-atm. input pressure and circulating velocities from 0.3 to 7.5 m/sec, and for water at 2.5 atm. input pressure and circulating velocities from 0.4 to 3.0 m/sec. Some expts. with water were conducted at 7 atm. In the work with water the change in heat flow had to be rapid because prolonged film boiling could not be maintained. This increased the spread of exptl. points, particularly at 7 atm. The crit. thermal flux was detd. for EtOH at 2-atm. input pressure and circulating velocities from 0.27 to 6.95 m/sec.

2009. Styrikovich, M. A., and Miropol'skii, Z. L.

TEMPERATURE REGIME OF HORIZONTAL HIGH-PRESSURE STEAM BOILER TUBES, Izvest. Akad. Nauk. S.S.S.R. Otdel. Tekh. Nauk, 1495-1512 (1951) (In Russian).

2010. Styrikovich, M. A., and Shitsman, M. E.

NEW RESULTS ON THE TEMPERATURE DISTRIBUTION IN A BOILER WATER PIPE AT VERY HIGH PRESSURES, Translated from Doklady Akad. Nauk S.S.S.R., 96, 69-72, AERE-Lib/Trans 561 (1954).

As a result of the investigation made on the limits of safe operating temperature conditions in a vertical boiler water pipe of diameter 30 mm at very high pressures (182 to 209 kg/cm^2) it has been found that: the region of unstable surface temperature, in the range of specific thermal fluxes and circulation parameters investigated, is found for weight steam contents considerably less than unity. For applied weight steam contents of over 300 kg/m^{2}sec, there is a considerable range of intermediate temperature distributions, characteristic of an increased steam content and a gradual decrease of the heat exchange from the values found in bubble boiling to those corresponding to dry saturated steam. The treatment of the "destruction of normal circulation" merely as a phenomenon of standstill or reversal of the circulation is not in accordance with the properties of processes in boilers at very high pressures. For specific thermal fluxes of (400 to 450) x 10^{3}kcal/m^{2}h, a decrease in the circulation rate to 0.4 or 0.5 m/sec, the weight steam velocity being about 100 or 150 kg/m^{2}sec, i.e. a decrease of the multiplicity of the circulation to 2 or 2.5, brings about a serious destruction of the normal circulation, which may lead to undesirable consequences.

2011. Styrikovich, M. A., and Shitsman, M. Ye.

AN INVESTIGATION OF THE TEMPERATURE CONDITIONS IN THE OPERATION OF A VERTICAL BOILING TUBE UNDER SUPERHIGH PRESSURES. Vsesoyuz. Sbornik Gidrodinam. i Teploobmen Kipenii v Kotlakh Vysokogo Davliniya, 206-28 (1955) Moscow, Acad. Nauk S.S.S.R. (Translated from Referat. Zhur. Mek. No. 3, p. 80 (1957).

The results of an investigation of the temperature regime in a 30 mm diameter vertical boiling tube were investigated. The experiments were conducted on a stand with pressures at 182 to 209 atm abs, specific heat flux at 230 to 720,000 kcal/m^2/hr, circulation velocities at 0.2 to 2.2 m/sec, and gravimetric steam content at 8 to 100%. It is established that a considerable range of intermediate regimes exists within the zone of pressures and circulation parameters investigated, during which, the intensity of the heat transfer gradually decreases from the values corresponding to a normal nucleate boiling to the values which correspond with heat transfer to dry saturated steam. It is pointed out that with specific heat fluxes of 400 to 450,000 kcal/m^2/hr a decrease in the circulation velocity to 0.4 to 0.5 m/sec and of the circulation multiplicity to 2.0 to 2.5 may lead to damage to the steam pipes of boilers operating at high pressures.

2012. Styrikovich, M. A., and Faktorovich, L. E.

EFFECT OF LENGTH OF PIPE ON CRITICAL HEAT FLUX IN FORCED MOTION OF A STEAM-AND-WATER MIXTURE, Doklady Akademii Nauk SSSR, 120, 1019-1020, NP-tr-180 (1958), 7 pp.

The effect of the length of the experimental section upon critical heat flux in forced motion of a steam and water mixture through a pipe was investigated. Pressures were varied from 76 to 180 atmospheres, velocities from 850 to 3000 kg/m^3-sec, and relative enthalpy from - 0.3 to 1. The results are discussed, including substantiation of conclusions. (NSA, 1959, #2409)

2013. Styrikovich, M. A., and Faktorovich, L. E.

EFFECT OF LENGTH OF HEATED SECTION OF PIPE ON VALUE OF CRITICAL THERMAL CURRENTS DURING FORCED FLOW OF STEAM-WATER MIXTURE, Teploenergetika 6, No. 2, 83-8 (1959).

Experimental study of such effect in vertically directed pipes.

2014. Styrikovich, M. A., and Mostinskii, I. L.

EFFECT OF NON-UNIFORM HEATING OF A TUBE'S PERIMETER ON THE MAGNITUDE OF THE CRITICAL HEAT FLOW, Dokl. Akad. Nauk SSSR 127, No. 2, 316-19 (1959) (In Russian).

Results are described and graphed of experiments carried out with models of boiler tubes of irregular section, the conditions of the experiments being as follows: pressure, 26, 100 and 180 atm (absolute); flow rates from 200 to 2000 kg m^{-2}sec^{-1}; steam content (x), from 0 to 1. The heating was effected by passing 50 c/s a.c. through the tube body (current density = 50A mm^{-2}). The following empirical formula is proposed for the critical heat flow (heat flow at which nuclear boiling passes into film boiling):

$$q_{cr}^{max}/q_{cr}^{0} = 1 + 12\,(1 - 0.4x)[(q_{max}/\bar{q}) - 1]/Pe_0^{0.25}\,Pr_0$$

where q_{cr}^{max} and q_{cr}^{0} are the local values of the critical heat flow in the place where the boiling crisis arises (the greatest wall thickness), for the irregular and regular section tube, respectively, and Pe_0 and Pr_0 are the Peclet and Prandtl numbers.

2015. Styrikovich, M. A. et al.

EFFECT OF PRECONNECTED ELEMENTS ON ONSET OF BOILING IN STEAM GENERATING PIPES: Teploenergetika 7, No. 5, 81-8 (1960).

Comparison of experimental data concerning critical thermal flow, mostly by Soviet authors.

2016. Styrikovitch, M. A., et al.

EFFECT OF UPSTREAM ELEMENTS ON CRITICAL BOILING IN A VAPOR GENERATING PIPE, Translated from Teploenergetika 7, No. 5, 81-7, AEC-tr-4740 (1960).

The experimental data compiled by various authors on critical thermal flow during the boiling of water in pipes are examined. The experimental results establishing the effect of the elastic properties of a medium in upstream volumes and of the magnitude of these volumes on the beginning of critical boiling in vapor generating pipes are clarified.

2017. Styrikovich, M. A., Corresponding Member AS USSR, Miropol'skiy, Z. L., and Shen Chao-Yuan.

EFFECT OF NONUNIFORM HEATING ALONG A TUBE ON THE AMOUNT OF CRITICAL THERMAL CONVECTION, Akademiya nauk SSSR. Doklady, 139, No. 4, 1961, 859-862.

In connection with the design of high-power heat exchangers, the authors studied the effect of a nonuniform heating along a tube on the occurrence of a boiling crisis. Experiments were made with steam-water mixture and/or with water moving upward in a tube not heated up to saturation temperature; pressures ranged from 100-180 at. The flow rates were 400, 850, and 2,000 $kg/m^2 \cdot sec$. The experimental setup has been described in an earlier paper by Miropol'skiy et al. [Teploenergetika, No. 1, 80 (1959)]. The arrangement consists of an open circuit with superheater. Pressure and flow rate can be adjusted by valves. Two types of nonuniform heating of the tubes were employed. Data are given obtained with tubes with a ratio of the maximum thermal flow to the mean flow of 2.3. The minimum to maximum thermal flow ratio was 4.9. Occurrence of the boiling crisis was determined visually. The local value of specific thermal convection at the point of the arising crisis is regarded as the critical thermal convection. Critical thermal convection in the case of nonuniform heating of the tubes (q^{nonu}_{crit}) is found to surmount the critical values in the case of uniform heating of the tubes (q^{u}_{crit}) by about twice their amount. A rather complex dependence was obtained only when pulsations (100 at, 400-850 $kg/m^2 \cdot sec$) developed. In this case, when incompressible water in the space at the entrance of the test tube is replaced by elastic water-vapor mixture, the q^{nonu}_{crit} values drop jumplike. The ratio between q^{nonu}_{crit} and q^{u}_{crit} is then nearly reciprocal to that given above. Experiments with decreasing thermal flow in the direction of the moving medium showed that q^{nonu}_{crit} was only half of q^{u}_{crit} when the crisis was located near the exit of the tube. On the other hand, q^{nonu}_{crit} lay considerably above the q^{u}_{crit} value when the crisis was near the entrance of the tube. The authors show in the discussion of the results that the latter are determined by the percentage of vapor in the boundary layer. There are 2 figures and 3 Soviet-bloc references.

2018. Styrikovich, M. A., Miropol'skii, Z. L., and Eva, V. K.

THE EFFECT OF A LOCAL INCREASE IN HEAT FLUX ALONG A CHANNEL ON THE BURNOUT HEAT FLUX, Dodlady Akad. Nauk SSSR, 145, 93-6 (July 1, 1962).

Heat transfer experiments were run on a vertical section of 18Cr9Ni stainless steel with an internal diameter of 8 mm. Most experiments were made with creation of a "hot spot" on the upper exit end of the tube. The ratio of heat flux at the "hot spot" to heat flux over the rest of the tube was varied from 1.35 to 2. The experiments were carried out at a pressure of 100 atms with mass flows of 2000, 850, and 400 kg/m^2-sec. The relative enthalpy of the heat transfer medium at the exit varied from 0.2 to 1.0. The tube wall was heated by alternating current, and the burn-out flux was determined from the sharp jump in wall temperature as measured by a thermocouple. The critical heat flux q_{cr} depended significantly on the length of the hot spot. The value of the critical heat flux q_{cr} was greater for high vapor content in the liquid for a hot spot length of 160 mm than it was for lengths of 500 and 945 mm. With a low content of steam in the fluid, the critical heat flux did not vary very much irrespective of tube length or mass velocity. (NSA 62-30562)

2019. Susskind, H.

A SURVEY OF BULK BOILING STUDIES IN PRESSURIZED WATER REACTOR SYSTEMS, BNL-636 (1960), 16 p.

A general survey was made of the published literature to determine the current status of the bulk boiling studies of pressurized-water systems in the 1500- to 2000 psia pressure range. This survey includes departure-from-nucleate-boiling ("burnout") heat flux correlations and other thermal considerations, two-phase pressure drop correlations, flow redistribution, and other hydrodynamic considerations, under steady-state and transient conditions and uniform and nonuniform heat flux distributions. The information is evaluated, and areas requiring further development are indicated. 17 refs.

2020. Tippets, F. E.

CRITICAL HEAT FLUX AND FLOW PATTERN CHARACTERISTICS OF HIGH PRESSURE BOILING WATER IN FORCED CONVECTION, GEAP-3766 (1962).

2021. Topper, L.

A DIFFUSION THEORY ANALYSIS OF BOILING BURNOUT IN THE FOG FLOW REGIME, NYO-10448 (Sept. 1962).

A boundary-value problem, describing an idealized model for the flow of a fog of liquid droplets in their own vapor through a heated tube, is solved. The theoretical solution for a burnout criterion is in good agreement with some experimental burnout results for a fog of water droplets in high pressure steam. (NSA 62-31797)

2022. Torikai, K., Hori, M., and Ouchi, Y.

THE SURFACE BOILING BURNOUT IN A CHANNEL, J. Atomic Energy Soc. Japan, 3, 333-337 (1961).

The phenomena of surface boiling burnout were observed photographically. It is found that the burnout in a channel consists of either a stable flow or an unstable flow. The latter type occurs in the piston flow pattern in which the flow rate and wall temperature are unstable and oscillatory. Therefore, it is considered that the burnout heat flux in unstable flow

is affected not only by the local condition of the channel but also by the system characteristics such as pumping power and flow resistance of the circulating system. The burnout heat flux in a circular channel is also measured at atmospheric pressure, and is correlated with the coolant velocity and subcooling.

2023. Torikai, K.

HYDRODYNAMIC STUDY OF BURNOUT IN BOILING, Rept. No. 17, JAERI-1017 (1961), 48 p.

The burnout mechanism, by which a heating surface is melted down in the high-heat flux as the heat transfer coefficient is suddenly decreased, is investigated on the basis of hydrodynamic aspects. A completely vaporized area is created, when bubbles in boiling grow from the nucleates of bubbles on the heating surface, the bubbles are detached from the surface, and the growth of the bubbles ends. A fluid-flow resistance between the fluids occurs when the vapor rises in the area and the liquid of the same flow rate with that of the vapor comes down. When the force, necessary to overcome the fluid-flow resistance, is not given to the fluids, there will be a limit to the flow rate. A semi-theoretical analysis was made in pool-boiling. An experiment was made on the counter flow between air and water. In consequence, it was recognized that there are limits in the flow rate and that the calculated limit values would be the same with the heat flux in burnout. In forced-circulation boiling, a semi-theoretical analysis was made and the equation of the maximum heat flux,

$$q_{B.O.} = u_m \gamma p(\lambda/8)(1 - A_v) \quad ,$$

was obtained, under the assumption that burnout mostly occurs when the flowrate of the liquid coming to the heating surfaces is less than that of the vapor going out of the surface when forced circulation in boiling makes a kind of turbulent diffusion. Maximum heat flux equations for various conditions of the flow and heating surface were introduced, and were found in good agreement with the data of many experiments on the forced-circulation boiling of water.

2024. Tramontini, V. N. et al.

FINAL REPORT ON STUDIES IN BOILING HEAT TRANSFER, COO-24 (1951), 516 p.

In the investigation of which this is the final report, the desire to use water as a heat-transfer medium in the process of converting energy released in a nuclear reactor to useful work led to obtaining data at fluid pressures up to 2500 psia, temperatures up to 650°F, local velocities up to 55 fps and heat flux densities up to 3.8 x 10^6 Btu/hr/ft^2. Presented in this lengthy and detailed report are the forced-convection heat transfer and pressure-drop studies at elevated pressures with and without surface boiling; the analysis,design and development of an x-ray densitometer; fundamental studies including boiling heat transfer from various metals to water in an annular flow system, an investigation of liquid superheat, shadowgraphic studies of boiling on a submerged horizontal cylinder, and remarks on the mechanism of heat transfer to boiling liquids; and the design and development of a burnout control system. 171 figures. (Chapter III, section A on Boiling Heat Transfer from various Metals to Water in an Annular Flow System was abstracted in NSA as NSA 5-1548.)

2025. Troy, M., and Roarty, J. D.

UPFLOW BURNOUT DATA FOR 0.059 INCH x 1 INCH x 27 INCH LONG RECTANGULAR CHANNELS AT 2000 psia, WAPD-TH-276 (1956), 13 p.

2026. Troy, M.

ZERO NET FLOW BURNOUT TESTS AT 2000 psia, WAPD-TH-251 (1956), 6 p.

This report supersedes WAPD-TH-240.

A free convection (zero-net flow) burnout test was conducted at 2000 psia in a vertical rectangular channel measuring 0.050 x 1 x 27 in. long. Heat flux was applied in increments of about 1000 Btu/hr-ft^2 and steady state wall temperatures were recorded at each increment. Three zones of heating were noted: (1) Below heat fluxes of 2500 Btu/hr-ft^2 a free convection zone was evident, where the wall temperatures were below the saturation temperature. (2) Between heat fluxes of 2500 to 7500 Btu/hr-ft^2, a nucleate boiling zone was detected; here the wall temperatures remained constant at essentially the saturation temperature. (3) At heat fluxes about 7500 Btu/hr-ft^2, a semi-film boiling region existed. The wall temperatures increased steadily with increasing heat fluxes, reaching a value of 900°F at heat fluxes of about 9400 Btu/hr-ft^2, at which point the test was terminated. The highest wall temperatures were noted about $3\frac{1}{2}$ in. from the bottom and decreased steadily up the channel.

2027. Troy, M.

ZERO-NET FLOW BURNOUT TESTS FOR WATER AT 2000 psia IN A VERTICAL 0.101 x 1 IN. x 6 IN. LONG RECTANGULAR CHANNEL, WAPD-TH-304 (1957), 9 p.

2028. Troy, M.

UPFLOW BURNOUT DATA FOR WATER AT 2000 psia IN 0.097 IN. x 1 IN. x 27 IN. LONG RECTANGULAR CHANNELS, WAPD-TH-340 (1957), 13 p.

To extend the range of variables, burnout tests were made on water at 2000 psia, flowing vertically upward in 0.097 in. x 1 in. x 27 in. long rectangular stainless steel channels (nominal L/D = 153). A total of 53 burnout points were obtained covering conditions from 100% exit quality to 80°F exit subcooling, mass velocities from 0.1 to 4.7 x 10^6 lb/hr-ft^2 and inlet water subcoolings from 36° to 536°F. Most of the points for higher heat fluxes and flow rates were obtained with the new 2500 KW power supply. This region could not previously be studied with the old power supply.

2029. Troy, M.

UPFLOW BURNOUT DATA FOR WATER IN RECTANGULAR CHANNELS AT PRESSURES FROM 600 to 1870 psia, WAPD-TH-321 (1957), 29 p.

Because of interest in operating reactors at pressures below 2000 psia, upflow burnout tests were performed on water at pressures from 600 to 1870 psia in vertical rectangular channels having length-to-equivalent diameter ratios (L/D) of 33, 153, and 242. (A total of about 90 burnout heat flux points were obtained, ranging from 0.134 to 2.26 x 10^6 Btu/hr-ft^2). The ranges of experimental variables (other than pressure) were mass velocities from 0.178 to 4.0 x 10^6 lb/hr-ft^2, inlet subcooling from 13 to 475°F, and exit qualities from 3 to 100% (See Table 1). In general, for all channels and pressures the burnout heat flux at given enthalpy increased as the pressure decreased. For the channel of L/D = 153 (at pressures below 2000 psia) the burnout heat flux at a given burnout point enthalpy appeared to increase from 40 to 110% with an increase in inlet subcooling of about 200°F. No such effect was observed with the other channels at any other conditions. The ranges of the ratio of measured to calculated burnout heat flux (calculated by the existing 2000 psia Thermal Design Criteria, Ref. 8), were 3.2 to 10.0 for the 0.101 in. x 1 in. x 6 in. channels, 1.3 to 7.3 for the 0.097 in. x 1 in. x 27 in. channels and 1.2 to 5.5 for the 0.059 in. x 1 in. x 27 in. channels. Efforts are underway to formulate new burnout design equations for these pressures below 2000 psia.

2030. Troy, M.

UPFLOW BURNOUT DATA FOR WATER AT 2000, 1200, 800, and 600 psia IN VERTICAL 0.070 IN. BY 2.25 IN. BY 72 IN. LONG STAINLESS STEEL RECTANGULAR CHANNELS, WAPD-TH-408 (1958), 18 p.

Upflow burnout data for water at 2000, 1200, 800 and 600 psia in vertical 0.070 in. by 2.25 in. by 72 in. long stainless steel rectangular channels are presented. The burnout heat fluxes for these channels are presented. The burnout heat fluxes for these channels depend upon the same parameters as did previously tested channels with much smaller L/D ratios. Bettis burnout design equations were used in calculations.

2031. Troy, M.

ANALYSIS OF MSAR TRANSITION BOILING AND FILM BOILING DATA FOR WATER AT 2000 psia, WAPD-AD-TH-492 (1959), 21 p.

Data recently obtained for transition boiling of water at 2000 psig and surface temperature less than 1050°F in a 0.152 in ID by 12.5 in. long round tube were correlated to ±35% by an equation. The approximate ranges of experimental conditions for transition boiling covered by the data are given. The form of the correlation equation was incorporated into an IBM-704 computer code to be used for reactor design calculations.

2032. Van Antwerpen, F. J., Jr., Ed.

HEAT TRANSFER - LOUISVILLE, Chemical Engineering Symposium Series, 52, No. 18, 1956, American Institute of Chemical Engineers, 116 p.

A generalized correlation is presented that predicts the burnout conditions over a wide range of pressures, velocities, geometrical configurations, and heat-flux densities but is limited to the local boiling region for water. Heat transfer coefficients were determined for Hg vapor condensing on both water- and air-cooled vertical steel, copperplated steel, nickel, and stainless steel. The data and correlations for the rate of convective heat transfer for gases flowing across a cylinder was re-examined. Experimental results are reported for pressure drop during forced-circulation boiling of distilled water in an electrically heated horizontal tube. Circulation rates and over-all temperature driving forces in a vertical thermosyphon reboiler were measured. Heat and mass transfer in cooler condensers of $TiCl_4$-N_2 system is presented. The effect of air rate, water rate, temperature, and packing density in a cross flow cooling tower are described. A study of heat transfer to organic liquids in single-tube, natural circulation, vertical tube boilers is presented. Heat transfer and fluid friction in a shell- and-tube exchanger with a single baffle are described.

2033. Vanderwater, R. G.

AN ANALYSIS OF BURNOUT IN TWO-PHASE, LIQUID-VAPOR FLOW, PhD. Thesis, University of Minnesota (1956).

2034. Viscardi, J. E., Ed.

BOILING BURNOUT NEWSLETTER, No. 4, NDA-6 (1955), 9 p.

Extracts from a status report on Al-H_2O reactions by O. J. Elgert, T. J. Boland, and G. L. Smith (Phillips Petroleum Co.) are presented. Six Al-U samples (Al-U core clad on one side with Al) in contact with H_2O and contained in pressure capsules were exposed in the MTR core for 6 to 12 sec. Three of the samples melted at the face in contact with H_2O. Capsule pressure changes occurred only when melting took place. Two of the 3 melting situations produced pressure transients and temperature rises that are discussed in some detail. A series of nucleate boiling burnout tests in the MTR has been proposed by WAPD in order to establish whether significant differences exist between electrical and inpile burnout data. A study by J. E. Zerbe (WAPD) of length-to-diameter ratio on the burnout heat flux of rectangular, vertical Zircaloy-2 channels is reported.

2035. Viscardi, J. E., ed.

BOILING BURNOUT PROGRESS, Issue No. 5, NDA-8 (1955), 8 p.

Preliminary burnout data were obtained for machined and hot-rolled rectangular Zircaloy-2 channels inclined at an angle of 45°. The test was performed to determine the effect of inclining the channels on burnout heat flux. The data are presented in tabular form.

2036. Viscardi, J. E.

BOILING BURNOUT PROGRESS, Issue No. 6, NDA-13 (1956), 6 p.

A study was made of nucleate boiling, film formation, and burnout for a 1 mil W wire heated by the superposition of impulse and dc heating in water at 200°F and an atmospheric pressure. In this study nucleate boiling is distinguished from film boiling by the characteristic bubble formation without a knowledge of the wire surface temperature. Film boiling is recognized when a continuous film covers all the surface of the wire in the field of view.

2037. Viscardi, J. E.

BOILING BURNOUT PROGRESS, Issue No. 7, NDA-22 (1955), 12 p.

Studies are reported in boiling burnout with simulated fuel elements, heat transfer to binary liquid mixtures, accurate determination of heat transfer to boiling H_2O-$CH_3COC_2H_5$ mixtures, and definition of terms related to boiling heat transfer.

2038. Viscardi, J. E., ed.

BOILING BURNOUT PROGRESS, Issue No. 8, NDA-24 (1956), 51 p.

There is no Classified Section Issue No. 8.

The latest experimental results on boiling and related phenomena are reported and discussed. Burnout, maximum heat transfer rates, frequency and formation characteristics of bubbles and vapor films, influence of element shape and surface properties, role of impurities, dissolved gases and pH values, temperature and density distributions, pressure drops, instability, corrosion, cavitation, and metal-water reactions are among the topics treated.

2039. Viscardi, J. E.

REACTOR HEAT TRANSFER PROGRESS NO. 12, NDA-31 (1956).

2040. Viscardi, J. E., ed.

REACTOR HEAT TRANSFER PROGRESS, Issue No. 12, NDA-30, AT(30-1)-862 (Oct. 30, 1956).

Abstracts are given for 26 papers on the latest results in high-performance heat transfer research and development for all types of nuclear reactor systems.

2041. Viscardi, J. E.

REACTOR HEAT TRANSFER PROGRESS NO. 13, NDA-33 (1957).

2042. Viscardi, J. E.

REACTOR HEAT TRANSFER PROGRESS NO. 13, NDA-35 (1957).

2043. Viskanta, R.

CRITICAL HEAT FLUX FOR WATER IN SWIRLING FLOW, Nuclear Science and Engineering, 10, No. 2, 202-203 (1961).

Concludes that of the several factors influencing the heat transfer mechanism, the mixing due to the density difference in the presence of the centrifugal force field is probably the most important. The test results indicate that centrifugal forces are effective in breaking up the vapor film on the heated surface and increasing the critical heat flux in swirling flow. On the basis of constant pumping power, the critical heat fluxes obtained with swirl flow are a maximum of $2\frac{1}{2}$ times higher than those for straight flow.

2044. Von Glahn, U. H.

EMPIRICAL CORRELATION OF CRITICAL BOILING HEAT FLUX IN FORCED FLOW UPWARD THROUGH UNIFORMLY HEATED TUBES, NASA Tech. Note D-1285 (1962).

Exptl. data were obtained on the max. crit. heat-flux (burnout condition) for H_2O,N, and H. Data for H_2O, were obtained at 14.7-2000 and for N and H at 50 lb/sq in. abs. An empirical correlation consisting of several dimensionless groups contg. variables which include fluid mass velocity, tube geometry, and fluid property terms is presented for prediction of max. crit. heat flux. (CA-62-13580f)

2045. Weatherhead, R. J.

BURNOUT WITH NET STEAM GENERATION IN VERTICAL, ROUND AND RECTANGULAR CHANNELS, ANL, Presented at the Reactor Heat Transfer Conference, New York, Nov. 1956, ANL-6675.

An empirical analysis is used to equate the pressure term in the Jens-Lottes nucleate boiling wall superheat equation to the liquid coolant surface tension, which modifies the equation to:

$$T_w - T_f = 0.18 \times 10^6 \sigma (Q''/10^6)^{1/4}$$

for surfaces of "average" nucleation capability. This equation is used to determine the pressure-dependency of several nucleate boiling characteristics, including proportionate nucleate bubble sizes. The pressure-dependency of the nucleate bubble-size characteristic is shown to be virtually identical with the pressure-dependency of the mass velocity term in the Jens-Lottes subcooled water critical heat flux correlation. Other alterations and additions are explained, and the modified form of the equation:

$$Q''_c/10^6 = \frac{2}{3} D_e^{-1/2} (H_{fg}/10^3)(G/10^6)^m \left[1 + \tanh \frac{H_f - H}{100}\right]$$

with $m = 0.175 \times 10^{-3} (v_{fg}/H_{fg})^{-1}$, is compared with data for circular and rectangular flow channels.

Several subcooled boiling flow regimes are hypothesized and explained to account for the unusual effect of the mass velocity upon the critical heat flux in the low subcooling-low steam quality region. A pronounced surface effect, paralleling the nucleate

boiling surface effect, upon the critical heat flux occurrence at the higher subcoolings is illustrated and used to explain apparent discrepancies within and among several representative bodies of critical heat flux data.

2046. Weatherhead, R. J.

HYDRODYNAMIC INSTABILITY AND THE CRITICAL HEAT FLUX OCCURRENCE IN FORCED CONVECTION VERTICAL BOILING CHANNELS, TID 16539 (April 19, 1962).

An analysis of the relations between hydrodynamic instability and the critical heat flux in water cooling systems is presented. It is concluded that hydrodynamic instability results from slug flow, which is precipitated in the bubble flow regime by coalescence of flow-stream bubbles to form vapor slugs. At constant pressure and rate of bubble generation, the initiation of slug flow is directly dependent on the local steam quality and inversely dependent on the mass velocity. Once initiated, the degree of hydrodynamic instability is dependent on the length of channel in the slug flow regime; this in turn is dependent on both the inlet subcooling and the L/D ratio. The critical heat flux occurrence is directly dependent on the degree of hydrodynamic instability, the significant variables being system pressure, local steam quality, mass velocity, inlet subcooling, and L/D ratio. (NSA 62-30554)

2047. Weatherhead, R. J.

HEAT TRANSFER, FLOW INSTABILITY, AND CRITICAL HEAT FLUX FOR WATER IN A SMALL TUBE AT 200 psia, ANL-6715, (June 1963).

Forced convection and local boiling heat transfer data for a 0.114-cm (0.045-in.) ID vertical tube at 14 kg/cm^2 (200 psia) is presented and compared with an appended simplification of the Dittus-Boelter equation and the Jens and Lottes equation for local boiling wall superheat. Deviations between the data and the latter are discussed.

Critical heat flux data for the nucleate and net boiling regions is discussed, and arguments for a purely hydrodynamic causation of the net boiling critical heat flux are presented.

2048. Weiss, A.

HOT PATCH BURNOUT TESTS IN A 0.097 in. x 1 in. x 27 in. LONG RECTANGULAR CHANNEL AT 2000 psia, WAPD-TH-338 (1957), 12 p.

A series of upflow burnout tests were conducted in the Bettis Burnout Loop No. 23 on a 0.097 in. x 1 in. x 27$\frac{1}{16}$ in. long (L/D_e = 140) test specimen that contained a local "hot patch" which had a flux peak 1.98 times that existing in the remainder of the test specimen. The "hot patch" was 1$\frac{3}{8}$ in. long ($L_{patch}/D_e \approx 7$) located $\frac{3}{8}$ in. from the exit of the channel. The range of variables investigated were mass velocities of 0.35 x 10^6 to 2.0 x 10^6 lb/hr-ft^2 at inlet temperatures of 100, 300, and 500°F. The results of these tests indicate a peak effectiveness varying from 100 to 4% as the enthalpy at burnout varies from 550 Btu/lb to 918 Btu/lb.

2049. Weiss, A.

EMERGENCY COOLING TESTS ON ELECTRICALLY HEATED SUBASSEMBLIES WITH WATER AT 2000 psia, WAPD-AD-TH-559 (1960).

2050. Wett, J. F.

NATURAL CIRCULATION BURN OUT HEAT FLUX FOR THE ORR, CF-60-2-61 (1960), 23 p.

Natural circulation flow rate is calculated for the ORR core. From this flow rate, the burn out heat flux is found to be between 22,000 and 35,000 Btu/ft^2-hr. It is concluded that under present conditions a positive acting after heat removal system is necessary for 30 Mw operation.

2051. Williams, J. S., Jr.

RESPONSE OF PLATE-CHANNEL SYSTEMS IN THE "BEYOND DNB" HEAT TRANSFER REGION AS CALCULATED WITH FOO_{22}, WAPD-AD-TH-487(Del.) (March 30, 1959), 14 p.

A quantitative analysis was made of the response of plate fuel elements in the "beyond DNB (direct nucleate boiling)" heat transfer region. Two solutions were derived, one with no scram and the other with a scram at 0.8 sec. after start of accident, and a forced DNB 0.5 sec after accident is assumed in both cases. Plots are given for inlet flow, pressure drop, and temperature variations with time. The results for no scram showed that meltdown was imminent at 2.3 sec after the start of the accident, and a scram after 0.8 sec gave recovery from DNB and a metal temperature excursion of only 33°F before recovery.

2052. Wilson, R. H., and Ferrell, J. K.

CORRELATION OF CRITICAL HEAT FLUX FOR BOILING WATER IN FORCED CIRCULATION AT ELEVATED PRESSURES, BAW-168 (1961), 34 p.

The development of a critical heat flux correlation for water in forced circulation at elevated pressures is described. In contrast to earlier correlations in the literature, which present critical heat flux as a function of dependent variables such as outlet subcooling or enthalpy, this correlation presents the critical heat flux as a function of the independent variables, mass velocity, channel thickness, channel length, and subcooling at the channel inlet. Comparisons with experimental data in the form of frequency plots show the superiority of this critical heat flux equation for correlating existing data.

2053. Woodson, C. W., and Batch, J. M.

A COLLECTION OF BOILING HEAT TRANSFER AND BURNOUT CORRELATIONS, HW-71684, (1961), 37 p.

Boiling correlations collected from several publications are presented using common nomenclature. The correlations are classified according to an included list of cases. These cases depend on the mode of flow, the coolant condition, and the type of boiling. Definitions and a list of standard symbols are included.

2054. Yashnov, V. I.

THE INFLUENCE OF CERTAIN SURFACE PROPERTIES ON CRITICAL BOILING, Teploperedacha Energ. inst. AN SSSR. Ed. by M. A. Mikheyev., Moscow, Izd-vo AN SSSR, 1962, 116-123.

Previous workers have observed that if a heating surface is conditioned by boiling water on it for a period the critical heat transfer rate which it can carry may be much greater than with a clean fresh surface. The present work was undertaken to investigate the effect further. Tests were made with stainless steel 1X18119T (1Kh18N9T) tube heated by alternating current using the following classes of finish: rough (80 to 40μ); smooth (3.2 to 1.6μ); polished (0.2μ). The smooth tubes in the initial clean condition display critical boiling at a heat transfer rate of about 650 x 10^3 kcal/m^2 hour and on conditioning the tubes by boiling water with them at a rate of 200 x 10^3 kcal/m^2 hour, the critical boiling rate was raised to about 1150 x 10^3 kcal/m^2 hour. The rate of stabilization could be increased by raising the heat transfer rate during the conditioning period. The conditioned surface remained stable when the tubes were exposed to air. The conditioning effect was very much less marked on the rough tubes which from the start had a critical heat transfer rate of 900 to 1150 x 10^3 kcal/m^2 hour. With polished tubes the initial rate was 600 x 10^3 kcal/m^2 hr. and here again the conditioning effect was less than on smooth tubes, the critical rate being increased by 30% after boiling. There are 4 figures and 1 table.

2055. Zenkevich, B. A., and Subbotin, V. I.

CRITICAL HEAT LOADINGS IN FORCED FLOW OF WATER HEATED BELOW BOILING, Atomnaia Energiia 3, No. 8, 149-52 (1957), English translation in: Soviet Journal of Atomic Energy 3, 915-919 (1957).

Works that have been published to date describing experimental investigations directed to the study of conditions of incipient criticality in boiling regime under forced flow of water that is heated below saturation temperature, cover a range of pressures no higher than 140 atmospheres. However, the range of pressures above 140 atmospheres is also of interest to power reactor design. This work is devoted to the study of critical heat loadings, for flow in vertical tubes, of water with bulk heated to below saturation temperature in the range of pressures between 140 and 220 atmospheres.

2056. Zerbe, J. F., (Chairman).

WORKING CONFERENCE NO. II: BURNOUT IN NATURAL AND FORCED CONVECTION, in Reactor Heat Transfer Conference, New York, Nov. 1 and 2, 1956 (J. E. Viscardi, ed.) TID-7529 (Part I) (p. 586-607)

2057. Nuclear Development Associates.

BOILING BURNOUT NEWSLETTER NO. 1, M-5508 December 1, 1954, 23 p.

2058. Societe Nationale d'Etude et de Construction de Moteurs 'd Aviation.

INFLUENCE OF CENTRIFUGAL TWISTED TAPES ON FREON BURN-OUT FLUX, Review of Test. Special Report No. 4, EURAEC-145 (1961), 72 p.

Activities in a program to obtain preliminary results on the heat transfer improvement in boiling liquids through vortices induced by twisted tapes are described. The installation and operation of a large hot water test loop is also described. Freon was used in the boiling liquid heat transfer tests, the data from which are for use in preparing tests in the boiling water loop.

2059. Centro Informazioni Stud, Esperienze, Milan.

DEVELOPMENT PROGRAM ON THE APPLICATION OF STEAM-WATER SPRAY TO REACTOR COOLING. CAN 3-Progress Report No. 1, Dec. 15, 1961-Mar. 31, 1962, EURAEC 289, (Apr. 5, 1962)

Initial progress is reported in a program concerned with large scale experiments on heat transfer and hydrodynamics using steam-water mixtures, and in-pile experiments on the behavior of steam-water mixtures under radiation (radioactivity entrainment, radiolysis, corrosion). The facilities used for these experiments are respectively, a loop, modified and expanded, existing at Ansaldo, Genoa, and already exploited under the CAN-1 program for steam-water mixing and separation tests, and a loop, specially designed, for in-pile experiments. Modification work is in progress on the Ansaldo loop. This facility will be equipped with a d-c generating system for electrical heating of the test elements (maximum power 1.16 Mw). The design of the in-pile loop is in progress with the help of preliminary experiments now under way. Orders were placed for all the components of the loop. Completion of loop assembly was expected by July 1962. (NSA 62-31791)

CRYOGENIC FLUIDS

2060. Arnett, R. W.

BULK DENSITY OF BOILING LIQUID OXYGEN, Advan. Cryog. Eng. 7, 214-18 (1961).

Expressions are detd. for flow velocity in a liquid-O tank, both from head-loss and from heat-balance equations. Simultaneous solution of these equations permits evaluation of various parameters involved. The calcd. values of bulk d. are generally less than the exptl. ds. based on satn. at the ullage pressure. Resolution of this discrepancy is discussed. (CA-62-12282g)

2061. Class, C. R., et al.

BOILING HEAT TRANSFER TO LIQUID HYDROGEN FROM FLAT SURFACES, Advances in Cryogenic Engineering 5, K. D. Timmerhaus, ed., Plenum Press, New York (1960).

Presents the experimental data obtained for the transfer of heat to boiling hydrogen from a relatively large flat surface under a variety of conditions. These conditions include the angle of orientation of the surface, surface condition, and hydrogen pressure. The effect of vertical height of the heating surface was also noted. A limited amount of experimental data can be found in the literature on heat

transfer to boiling hydrogen, but the results are not in close agreement. In almost every case a very small heater was used and the effects of a number of variables were not investigated. Although the experimental data bracketed data obtained by theoretical correlations, it was not possible to determine which experimental data were more accurate.

2062. Dean, J. W.

HEAT TRANSFER COEFFICIENTS FOR BOILING AND CONDENSING NITROGEN, M. S. Thesis, University of Colorado (1958).

2063. Drayer, D. E., and Timmerhaus, K. D.

AN EXPERIMENTAL INVESTIGATION OF THE INDIVIDUAL BOILING AND CONDENSING HEAT TRANSFER COEFFICIENT FOR HYDROGEN, Paper J-6, presented at 1961 Cryogenic Engineering Conference, Ann Arbor, Mich. Published in Advances in Cryogenic Engineering, Vol. VII, p. 401.

The efficient design of low-temperature hydrogen heat exchangers requires detailed heat-transfer information relevant to temperature gradients, heat fluxes, surface conditions and geometry, materials of construction, flow rates, and other important variables. This investigation determined only the relationship between the individual film heat-transfer coefficients and the variables of temperature difference and heat flux for boiling and condensing hydrogen films on a smooth vertical tube surface. The boiling occurred on the outside surface while the condensing took place on the inside surface.

Several theoretical and empirical correlations have been developed for predicting boiling and condensing heat-transfer coefficients for normal fluids, i. e., fluids whose boiling points are near room temperature. However, for cryogenic fluids many of these correlations fail to apply. An added objective of this investigation was to make such comparisons between calculated and experimental heat-transfer coefficients to establish the applicability of these correlations to boiling and condensing hydrogen. Other investigators have done this for the boiling heat-transfer coefficient but this study is the first to do it for the condensing heat-transfer coefficient as well.

2064. Dupre, A., van Itterbeek, A., and Brandt, G.

ON THE INCREASE OF THE BOILING TEMPERATURE OF LIQUID OXYGEN IN A MAGNETIC FIELD, Physica, vol. 28, No. 4, 353-6 (Apr. 1962).

The boiling temperature of liquid oxygen at atmospheric pressure was measured by means of a platinum thermometer in magnetic fields up to 28.8 kG. After taking into account a rough correction for magnetoresistance of the platinum and for nitrogen impurities in the liquid oxygen, the increase of the boiling temperature amounts to about 70% of the value calculated by Kapitza (1937) for a paramagnetic liquid in an inhomogeneous magnetic field. The discrepancy between the actual result and the theoretical value is believed to be due to heat transport in the liquid. (SA 62-9456)

2065. Flynn, T. M., et al.

NUCLEATE AND FILM BOILING CURVE OF LIQUID NITROGEN AT ONE ATMOSPHERE, Advan. Cryog. Eng. 7, 539 (1961).

Heat transfer from metal wall to boiling liquids is the least developed phase of heat transfer. Existence of 4 distinct regions, convective, nucleate, metastable, and stable film boiling, was established in the mechanism of boiling. These regions depend on temp. difference across the film. The complete curve representing boiling heat transfer in liquid N throughout the nucleate, metastable, and film boiling regions was detd. on a single surface. The elec. heated app. used for detg. heat flux vs. temp. difference is described. The data obtained, though highly consistent, differs from other previous sets and theoretical predictions mainly because of differences in nature of surfaces and selecting the proper temps. for fluid property evaluation. Hence, accurate prediction of boiling heat transfer rates in cryogenic fluids is still doubtful.

2066. Frederking, T.

HEAT TRANSFER IN VAPORIZATION OF LIQUEFIED HELIUM AND NITROGEN GASES, Forschung auf dem Gebiete des Ingenieurwesens 27, 17-30; 58-62 (1961).

Heat transfer in vaporization, on electrically heated platinum wires, of liquefied helium and nitrogen gases, particularly during natural convection film boiling; results of measurements, together with theoretical data for horizontal cylinder and literature data for other gases, are used to draw conclusions on effect of diameter on heat transfer coefficient. 54 refs.

2067. Gaffee, D. I., and Monroe, A. G.

HEAT-TRANSFER COEFFICIENT TO BOILING OXYGEN, Congr. intern. froid, 9^{e}, Paris, 1955, Compt. rend. trav. comm. I et II, 1011-23.

Heat-transfer coeffs. for oxygen in the supercrit. region were measured by using hot water and steam as the heating fluids in tubes 0.5 in. in diameter.

2068. Grassmann, Peter.

SIMULTANEOUS MASS AND HEAT TRANSFER BETWEEN VAPOR AND LIQUID IN A TWO COMPONENT SYSTEM, Dechema Monograph 26, 154-67 (1956).

The mechanism of mass and heat transfer on the bottom of a plate in a distn. column, was examd. A gaseous mixt. of N_2-O_2 was pumped through an orifice into a liquid mixt. of the same compn. Gas velocities, concns., temps. and pressures were measured. Bubble formation, shape, and movement were followed with a camera taking 1000 pictures per sec. Relations of Reynolds, Nusselt, Schmidt, and Weber nos. were derived and plotted.

2069. Grassmann, P., et al.

HEAT TRANSFER TO LIQUID HELIUM BY NUCLEATE AND STABLE FILM BOILING, Kaltetechnik 10, 206-9 (1958).

Electrically heated probes were used to det. the heat-transfer coeff. for nucleate boiling at 2.83, 3.05, and 3.57°K. The temp. difference ΔT between the

probe surface and liquid He ranged from 0.1 to 1°K. Thin Pt wires (30 to 50μ) or wollaston-coated Pt wires (<30μ) were used to measure film boiling coeffs, at $30 < \Delta T < 1000$°K. The heat-transfer coeffs. for wire diams., d, between 5 and 50 μ were approx. proportional to $\Delta T^{0.28}/d^{0.7}$.

2070. Gurevich, M. I.

HEAT TRANSFER IN A VAPORIZING HEAT EXCHANGER OF AN OXYGEN APPARATUS WITH A LIQUID PUMP., Tr. Ural'sk. Politekhn. Inst., Sb., No. 108, 89-96 (1961).

An anal. study was made of heat transfer in the vaporizing heat exchanger of an air-sepg. app. with a liquid O pump. The heat exchanger studied was a concentric pipe type, in which evapg. O flows through the inner pipe, cooled by air flowing countercurrently in a circumferential channel and with exhaust N flowing through the outer pipe. At the same time heat exchange takes place between the air and O through the surface of the inner pipe and between the air and N through the surface of the outer pipe. Differential equations are given for the heat fluxes through both surfaces and for the total heat flux. Equations are obtained giving temp. curves for N, O, and air; the desired length of the heat exchanger pipes can be detd. with the aid of these equations by using a method of successive approximations. From Ref. Zh., Khim. 1962, Abstr. No. 10K90. (CA-62-16354e)

2071. Haselden, G. G., and Peters, J. I.

HEAT TRANSFER TO BOILING LIQUID O_2 AND LIQUID N_2, Trans. Inst. of Chem. Eng. (London), 27, 201-208 (1949).

Lab. app. for studying heat transfer to boiling liquid O_2 and N_2 is described and the effect of certain variables on h, the heat transfer coeff., noted. The value of h is unaffected by tube diam. and depth of immersion in the range of $\frac{1}{4}$ to 18 in., but it is strongly increased by an increase in Δt. For horizontal tubes the top of the tube is found to be hotter than the bottom, the difference from top to bottom being greatest when the Δt from tube to liquid is lowest. Agitation greatly increased h at low Δt values but has hardly any effect with $\Delta t > 7$°F. Formulation of a general equation for boiling is considered premature because of the wide divergence of exptl. data and predictions of equations which have been proposed.

2072. Henricks, R. C., et al.

EXPERIMENTAL HEAT TRANSFER AND PRESSURE DROP OF LIQUID HYDROGEN FLOWING THROUGH A HEATED TUBE, NASA TN D-765 (1961), 62 p.

Heat-transfer and pressure-drop characteristics of liquid parahydrogen flowing through a vertical tube are correlated on film conditions using the Martinelli parameter and a modified Dittus-Boelter experimental Nusselt number relation. Conditions investigated were: inlet pressure, 30 to 70 lb/sq in. abs; heat flux to 1 Btu/(sq in.)(sec); temperature differential, 50° to 750°R between wall and bulk. The friction losses are negligible relative to the momentum losses, and pressure drop may be predicted by the one-dimensional momentum equation. Paraortho conversion is discussed, and property data and a design procedure are presented.

2073. Henricks, R. C., et al.

CORRELATION OF HYDROGEN HEAT TRANSFER IN BOILING AND SUPERCRITICAL PRESSURE STATES, Am. Rocket Soc. J. 32, 244-52 (Feb. 1962).

The use of hydrogen as a working fluid in both chemical and nuclear propulsion systems necessitates convective heat transfer information over a broad range of fluid states. Current heat transfer correlation schemes available in the literature are discussed in terms of their applicability to hydrogen heat transfer. Similarities in the subcritical and supercritical (pressure) heat transfer mechanisms and associated experimental data are reported. Summarized are correlation schemes formulated from heated tube data which apply to: 1) film boiling of liquid hydrogen; 2) hydrogen at supercritical pressure just above and below critical temperature; and 3) low temperature hydrogen (150 to 250°R) above the critical pressure. Parts 1 and 2 have required correlation schemes that depart from the conventional convective pipe flow concepts. It does appear that the conventional pipe flow heat transfer theory can be applied to part 3.

2074. Hoge, H. J., and Brickwedde, F. G.

RATE OF HEAT TRANSFER FROM A HORIZONTAL, HEATED COPPER TUBE IN BOILING LIQUID HYDROGEN OR OXYGEN, A-366 (1942), 6 p.

Measurements were made to determine the rate of transfer of heat from a horizontal, heated Cu tube immersed in boiling liquid H_2 as a function of the difference in temperature between the Cu surface and the liquid bath. Similar measurements were made with liquid O_2 replacing the liquid H_2 as a check on the reliability of the liquid H_2 results.

2075. Ivanov, M. E. et al.

HEAT EMISSION DURING THE BOILING OF OXYGEN AND NITROGEN, Kislorod 11, No. 3 (1958).

2075a. Lewis, J. P., Goodykoontz, J. H., and Kline, J. F.

BOILING HEAT TRANSFER TO LIQUID HYDROGEN AND NITROGEN IN FORCED FLOW, NASA TN D1314 (1962), 56 p.

Bulk boiling inside an electrically heated cylindrical tube was studied under vertically upward forced flow. Tube-wall temperatures and heating rates were obtained over a range of fluid-flow rates for small variations in inlet pressure and at low values of inlet subcooling. Transition in the type of boiling heat transfer was obtained at various positions along the tube. The maximum critical heat flux corresponding to transition varied with fluid-flow rate and transition length in a manner similar to results obtained with water. Fluctuations of temperature, flow rate, and pressure occurred during some of the boiling tests. No measurable pressure drop across the test section was obtained.

2076. Lukomskii, S. M.

HEAT EXCHANGE IN BOILING CARBON DIOXIDE IN TUBES UNDER HIGH PRESSURE, Izvest. Akad. Nauk SSSR, Otdel, Tekh. Nauk. 967-75 (1947).

The effect of pressure on heat transfer when CO_2 was boiled in tubes was studied over the range from 55 to 74.5 kg/sq mm abs (from 0.7 to 1.0 times the crit. pressure) with heat flows from 10,000 to 140,000 kcal/(sq m hr) at temp. differences from 1 to 200° with liquid velocities from 0.1 to 1.5 m/sec. With increased pressure, max attainable heat flow decreased at a Δt of 20° from 113,000 to 12,000 kcal/(sq m hr) for a change in pressure from 65 to 74 kg/sq cm abs. The crit. temp. difference (corresponding to the transition between bubble and film boiling also decreased with increase in pressure: from 20° at 0.9 of the crit. pressure to near 0° at 0.97 of the crit. pressure. Heat-transfer coeff. is almost independent of pressure for bubble boiling but increases with an increase in pressure in the case of film boiling. Max. and min. heat flow, q, as a function of temp. difference decreases with increase in pressure and tends to become one and the same. In bubble boiling, liquid velocity was found to have no effect, but a marked effect was noted in the case of film boiling. L.'s work agrees qualitatively with the previously published work of Nukiyama.

2077. Malacarne, O. J., and Pashley, J. H.

TESTING OF KARBATE AND IMPERVITE IN BOILING AND CONDENSING HYDROGEN FLUORIDE AZEOTROPE, K-1377 (1958), 18 p.

Boiler-condenser units, fabricated of Karbate and Impervite (resin-filled graphites), have exhibited excellent resistance to boiling and condensing HF-H_2O solns. of azeotropic concn. (38% acid). No visible attack on the heat transfer surfaces of either unit was observed after operation at total reflux for over 5000 hrs. Standard tensile and compressive strength tests indicated no significant weakening of the Karbate, and chem. analyses indicated a low fluoride content consistent with the porosity of the material. Both materials should be satisfactory for plant service with aq. HF of at least the azeotropic concn., and temps. of at least 300°F, providing the structural limitations are recognized in design and operation. From Nucl. Sci. Abstr. 14, Abstr. No. 21544 (1960).

2078. Merte, H., Jr., and Clark, J. A.

BOILING HEAT TRANSFER DATA FOR LIQUID NITROGEN AT STANDARD AND NEAR ZERO GRAVITY, Advan. Cryog. Eng. 7, 546-50 (1961).

Transient flux rates for cooling of a Cu sphere immersed in boiling N were measured with a recording thermocouple at 1.0 g and at approx. 0.01 g. with the container in free fall. Definitely lower values for heat flux were found in free fall as compared to those found at rest. The ratio of the peak rates at the 2 conditions is 0.45 and in reasonable agreement with expts. on burnout of a Pt wire in H_2O. Because of the short (1.4 sec) zero-gravity period, the results are to be considered tentative.

2079. Minkoff, G. J., Scherber, F. I., and Stober, A. K.

SUPPRESSION OF BUBBLING IN BOILING REFRIGERANTS, Nature 180, 1413-14 (1957).

Bubbles in the body of a refrigerant can be eliminated by introducing a stream of an insol. gas, having a b.p. much lower than that of the refrigerant. Thus, He, H, and Ne suppressed bubbling of liquid N; similarly, He in liquid air, liquid O, and liquid A. Introducing the gas stream below the surface rather than over the surface reduced the rate of gas flow necessary to suppress bubbling.

2080. Monroe, A. G., Bristow, H. A. S., and Newell, J. E.

HEAT TRANSFER TO BOILING LIQUIDS AT LOW TEMPERATURES AND ELEVATED PRESSURES, J. Appl. Chem. 2, 613-24 (Nov. 1952).

The work on heat transfer to boiling liquids is reviewed, and a special note is given to the various types of boiling observed. Liquid O and N were boiled in tubes at pressures from atm. to 2000 lb/sq in. gage. The heat-transfer coeffs. followed the general theory for metastable film boiling, i.e. decreasing with increasing temp. difference. At low Re nos. the film coeff. was a function of $Re^{0.8}$. At higher values this relation did not hold owing to an increase of liquid in the mixt. At pressures above crit., the heat-transfer coeff. increased with pressure increase and flow rate, but decreased with increasing temp. difference.

2081. Richards, R. J., et al.

HEAT TRANSFER TO BOILING LIQUID NITROGEN AND HYDROGEN FLOWING AXIALLY THROUGH NARROW ANNULAR PASSAGES, Advances in Cryogenic Engineering 3, K. D. Timmerhaus ed., Plenum Press, New York (1960).

The purpose of the investigations described here was to obtain information concerning the maximum heat dissipation of boiling nitrogen and hydrogen flowing through narrow channels. The sponsoring agency had two uses for this information: 1) To provide a check for the theory of Sydoriak and Roberts.* 2) To provide a check on the LASL experimental data. The studies by Sydoriak and Roberts were not extensive; it was felt that a thorough investigation might provide more reliable predictions of maximum heat dissipation by boiling cryogenic liquids. Considering practical application of this work, the only concern here was the prediction of the maximum safe operating power of an electromagnet cooled to 20°K by boiling hydrogen. This magnet, described in the Sydoriak and Roberts' paper, has narrow channels (the order of 0.010 in. gap width) through which boiling hydrogen would flow. The studies here were conducted using a test apparatus simulating an electromagnet.

*J. Appl. Phys. 28, 143-8 (1957).

2082. Sydoriak, S. G., and Roberts, T. R.

STUDY OF BOILING IN SHORT NARROW CHANNELS AND ITS APPLICATION TO DESIGN MAGNETS COOLED BY LIQUID H_2 AND N_2, J. Appl. Phys. 28, 143-148 (1957).

A study has been made of the critical heat input, $\dot{Q}_c$, to liquid H_2 and N_2 boiling in an annular gap, of cross-section area, A, between a vertical cylindrical heater of height, Z, and various concentric plugs. The data are in approximate agreement with calculations based on an assumption of homogeneous and frictionless two phase flow. The pressure drop across the channel is spent primarily to accelerate the vapor being formed and the liquid carried with it. The derived relation does not contain any empirical coefficients or exponents. For $\rho_{V,2} \ll \rho_L$ the general equation reduces to

$$\dot{Q} = AL(\rho_{V,2}\rho_L Z_e g f_2)^{1/2} \quad ,$$

where L is the latent heat of vaporization, $\rho_{V,2}$ the exit vapor density, ρL the liquid density, g the gravitational acceleration, Z_e the hydrostatic head equivalent to the pressure drop across the heater, and f_2 the mass fraction of vapor in the fluid leaving the heater.

Forced flow experiments give f_2. At $\dot{Q}_C$ equal to that found in natural convection boiling, $f_2 \doteq 0.5$ for both liquids. For Z = 3 or 6 in. and a channel thickness of 0.022 in. the ratio of observed to calculated $\dot{Q}$ is 0.95 for N_2 and 0.70 for H_2. The calculation is equally good for critical natural convection experiments, $Z_e = Z$, and for subcritical as well as critical forced flow measurements, which extend up to $Z_e = 70$ Z.

The optimum operating vapor pressure is discussed for magnets cooled by ideal natural convection boiling. A simple roll-type of coil is discussed and is shown to be superior in some respects to more conventional windings.

2083. Vishnev, I. P.

HEAT EXCHANGE WITH EBULLITION OF LIQUEFIED GASES IN PIPES, Referativnyy zhurnal, Mekhanika, No. 4, 1962, 91-92, abstract 4B603 (Achievements and problems in the use of cold in the national economy of the USSR, Moscow, 1960, 47-55).

A study is made of the ebullition of liquid O_2 in vertical copper pipes of internal diameter d = 4 - 99 mm, and length l = 340 - 5060 mm (l/d = 45 - 650) with thermal loads q = 100 - 50,000 kcal/m^2hour, with volumetric vapor content 0 - 99.9% and apparent liquid level h = 0.26 - 0.98. Within fixed limits of h, on lowering the liquid level the coefficient of heat-exchange with ebullition α_{ebull} increases, and the greatest intensity of heat-exchange takes place with minimum velocity of the liquid on entrance into the pipe; for $l/d > 500$ the effect on the heat-exchange disappears. The experimental data, obtained for all the pipes tested, are described by the criteria equation $N = 0.0376 P^{0.35} R_x^{0.7} h^{-m}$, where $R_x = 4q(l/d)^{0.65}[\sigma/(\gamma_{liq.} - \gamma_{vap.})]^{0.5}/r\gamma_{vap.}\nu$; σ is the surface tension at the boundary liquid vapor, $\gamma_{liq.}$ r and ν are the density, latent heat of vaporization and kinematic viscosity of the liquid, $\sigma_{vap.}$ is the density of the vapor;

$$m = 2900(l/d)^{-1.65} 10^{-1g[29000(l/d)^{-1.65}]g/0.1 q_{cr}}$$

q_{cr} is the critical thermal load for transition from a bubbling to a film regime of ebullition in a large volume of the liquid. (Abstracter's note: Complete translation.]

2084. Vishnev, I. P., and Elukhin, N. K.

ON THE PROBLEM OF HEAT EXCHANGE DURING LIQUID BOILING IN TUBES, Translated from: Inzhener.-Fiz. Zhur., Akad. Nauk Belorus. S.S.R., 3, 74-80 (1960), UCRL-Trans.-677 (1960).

During the study of boiling in oxygen, the effect of geometrical dimensions of tubes on heat exchange was established. On the basis of theory of similarity, a criterial system was derived and a calculation formula proposed for determining heat exchange during boiling of different liquids inside of tubes.

2085. Von Glahn, U. H., and Lewis, J. P.

NUCLEATE AND FILM BOILING STUDIES WITH LIQUID HYDROGEN, Advances in Cryogenic Engineering, 5, K. D. Timmerhaus ed., Plenum Press, Inc., New York (1960).

Investigated nucleate and film boiling with cryogenic fluids, particularly liquid hydrogen, under conditions of forced flow. Heat transfer data using cryogenic fluids were to be compared with existing data for water in an effort to obtain general correlations of boiling heat transfer.

2086. Wallis, G. B.

SOME HYDRODYNAMIC ASPECTS TO TWO-PHASE FLOW AND BOILING, p. 319-40 of "International Developments in Heat Transfer, Part II." New York, The American Society of Mechanical Engineers, (1961).

Over-all heat transfer coefficients for condensing and boiling hydrogen films were determined for temperature gradients ranging from 0.38 to 6.06°F for a single smooth vertical brass tube. Temperature difference between the condensing and boiling films was regulated and observed by changes in vapor pressure. Over-all heat transfer coefficients under these experimental conditions were plotted not only as a function of the temperature difference but also of the heat flux and were compared as far as possible with known values in the literature and with computations based on standard texts. The latter comparison indicated that the computational values may in certain cases be off by as much as a factor of two to three. Consequently further investigations are being conducted to evaluate the over-all heat transfer coefficients and to check previously reported individual heat transfer coefficients especially with regards to the effect of surface conditions on these coefficients.

2087. Weil, Louis, and Lacaze, Albert

HEAT EXCHANGED IN BOILING HYDROGEN UNDER ATMOSPHERIC PRESSURE, J. de Physique et le Radium 12, 890, 1951.

The heat exchanged between a surface of liquid H under 750 mm pressure and a Pb wire is approx. 2 w/sq cm for a temp. difference of approx. 2°. The

values vary up to approx. 8 w/sq cm for a 200° temp. difference.

2088. Weil, L., and Lacaze, A.

HEAT EXCHANGE IN LIQUID NITROGEN BOILING UNDER DIFFERENT PRESSURES, Bull. inst. intern. froid, Annexe 1955-2, 85-8 (1954).

At a given pressure over the range 0.21 to 25 atm., the heat exchanged per sq cm plotted as a logarithmic function of the temp. difference between surface and liquid is independent of the nature and design of the surface. Curves for different pressures are roughly parallel. The higher the pressure, the lower is the temp. difference for the start of the large increase of heat exchange preceding film boiling. This difference is about 8° at 0.21 atms. and 2° at 25 atms. The heat exchange may, under pressure, reach 50 watts/sq cm.

2089. Wright, C. C., and Walters, H. H.

SINGLE-TUBE HEAT TRANSFER TESTS WITH GASEOUS AND LIQUID HYDROGEN, U. S. Dept. of Commerce, Office of Technical Services, PB-156,473 (1959), 58 p.

Single-tube heat transfer tests are described, which were conducted with gaseous and liquid H. In the gaseous H tests, the test unit was operated as a counterflow heat exchanger in which ambient-temp. He was used to heat normal H gas at a temp. of about 100°R, and a pressure of 700 lb/sq in. abs. In the liquid-H test, heat was applied to the outer surface of the Cu tube with an elec. resistance heating element, while satd. liquid was allowed to flow through the tube. Test results were obtained in both the nucleate boiling region and the stable film boiling region. The gaseous H test results agreed within ±20% of the predicted results. No data were obtained near the crit. point of H. The liquid-H tests gave interesting information on forced convection boiling. At a pressure of 1.6 atm. and a Reynolds no. of about 275,000, the peak heat flux for nucleate boiling occurred at a temp. difference of about 3.6°R. and the peak heat transfer coeff. was about 5900 Btu/hr ft.°R. At a pressure of 2.2 atm. and a Reynolds no. of about 510,000, the peak heat flux for nucleate boiling occurred at a temp. difference of about 6.1°R., and the peak heat transfer coeff. was about 6600 Btu/hr ft°R. The lowest temp. differences in the stable film boiling range were about 40-50°R. and the heat transfer coeffs. were only about 10% as high as the peak coeff. in the nucleate boiling range. The film-boiling heat transfer coeffs. were very nearly const. over the range of temp. differences that were obtained (40-300°R.). Test procedures, test app., and the methods of data redn. are also described. The test data are summarized in both tabular and graphical form. A comparison with available data in the literature is also made.

2090. Zuber, N.

TWO-PHASE FLOW AND BOILING HEAT TRANSFER TO CRYOGENIC LIQUIDS, American Rocket Soc., J., 32, 1332-41 (Sept. 1962).

The use of available information for predicting the rates of heat transfer to liquid hydrogen in particular and other fluids in general when a change of phase takes place is investigated and evaluated. The dimensionless groups are discussed, and various methods of correlation are compared with the experimental data for liquid hydrogen. (NSA 62-33133)

DENSITY STUDIES

2091. Antonov, A. Ya., and Panasenko, M. D.

THE INFLUENCE OF THE VAPOR VOLUME FRACTION UPON THE CRITICAL HEIGHT OF THE VAPOR SPACE IN A BOILER, Teploenergetika, 4, No. 8, 39 (1957).

2092. Bailey, R. V., et al.

TRANSPORT OF GASES THROUGH LIQUID-GAS MIXTURES, CF-55-12-118 (1955).

The designs and analyses of many operations involving interaction between liquid and gaseous systems (e.g., fractionating towers, evaporators, steam generators, boiling nuclear reactors, etc.) suffer from a lack of information of the gas throughput versus gas hold-up in the system. For the gas throughput versus gas hold-up in vertical pipes the following data and analyses are presented: Experimental data in non-circulating systems to show the effect of pipe size and the effect of the physical properties of the gas and liquid; experimental data in non-circulating systems for the average fluctuation of the gas hold-up; experimental data of the radial gas distribution; an analytical model for the prediction of gas throughput versus gas hold-up in circulating systems (both gas and liquid flowing through the pipe); and an experimental confirmation of the utility of an analytical model.

2093. Bankoff, S. G.

A VARIABLE DENSITY SINGLE-FLUID MODEL FOR TWO PHASE FLOW WITH PARTICULAR REFERENCE TO STEAM WATER FLOW, ASME Paper 59-Ht-7, for meeting Aug 9-12 (1959), 9 p.

Model proposed for turbulent, cocurrent flow of liquid and gas or vapor through pipe or channel, which assumes fluid to be single phase whose density is function of radial position; model is applied to steam-water flow, and is shown to give good agreement with R. C. Martinelli-D.B. Nelson correlation. (EI (1959) p. 478)

2094. Blickle, Tibor.

A NEW EQUATION FOR THE DEFINITION OF THE CHANGES IN FREE VOLUME IN FLUIDIZED LAYERS, Magyar Kem. Folyoirat 65, 221-3 (1959).

The equation $\epsilon^2 - \epsilon_M^2 = (V - V_m)/k\sqrt{gd}$, where ϵ is the percentage free vol., ϵ_M is that at the fluidization

point, V is the linear gas rate in the empty tube, V_m is that at the fluidization point, k is a const., g is the gravitational acceleration, and d is d., was developed to describe the changes in the free vol. of fluidized layers in relation to gas velocity. Correlation with exptl. detns. was found to be satisfactory.

2095. Clough, R.

DENSITY CHANGE AND PRESSURE DROP IN BOILING REACTOR, BWR-3 (1954), 12 p.

Density variation along the coolant tube, mean density in the tube, over-all density in the core and tube pressure drop have been found for various annulus widths and water velocities. An over-all fluid density in the core of up to about 38 lb/ft^3 or 0.6 relative density could be obtained without much difficulty. A moderate increase in tube pitch (say about 15%) would enable a satisfactory water to uranium ratio to be obtained without going to very high circulation rates. It is possible that the pumping power would be considerably less than for LEO.

2096. Costello, C. P.

LOCAL BOILING EFFECTS ON DENSITY AND PRESSURE DROP, Technical Report No. 3, Nuclear Technology Laboratory, Stanford University (1960).

An accurate method of determining average density and static pressure drop due to liquid acceleration during boiling of subcooled liquids has been devised and employed in the tests reported in this paper. The effects of system parameters and geometry on average density and acceleration pressure drop are discussed quantitatively. A semi-analytic method of predicting average density and acceleration pressure drop caused by vapor formation is proposed. The method relies on photographic data and appears to be valid only to the point at which bubbles coalesce to form vapor clots. It is also indicated that the most severe effects of vapor formations occur if vapor clotting takes place.

2097. Egen, R. A., Dingee, D. A., and Chastain, J. W.

VAPOR FORMATION AND BEHAVIOR IN BOILING HEAT TRANSFER, BMI-1163 (February 1957), 51 p.

An experimental program was conducted to study the formation and distribution of vapor in a rectangular channel under boiling-heat-flux conditions at 2000 psia. In addition, the problem of preferential distributions was studied to determine its effect on the validity of the results of this program. Over the range of variables tested, there was no flow-rate effect, and the slip, where determinable, appeared to be constant. The void fraction is correlated with the quality and heat flux, in the vicinity of zero quality; the dependence upon heat flux decreases with increasing quality in this region. Inlet-temperature variation has no effect on the value of the void, providing the inlet temperature is below the temperature necessary for local boiling.

2098. Eriksen, V. O.

VOID EFFECTS IN BOILING HEAVY WATER REACTORS, A paper (572) presented at the 2nd Geneva Conf. on the Peaceful Uses of Atomic Energy, Geneva, 1-13 Sept. 1958. (11, p. 466-69).

One of the important problems in the physics of boiling reactors is the determination of void coefficients. In order better to understand the effect of voids on the behavior of the Halden reactor, a series of experiments was undertaken in JEEP and on R1, the Swedish reactor. Voids were introduced as air-bubbles in the moderator. Air does not simulate steam effects very well, and the spatial distribution of the air voids was quite different from the steam distribution we would expect in an actual boiling reactor. The object of the work was, however, more directed towards a study of the general physics of the influence of the void formation on the reactivity of the reactor, than to obtain design parameters for immediate use. All experiments were performed at room temperature.

2099. Eurola, A. T.

ON THE MEASUREMENT OF THE DYNAMIC PROPERTIES OF THE STEAM VOID FRACTION IN BOILING WATER CHANNELS, ANL-6369 (1961), 61 p.

The problem of determining the dynamic properties of the steam void fraction undergoing random variations at a particular location in a boiling channel was studied. Emphasis was placed on a gamma attenuation method and on a method employing sensitive flowmeters at suitable locations of the channel. The dynamic properties of interest were the autocorrelation function and the power density spectrum of the variations. Equations were derived for computing the desired quantities on the basis of gamma records obtained during actual boiling experiments and from runs with empty and full, nonboiling channels. The equations consider the statistical variations of the gamma source and detector. A procedure was outlined for estimating the measurement effort to obtain a predetermined accuracy. Two models were developed to correlate the variations of flow with fluctuations of the steam void. Both models were based on the mass continuity equation for a two-phase fluid. The simpler model leads to a first-order, linear differential equation with randomly varying coefficients. The desired quantities can be computed from the equation. The second model leads to a linear integral equation of the third kind. This equation relates the power density spectrum of the void fraction with the spectra of the water velocities. A frequency range from zero to five cycles per second was investigated. A comparison of the results obtained with the gamma-ray and velocity methods on a 42-atm heat-transfer loop indicated that neither model satisfactorily relates the velocity variations with the steam void variations over the entire range of frequencies studied. However, if the steam transit time is about 0.1 sec and the frequency range of interest less than one cycle per second, both models are useful and have

approximately the same accuracy. At frequencies greater than one cycle per second, the deviation from the gamma results is more than three decibels for a 0.1-sec steam transit time. The second model gives slightly better results than the first. The accuracy of the models increases with decreasing steam transit time.

2100. Foglia, J. J., et al.

BOILING WATER VOID DISTRIBUTION AND SLIP RATIO IN HEATED CHANNELS, BMI-1517 (1961), 36 p.

Distribution of void and the behavior of slip ratio in light water in a rectangular heated test section were investigated with a beta-particle-attenuation technique. The amount of void in the subcooled region was determined to within ±3% void. Various combinations of the following conditions were investigated: pressures from 700 to 1300 psia, mass flow rates from 1.0 to 3.0 x 10^6 lb/hr/ft^2, and heat fluxes from 0.10 to 0.60 x 10^6 Btu/hr/ft^2. The test section was heated with both a-c and d-c power, and no significant difference in the results was detected. It was found that the slip ratio at a high Reynolds number is much more a function of the Reynolds number than of pressure. Furthermore, for Reynolds numbers between 50,000 and 90,000 the slip ratio at constant void fraction reaches a maximum. Some of the recent theoretical correlations of subcooled and bulk boiling were tested. The experimental bulk boiling results compare reasonably well with the most recent theoretical models. Void fraction at zero quality can be correlated by the expression: $\alpha = 0.113 X_{ex} (L/L_B)/(P_c/P_{sat} - 1)$.

2101. Fohrman, M. J.

THE EFFECT OF THE LIQUID VISCOSITY IN TWO-PHASE, TWO-COMPONENT FLOW, ANL-6256 (1960), 108 p.

An evaluation was made of the effect of the liquid-phase viscosity on slip ratio using a forced-circulation two-phase two-component system operating at atmospheric pressure for air and glycerol-water mixtures. The effect of liquid-phase viscosity on pressure drop was observed, and the flow regimes were identified and studied. The approximate ranges of the variables investigated were: liquid viscosity, 0.75 to 500 cp; quality, 0.005 to 0.0184; liquid flow rate, 0.2 to 0.8 lb/sec; air flow rate, 0.001 to 0.015 lb/sec; and void-volume fraction, 0.34 to 0.78. The void-volume fraction and the approximate distribution of the two-phase mixture at a particular cross-sectional element of the test section were determined by γ-attenuation techniques. The slip-ratio and pressure-drop results were not found to indicate any considerable variations caused by changes in flow pattern or liquid flow rates for the range of flow conditions and liquid viscosities encountered.

2102. Fortescue, P.

NOTES ON DENSITY RELATIONSHIP IN BOILING TUBES, AERE-ED-M-27 (1955), 6 p.

A quantity of greater importance than tube exit density in boilers is the mean tube density, since this determines the natural circulation potential, and the reactivity, in the case of a boiling reactor. Where bubble slip and secondary effects of tube pressure drop can be neglected, and there is zero initial subcooling, there exists an extraordinarily simple relationship between exit and mean tube density.

2103. Fujie, Hideo.

A RELATION BETWEEN STEAM QUALITY AND VOID FRACTION IN TWO-PHASE FLOW, 55th AIChE meeting, Annual (1962).

2104. Fukai, Y., et al.

CALCULATIONS OF FLUX DISTRIBUTION IN A BOILING WATER REACTOR, Nuclear Science and Engineering 6, 298-305 (1959).

Distribution of neutron flux and void in orificed core of boiling water reactor calculated analytically by use of relation between void generation and power; analytical method described; it is shown that comprehensive surveys of nuclear and heat performance of boiling water reactor are possible with little effort; as example, technique of making void map is shown; alternate method also described.

2105. Greenfield, M. L., et al.

STUDIES ON DENSITY TRANSIENTS IN VOLUME-HEATED BOILING SYSTEMS, AECU-2529 (1953), 135 p.

The results of experiments designed to investigate the transient density response of volume-heated liquid systems subjected to a sudden, short-duration increase in heating intensity are presented. Also included are the results of experiments designed to give information about the characteristics of liquid-solid systems with regard to their maximum superheats. Analytical studies pertaining to limits of the rate of density change, to liquid structure, critical bubble size, and growth rates of bubbles are included. A description of all experimental equipment is given as are descriptions of systems investigated. Density transients are presented for water systems having a 0.05% concentration (approximately) of KOH. Most tests were performed at atmospheric pressure; some were performed at about 125 to 260 psia. Time lag, the time from the initiation of a heating pulse to the start of a density transient, ranged significantly from about 80 to 700 msec for the systems and variables investigated. The superheat studies revealed that maximum liquid superheat was attained for a glass-water system at atmospheric pressure; the boiling temperature was 240°F above the normal boiling point. Data on superheat up to pressures of about 800 psia are presented for all systems studied. The glass-water system characteristically permitted higher superheats, for all pressures, than were obtained with other systems investigated. For systems

employing solutions of $UO_2(SO_4)$, superheats attainable were found to be influenced by the length of time the solution was subjected to superheat.

2106. Greenfield, M. L., et al.

STUDIES ON DENSITY TRANSIENTS IN VOLUME-HEATED BOILING SYSTEMS, FINAL REPORT, AECU-2950 (1954), 135 p.

The mixture density transient response of volume-heated liquid systems subjected to a step increase in the heating rate is studied. Experimentally, measurements have been made by means of x-ray absorption of the density changes in liquids subjected to time varying distributed volume heat sources. The local liquid superheat was measured, and photographic records of the region of interest were made. Density transient data are presented for the tested systems at atmospheric pressure and about 135 psia. From experiments the small contribution to the density change of bubbles present during steady state boiling is deduced, thus the importance of nucleation is shown. The effect of a bubble initiator to increase the density response and decrease the steady state superheat is shown. The effect of pressure is to retard the density response. Analytically, the problem of energy requirements and heat conduction into a growing vapor bubble (a "moving-boundary" problem) is first treated. Then, by considering the heat diffusion through the hydrodynamics of an incompressible, inviscid liquid, an integro-differential equation which describes the growth of a single bubble in a superheated liquid with uniformly distributed heat sources is formulated. An analytic solution in closed form is presented which compares favorably with published experimental data. A relation between the bubble wall temperature and radius is given. Expressions for the heat transfer coefficient and the thickness of the thermal boundary layer are derived. Using the result of the single bubble analysis, equations are derived which give the density behavior of a liquid containing an ensemble of bubbles as function of time, in terms of the steady state superheat, power pulse, and bubble population. The theoretically predicted density transients are compared to the experimental data. The comparison is favorable. The experimental and analytical results show the high temperature-sensitivity of the density transients and the importance of nucleation to the phenomenon. (NSA-9-936)

2107. Griffith, P., Clark, J. A., and Rohsenow, W. M.

VOID VOLUMES IN SUB-COOLED BOILING SYSTEM, Paper No. 58-HT-19, Presented at the ASME-AIChE Joint Heat Transfer Conference, Chicago, Ill. (August 18-21, 1958).

In this paper the results of an experimental investigation of the void volumes in systems at 500, 1000 and 1500 psia are presented. A semi-empirical method of predicting the void volumes is then presented. Finally, a comparison of measured and predicted void volumes is made with data collected at 2000 psia under completely different conditions. Agreement with the data is good.

2108. Hoogendoorn, C. J., and Buitelaar, A. A.

EFFECT OF GAS DENSITY AND GRADUAL VAPORIZATION ON GAS-LIQUID FLOW IN HORIZONTAL PIPES, Chem. Eng. Sci, 16, 208-21 (1961).

The flow of superheated Freon-11 vapor and H_2O, and also flashing Freon-11 in horizontal 15-mm pipes was investigated. The Kosterin diagram (cf. H., CA 54, 1942a) satisfactorily presents the data in a plot of the gas fraction based on volumetric flow against the velocity of the mixt. Various fields on this plot represent the flow regimes, stratified, wave, slug, plug, and froth. This diagram is not affected very much by gas d. changes in the range 1-12 kg/cu m., and also holds for a vaporizing flow. Pressure drop due to accelerating flow becomes significant at total mass velocities above 500 kg/sq m-sec. (CA-62-13582a)

2109. Houghton, Gerald.

SOME THEORETICAL ASPECTS OF VAPOR VOID FORMATION IN HEATED VERTICAL CHANNELS, Nuclear Sci. and Eng. 11:121-8 (1961).

Fundamental flux vectors have been obtained for the diffusion of bubbles in heated channels by considering bubble motion in a turbulent liquid as a Markoff process. The flux vectors lead to a nonlinear partial differential equation representing the void fraction, which has been linearized for the case of small void fractions and coupled to a similar partial differential equation governing heat flow into the liquid phase. The coupled differential equations are transformed into coupled integral equations which are solved to obtain axial void fraction and temperature distributions in a heated channel. The rate of vapor production at the wall and the rate constant for bubble growth have been calculated from experimental data on void fraction distributions at constant uniform flux. The model predicts the correct shape for the void fraction distribution curve as well as providing a plausible explanation of burnout phenomena in terms of the bubble slip velocity.

2110. Houghton, Gerald.

AN ANALYSIS OF VAPOR VOID PROFILES IN HEATED CHANNELS, Nuclear Sci. and Eng. 12, 390 (1962).

The coupled nonlinear differential equations representing the void fraction and liquid temperature in a heated channel are solved by neglecting the slip velocity and assuming that there is no nucleation in the bulk liquid. In agreement with the experimental data for uniformly heated channels, the general solution of the void fraction equations predicts a sigmoidal vapor fraction profile. Theoretical temperature profiles show that, even in the high void fraction region, thermal equilibrium is not attained in the channel, indicating that the void profiles at high vapor fractions are still a complicated function of the liquid velocity, heat flux, vapor production, and channel spacing.

2111. Hubers, C.

VOID VOLUME RATIOS DURING STEADY STATE LOCAL BOILING IN CASE OF CONSTANT POWER DISTRIBUTION, Nuclear Sci. and Eng. 13, 54-9 (1962).

A tentative method for the calculation of the void volume fraction at zero quality in case of constant heat input along the channel is presented. By assuming a constant volumetric condensation density, proportional to the squared flow velocity, the void volume fraction at zero quality can be predicted. Comparing the calculated void volumes with actual measurements for water, the error in the void calculation is less than ±25%.

2112. Hughes, R. A.

STEAM-WATER MIXTURE DENSITY STUDIES IN A NATURAL CIRCULATION HIGH-PRESSURE SYSTEM, Babcock and Wilcox Co., Research Center, Alliance, Ohio, Report No. 4.

2113. Hughmark, G. A.

HOLDUP IN GAS-LIQUID FLOW, Chem. Eng. Prog. 58, 62-65 (1962).

The flow parameter has been correlated using the Reynolds number, Froude number, and a no-slip liquid volume fraction. Results indicate a more general application for this method.

2114. Isbin, H. S., Sher, N. C., and Eddy, K. C.

VOID FRACTIONS IN TWO PHASE STEAM-WATER FLOW, AIChE Jour. 3, 137 (1957).

Void fractions and pressure drops for steam-water flows were measured in an 0.872 in. I.D. vertical tube at atmospheric pressure over a quality range of 0 to 4%. The test section was the hot leg of a natural-circulation loop, and the inlet liquid flow rate ranged from 1 to 3 ft/sec. A new technique for measuring void fractions was used, and the method utilizes the difference between the gamma-ray absorption coefficients of water and steam.

2115. Isbin, H. S., et al.

VOID FRACTIONS IN TWO PHASE FLOW, AIChE Jour. 5, 427-432 (1959).

Void fractions (fraction of the flow cross-sectional area occupied by the gas phase have been measured for steam-water flows in an adiabatic, horizontal test section of 0.484 in. I.D. at 400, 600, 800, and 1,000 lb/sq in. gauge. A comprehensive survey of void data for two-phase concurrent flow is included in the paper, and the data, including the Martinelli and homogeneous flow model predictions, are compared. System characteristics, involving one-and two-component flows in horizontal and vertical test sections with and without heat transfer over a range of flow ratios, total flow rates, and pressure, are too complex, and the data available are neither extensive nor precise enough to warrant the generation of over-all correlations. Use of the void data in correlating two-phase frictional pressure drops is discussed. A model has been presented for the prediction of critical flows based upon the void data, and calculations have been made for steam-water critical flows over a range of critical pressures from 15 to 2,000 lb/sq in. abs.

2116. Johnson, H. A., et al.

TEMPERATURE VARIATION, HEAT TRANSFER, AND VOID VOLUME DEVELOPMENT IN THE TRANSIENT ATMOSPHERIC BOILING OF WATER, University of California, Institute of Engineering Research, Berkeley, California, Series 163, Issue 2 (1960).

2117. Kaminsky, S.

STUDY OF NUCLEATION AND BUBBLE DYNAMICS TO EVALUATE VOID SHUT DOWN MECHANISM IN A HETEROGENEOUS WATER MODERATED REACTOR, KLX-1809 (May 1959), 95 p.

A two-fold effort is described which was directed toward the ultimate formulation of a function which can be used to predict void volumes during the "runaway" of a pressurized water reactor. The available literature was utilized and extended in an attempt to resolve the numerous phenomena associated with transient void formations in nucleate boiling. Attention was directed to void formations which occur during nucleate boiling because it is speculated that they are the principal formations present during fast transients in a pressurized reactor.

2118. Laird, A. M., Scott, A. W., and Thomson, A. S. T.

TWO-PHASE FLOW IN THE RISER TUBE OF AN EXPERIMENTAL TWO-TUBE BOILER, Paper No. 9, Symposium (Preprint of Proceedings) on Two-Phase Fluid Flow, Inst. Mech. Engrs., London, England, February 7, 1962.

Density measurement of steam-water mixtures at the top of the riser tube using γ-radiation with an ionizing chamber.

2119. Larson, H. C.

VOID FRACTIONS OF TWO-PHASE STEAM-WATER MIXTURE, MS Thesis U. of Minnesota, 1957.

2120. Larson, H. C.

VOID FRACTIONS OF TWO-PHASE STEAM-WATER MIXTURES, PhD Thesis, Univ. of Minn. 1958.

2121. Lipkis, R. P., Liu, C., and Zuber, N.

MEASUREMENT AND PREDICTION OF DENSITY TRANSIENTS IN A VOLUME-HEATED BOILING SYSTEM, Chem. Eng. Prog. Sym. Ser. 52, No. 18, 105 (1956).

This paper is concerned with the mixture-density transient response of volume-heated liquid systems subjected to a step increase in the heating rate. This problem is studied experimentally and analytically.

Experimentally measurements have been made by means of X-ray absorption of the density behavior of several systems at atmospheric pressure and at about 135 lb/sq in. abs. Liquid superheat and bubble population were determined. The analysis of

the growth of a single bubble in a superheated liquid is extended to enable prediction of the density-time behavior of a boiling liquid containing an ensemble of bubbles. The theoretically predicted density transients compare favorably with the experimental data.

The experimental and analytical results show the high-temperature sensitivity of the density transients and the importance of nucleation to the phenomenon.

2122. McDuffie, H. F., and Kelly, D. C.

HOMOGENEOUS REACTOR PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING, ORNL-1895 (1955), 220 p.

. . . . . A method for correlating both volume boiling and surface boiling vapor slip velocities was developed and compared with experimental data. . . .

2123. Marchaterre, J. F.

THE EFFECT OF PRESSURE ON BOILING DENSITY IN MULTIPLE RECTANGULAR CHANNELS, ANL-5522 (1956), 90 p.

The effect of pressure on the density of steam-water mixtures in natural circulation boiling in multiple rectangular channels was studied to 600 psig with saturated inlet conditions. The effect of pressure on flow rate was also studied. The ratio of the velocity of the steam to the velocity of the water was found to be correlated by the inlet velocity. For a fixed average steam volume fraction, no effect of pressure on flow rate could be found. Neither velocity ratio or steam volume fraction could be correlated in terms of quality if a sufficient velocity range was studied. The assumption of constant velocity ratio over the channel length seems to be valid.

2124. Marchaterre, J. F., and Petrick, M.

THE PREDICTION OF STEAM VOLUME FRACTIONS IN BOILING SYSTEMS, Nucl. Sci. Eng. 7, 525-532 (1960).

The results of an extensive study of the relative velocity of two-phase mixtures at ANL are presented. The parameter ranges studied are pressure, 150-2000 psi, mixture quality, 0-0.25, superficial liquid velocity 0.5-8 ft/sec, and flow channel equivalent diameters of 0.4-2 in. The data were correlated by means of the velocity ratio (steam velocity/liquid velocity) which was calculated from the measured steam volume fraction. The steam volume fraction measurements were made by a radiation attenuation technique and the data were obtained from both adiabatic and nonadiabatic systems.

The data show that the velocity ratio is affected primarily by pressure, mixture quality, superficial velocity, and to a lesser degree by the flow channel geometry. The data are also compared with the data of other investigators for the vertical upflow of steam-water mixtures.

Working curves for the prediction of the velocity ratio are then presented which are adequate for system analyses. The working curves are given for 150, 250, 400, and 600 psi. A method of extrapolating the data for predicting working curves in the high pressure range is suggested.

2125. Marchaterre, J. F., and Hoglund, B. M.

CORRELATION FOR TWO-PHASE FLOW, Nucleonics, 20: No. 8, 142 (Aug 1962).

A correlation is presented which can be used for predicting vapor-liquid velocity ratios and thus the vapor volume fraction in a vertical channel in a boiling water reactor. The correlation is based on the equation $V_g/V_f = [X/(1 - X)][(1 - \alpha)/\alpha]\rho_f/\rho_g$, where V_g, V_f = local velocity of gas and liquid phases, relatively; X = gas/total weight flow rate ratio; α = gas/total volume fraction; and ρ = density. The correlation holds only for superficial velocities >0.8 ft/sec and for the region beyond local boiling. The correlation is compared with the data of various investigators. (NSA 62-29095)

2126. Martenson, A. J., et al.

MECHANISM OF VOID FORMATION TEST FACILITY, WAPD-V(FBE)-274 (1959), 28 p.

A test program to investigate the mechanism of void formation and to determine the amount of voids that can be maintained under conditions of high pressure and high flow is reported. The program includes a literature survey and a test program. The test facility which will be used in this program is a loop which is designed to operate with water at pressures up to 2000 psi and at temperature up to 650°F. It consists of several basic groups: test apparatus, the loop assembly, and external test equipment. The test apparatus contains the heated element; the loop assembly provides the proper conditions for the test; and the external equipment provides power and the data recording equipment, including a high speed camera. Each of these groups is described.

2127. Martin, W. L., et al.

DENSITY TRANSIENTS IN BOILING LIQUID SYSTEMS: INTERIM REPORT, AECU-2169 (July 1952), 131 p.

A program has been undertaken to study the density response of a liquid-vapor system when subjected to a change in the magnitude of a distributed heat source. The density transients are caused by the initiation, growth, and collapse of the vapor bubbles and by their travel into or out of the specified volume. A description of the apparatus used to create and record (by means of an x-ray densitometer and motion pictures) density transients at pressures from atmospheric to 1000 psia is given, and preliminary results on acidic and alkaline solutions are presented. Time lags, from the initiation of a heating pulse to the start of a density transient, of the order of 0.25 sec were most commonly observed in solutions of KOH at atmospheric pressure. In an attempt to correlate liquid superheat with system-density response, a static superheat apparatus and procedure have been developed, and a variety of superheat data obtained on H_2O and KOH solutions in glass and stainless steel is presented. The analytical phase of the program is directed toward deriving equations to describe bubble initiation and growth. Equations

from Döring's theory have been applied to water at elevated pressures, and the resultant calculated superheats are compared with the experimental measurements. In order to eliminate some of the approximations in the analytical work, a molecular approach has been used to evaluate the effects of surface tension on liquid superheat.

2128. Maurer, G. W.

A METHOD OF PREDICTING STEADY-STATE BOILING VAPOR FRACTIONS IN REACTOR COOLANT CHANNELS, WAPD-BT-19 (p. 59-70) (1960) Bettis Technical Review - Reactor Technology.

A 3-region method which predicts vapor fractions that are continuous between regions is presented. Agreement with limited Bettis data for a 0.087 x 1 x 17-in. channel is within ±5% of the vapor fractions. Test runs cover pressures of 1200, 1600, and 2000 lb/sq in. abs., mass velocities from 0.4×10^6 to 4×10^6 lb/hr-sq ft., inlet subcoolings to 315°F, and axially uniform fluxes up to 90% of the DNB heat flux.

2129. Noyes, R. E., Bergonzoli, F., and Gingrich, J. E.

A NON-DIMENSIONAL METHOD FOR DIGITAL COMPUTER CALCULATION OF STEADY STATE TEMPERATURE, PRESSURE, AND VOID FRACTION IN PIPE FLOW WITH OR WITHOUT BOILING, NAA-SR-5958 (1960), 58 p.

A method is described for computing steady-state wall-and bulk-fluid temp., void fraction, and local pressure in liquid-cooled closed channels in which the heating rate is specified. The method was programmed for the IBM 709 and the code, named "FUGUE," is described. In most instances, generally accepted physical relations developed by other investigators are used. The relations are expressed in general, nondimensional form and combined in an internally consistent manner to allow predictions for a variety of coolants and specified operating conditions. Variations in heat-transfer and hydraulic characteristics of the coolant caused by changes in its temperature, pressure, and state are handled by using continuously calculated local values of thermal conductivity, viscosity, density and quality. Changes are made in the working equations to reflect the sequence of coolant changes from all liquid flow to liquid flow with subcooled boiling to two-phase flow, and finally to all-vapor flow.

Computation is done by an iterative procedure using linearized forms of the working equations over short axial segments of the channel to calculate local conditions using assumed parameters. The parameters are then adjusted according to the calculated local conditions and the process is repeated until the correct solution is obtained. Working equations are presented in general form to allow their modification by using modified input data.

2130. Peterson, D. F.

CONCERNING THE RELATIVE MOTION OF STEAM AND WATER IN STEAM BOILER TUBES, Sovyetskoye kotloturbostroyenie, Nr 4 (1936).

2131. Polomik, E. E.

VAPOR VOIDS IN FLOW SYSTEMS FROM A TOTAL ENERGY BALANCE, GEAP 3214 (1959).

Calculations of vapor voids and instability threshold are made for a boiling system on the basis of a total energy balance. The results compare well with steam-water systems data in the pressure range of 114 to 2000 psia; a difference of 0.08 to 0.12 low was observed in the calculated vapor voids and is ascribed to lack of thermodynamic equilibrium in the flow process.

2132. Rodriquez, H. A.

VOID FRACTIONS IN TWO-PHASE, STEAM-WATER FLOW, M. S. Thesis, Univ. of Minnesota (1957).

2133. Schwarz, K.

INVESTIGATIONS OF THE DENSITY DISTRIBUTION, WATER AND STEAM VELOCITY, AND THE FRICTIONAL PRESSURE DROP IN VERTICAL AND HORIZONTAL BOILER RISER TUBES, Vereines Deutscher Ingenieure, Forschungsheft 445, 20, 1954.

Measurements were carried out with the purpose of obtaining reliable data for calculating the water circulation in natural circulation boilers. By using a full-size boiler model and applying novel measuring methods, the circulating water and steam rates, the distribution of density, and the velocities of water and steam flow established for the vertical and horizontal sections of up-flow tubes during operation as well as the pressure loss for the vertical section. Hitherto when calculating the water circulation, the lead velocity of steam had been based upon values established for stationary water and the friction coefficient determined for homogeneous liquids. The new values now obtained for circulating water-steam mixtures show substantial deviations from the values known up to this time, resulting in a decisive revision of the calculation of water circulation.

2134. Shapiro, J. L.

THE VOID COEFFICIENT IN AN ENRICHED WATER REACTOR, Nuclear Sci. and Eng. 12, 449 (1962).

An experimental and analytical study of the void coefficient of reactivity in the Ford Nuclear Reactor (a fully enriched, swimming pool type) was made. A stream of air bubbles was used to introduce voids. Out-of-pile calibration of the air flow system was necessary to account for variation in bubble rise velocity with average air concentration. This method is extremely simple except for the calibration procedure. With the results presented, the void coefficients of other reactors with similar fuel elements (18 plate, BSR type) can be measured without the necessity for recalibration. For the calculation of uniformly distributed void coefficients, relatively simple two-group diffusion theory is shown to be accurate provided the variation of leakage in all three dimensions is taken into account. This variation of leakage is computed by the use of a buckling iterative procedure. Second order effects, such as the variation of effective thermal neutron temperature and

disadvantage factor, may be neglected. For the calculation of localized void effects, the buckling iteration method is inaccurate due to the nonseparability of axial and radial flux distribution in this small core. To improve the accuracy an extension of this method to several region iteration is suggested. The principal value of this type of calculation is the short computer time required.

2135. Sher, N. C.

LIQUID HOLDUP IN TWO-PHASE STEAM-WATER FLOW, M. S. Thesis, Univ. of Minnesota (1955).

2136. Shippee, E. D.

RELATIVE VELOCITY OF TWO PHASES FLOWING IN A VERTICAL TUBE, U. of Ill., B. S. Thesis (1938).

An investigation leading to the correlation of frictional drop with two phases flowing in a vertical tube was carried out. The variables to be investigated in addition to the pressure drop along the tube include the relative amounts of the two phases, velocity of each through the tube and possibly some indication of the type of the mixture. In order to determine the relative velocity of the two phases flowing up a vertical tube, an apparatus was arranged with a glass tube with an internal diameter of 0.577 inch between two quick closing valves, so as to allow the mixture flowing at any time to be trapped. Measurements of the relative amounts of the two phases in the tube after the valves were closed, together with the data on the rates of flow of each phase allowed the calculation of the linear velocity of each phase.

Water and air were the two phases used, and a series of measurements,each of constant water rate, with several valves of inlet air were made. The data indicated that the ratio of air to water trapped in the tube was directly proportional to, but not equal to the ratio of rates of flow of inlet air to water, up to a value of 1.3 for the latter ratio.

Measurements of the pressure drop with the two phases flowing were also made, and while the range of the data was limited by rates of flow of water and air which could be obtained, the values found, when correlated by the Fanning equation, lay very close to the values obtained on the same apparatus with only only water flowing. Both sets of data showed derivations of the order of 25 per cent from an empirical plot of the Fanning equation.

2137. General Nuclear Engineering Corp.

A STUDY OF THE VARIATION OF STEAM VELOCITY IN VERTICAL BOILING CHANNELS, ANL-6251 (Nov. 1960), 69 p.

An analysis was made to correlate experimental boiling heat transfer data with the variable relative velocity (C_S - C_L). The correlation was based on a boiling model or mechanism. The range of variables encountered included pressure, water velocity, power density, subcooling, steam-volume fraction, steam quality, and channel distance. Forced and natural circulation tests were investigated. Results are reported.

2138. Stein, N.,et al.

THE SLIP VELOCITY OF GASES RISING THROUGH LIQUID COLUMNS, Trans. Am. Inst. Mining Met. Engrs. 195, Tech. Pub. No. 3394 (in J. Petroleum Technol 4, 233-40 (1952)).

The data were obtained in gas-liquid systems which included combinations of air-propane and natural gas (over 97% CH_4) with H_2O, lubricating oils, and crude oils. The gases rose through liquids in vertical tubes, inclined tubes, and vertical annuli. The data are incorporated in an empirical correlation which relates the mean slip velocity of gases flowing through liquids with the parameters gas rate, tube size, ratio of liquid velocity to liquid d., gas d., and the angle of the tube from the vertical. The correlation will be useful primarily in the design of subsurface gas-oil sepn. equipment for increasing the efficiency of oil-well pumping installations.

2139. Tolman, R. C.

THE SUPERFICIAL DENSITY OF MATTER AT A LIQUID VAPOR BOUNDARY, Chemical Physics, 17, 118-127 (1949).

The distribution of matter within the transition layer between the two phases of a fluid system is considered. Approximate values are obtained for the superficial density of matter Γ, calculated with reference to the Gibbs surface of tension as the dividing surface between the phases.

2140. Zavoiskii, V. K., et al.

DENSITY OF AN AQUEOUS VAPOR MIXTURE FORMED IN A VESSEL WITH HOT WATER UNDER REDUCED PRESSURE, Atomnaya Energiya 4, 285, (Mar. 1958).

Experiments were made to determine the aqueous vapor density in transition processes connected with rapidly reduced pressures in the active zone of a water moderated reactor. The scheme of the experimental apparatus is presented.

2141. Zavoiskii, V. K., et al.

THE DENSITY OF STEAM-WATER MIXTURES FORMED DURING RAPID REDUCTIONS IN PRESSURE, J. Nuclear Energy, 9, 183-5 (1959).

The temperature and density of steam-water mixtures in a steel cylinder of 20 cm internal diameter and 1.5 m height containing heated water were measured in order to assess the extent to which bulk boiling could occur in a pressurized water reactor. The apparatus is described and illustrated. The density was determined from the degree of absorption of a beam of gamma-rays from a radioactive Ag source. The pressure drop was from 50 to 5 atm. A graph of the experimental results showing the relation between the proportion of the cross-section of the cylinder occupied by steam and the velocity of the steam, for pressures of 20 and 40 atm, is given.

2142. Zuber, N.

ON THE VARIABLE DENSITY SINGLE-FLUID MODEL FOR TWO PHASE FLOW, Journal of Heat Transfer, 82, No. 3, p. 255-8 (1960).

FLOW PATTERNS

2143. Alves, G. E.

CONCURRENT LIQUID GAS FLOW IN A PIPELINE CONTACTOR, Chem. Eng. Prog. 50, 449 (1954).

The results of an experimental investigation on the isothermal flow of water-air and oil-air mixtures in a one-inch co-current pipe-line contactor is reported in this article.

The investigation was undertaken to provide basic data on flow patterns, pressure drop and liquid holdup for the flow of liquid-gas mixtures in this type of equipment. Descriptions of the various possible flow patterns are presented. Visual observations were made of most of these patterns in the straight pipe and the return bend, and photographs of typical flow patterns are given. Limited data show the degree of entrainment of the liquid as sprayed by the gas core for annular flow.

The pressure-drop data for the straight pipe and the holdup data were compared with those given in the published literature. Pressure-drop data for the flow of liquid-gas mixtures have been extended to include the return bends and the inlet mixing tee.

2143a. Ambrose, T. W.

LITERATURE SURVEY OF FLOW PATTERNS ASSOCIATED WITH TWO-PHASE FLOW, HW-52927 (1957).

A comparison of the flow patterns presented by the various authors has been made. This comparison indicates good agreement considering that the transitions between flow patterns are vague and were detected visually. The following general flow patterns were found to occur as the gas phase is present in increasing quantities: (1) pure liquid, (2) bubble flow (bubbles move along the upper part of the pipe at about the same velocity as the liquid), (3) plug flow (alternate plugs of gas and liquid), (4) stratified flow (vapor flowing above the liquid), (5) wavy flow (vapor above a wavy liquid surface), (6) slug flow (periodic frothy slugs pass through the pipe at greater velocity than the average liquid velocity), (7) annular flow (liquid flows in a film around the inside wall of pipe, and the gas flows at a higher velocity as a central core), (8) mist or spray flow (gas with liquid entrainment flowing in a pipe with wetted walls), and (9) pure gas. 15 references.

2144. Baker, O.

DESIGN OF PIPELINES FOR THE SIMULTANEOUS FLOW OF OIL AND GAS, The Oil and Gas Journal, 53, 185-95 (July 1954).

Measurements were made of pressure drops for oil and gas flowing simultaneously through four to ten inch diameter pipelines. These results were correlated with data from the literature for one-half to three-inch diameter pipelines. Previously published data were used to construct a generalized chart for predicting the type of flow pattern in the pipeline. The flow patterns described are bubble flow, plug flow, stratified flow, wavy flow, slug flow, annular flow, and spray flow. Our experimental data were shown to be consistent with the generalized flow pattern chart.

The calculation method proposed by Lockhart and Martinelli for designing two-phase pipelines was shown to be inadequate for larger diameter lines and also for some flow patterns. Modifications of the above method in the form of separate equations for each type of flow pattern are presented.

2145. Birkhoff, G., and Coywood, T. E.

FLUID FLOW PATTERNS, J. App. Phys. 20, 646-659 (1949).

A new photographic technique is described, for observing velocity fields in water, induced by the entry of solid missiles. The results of a number of observations are given, and compared with theoretical formulas. The corrections involved in the method are analyzed theoretically, and the theory of the corrections confirmed experimentally. It appears that the method is well adapted to velocity fields 5-100 feet per second, created by objects several inches or more in diameter, but may lead to troublesome corrections at other speeds or with smaller objects.

2146. Brancart, C. P.

EXPERIMENTAL STUDY OF TWO-PHASE FLOW REGIMES, B.S. Thesis, Massachusetts Inst. of Tech. (1958).

2147. Brown, R. A. S., et al.

THE UPWARD VERTICAL FLOW OF AIR-WATER MIXTURES. III. EFFECT OF GAS PHASE DENSITY ON FLOW PATTERN, HOLDUP, AND PRESSURE DROP, Can. J. Chem. Eng. 38, 62-6 (1960).

The correlation presented will permit the prediction of flow pattern, holdup, and pressure drop for the flow of immiscible gas and liquid H_2O phases with av. gas-phase ds. in the range 0.092-0.522 lb/cu ft and tube diams. of 0.5-3.0 in.

2148. Campbell, D. C.

MOTIONS OF A PULSATING GAS GLOBE UNDER WATER; A PHOTOGRAPHIC STUDY (1943) (David Taylor Model Basin Report), DTMB-512

2149. Cromer, Sylvan.

AN INVESTIGATION OF THE FLOW OF MIXTURES OF WATER AND AIR IN VERTICAL COLUMNS, University of Oklahoma, M. S. Thesis, 1937, pp. 54-

Many problems dealing with the production of petroleum and the removal of water from gas well must be solved by trial and error because the fluid being handled is neither a gas nor a liquid, but a mixture of the two. Fundamental data on the vertical flow of these mixtures, at present are meager.

In this investigation, mixtures of water and air flowing through vertical pipes 97 and 89 ft in height were studied.

Photographs taken at different levels and under various flow conditions, show definitely that 4 types of flow may exist: (1) liquid dispersed with gas; (2) gas dispersed with liquid; (3) pistons of gas

interspaced with slugs of liquid; (4) annular flow of the liquid along the walls of the tube surrounding a core of gas relatively free from liquid.

Curves and data presented show the effect produced on the flow characteristics of these tubes by varying the submergence, air-water ratio, and temperature.

Evidence is presented showing that the maximum quantity of liquid that will flow through any given tube is a function of the submergence, and that this relation may be expressed mathematically.

2150. Cromer, S., and Huntington, R. L.

VISUAL STUDY OF THE FLOWING OF AIR-WATER MIXTURE IN A VERTICAL PIPE, Trans. A. I. M. E., 136, 79-90 (1940).

Qualitative and quantitative investigation for flow of type encountered when gas and oil are produced from well; flow column 98 ft. in height, with Pyrex observation sections 2 ft long, at 14 ft intervals; experimental procedure results presented graphically; point of no flow due to insufficient air; point of maximum efficiency; point of maximum water flow; point of no flow due to excess of air.

2151. Cross, C. A.

CORRELATION OF SLOT OPENING WITH FLOW RATE FOR VAPOR BUBBLING INTO A LIQUID, Chemistry and Industry, 692 (1952).

The results obtained from HOAc-H_2O vapor mixts. bubbled into liquid follow closely a theoretical curve corrected for changes in vapor density and recalcn. of the crit. slot opening is the new surface tension of the liquid phase. (CA-47-6193i)

2152. Cross, C. A., and Ryder, H.

THE CORRELATION OF SLOT OPENING WITH FLOW RATE FOR AIR BUBBLING INTO WATER, J. Appl. Chem. (London) 2, 51-60 (1952).

The depression of water level on the air-inlet side, defined as slot opening, when air flows through a slot in a vertical diaphragm into a tank of water has been correlated with the rate of air in an investigation of one design feature of bubble-plate distn. columns. Detns. have been made with triangular and rectangular slots at air rates of 0.01-800 c ft/min. The results indicate a modification of the theory of Rogers and Thiele (C.A. 28, 64976) to the extent that below a crit. air rate, surface-tension effects alone det. the slot opening. Detn. of the constants involved show greater proximity to theoretical values. (CA-46-7375f)

2153. Galegar, W. C.

SIMULTANEOUS FLUID FLOW OF WATER AND AIR IN VERTICAL TUBES, University of Oklahoma, M. S. Thesis, 1953, pp. 51.

A flow pattern chart is presented for a water and air system. Within the limits of this chart, the types of flow may be predicted if the masses of fluids flowing are known. Boundary regions for the changing of one type of flow pattern to another are indefinite. It is not possible until further data are available to predict the influence of viscosity, surface tension and density on flow patterns.

A correlation is presented which allows the static pressure drop to be calculated for air-water systems in smooth tubes if the pipe diameter, flowing masses and other physical properties of the fluids are known. The correlation is limited to systems where evaporative losses and kinetic energy changes are small. It is not known whether the correlation is valid for high pressure systems. To what extent pipe roughness affects the two-phase pressure drop is not known. Data on commercial pipe would be helpful.

2154. Galegar, W. C., Stovall, W. B., and Huntington, R. L.

MORE DATA ON TWO PHASE VERTICAL FLOW, Pet. Ref., 33, 208-211 (1954).

This investigation presents experimental data on the performance of kerosine-air and water-air systems in two-phase vertical upward flow using two test sections of different sizes but having the same ratio of diameter to length. A tentative correlation is presented in conjunction with visual data on the flow patterns involved.

2155. Govier, G. W., Radford, B. A., and Dunn, S. C.

THE UPWARDS VERTICAL FLOW OF AIR-WATER MIXTURES. I: EFFECT OF AIR AND WATER RATES ON FLOW PATTERN, HOLDUP AND PRESSURE DROP, Can. Jour. Chem. Eng. 35, 58-70 (1957).

This is the first of a series of papers designed to: (1) clarify the terminology and descriptions of the flow patterns encountered; (2) present data on the influence of pertinent variables on flow pattern, holdup, and pressure drop; and (3) establish a general correlation permitting prediction of flow pattern, holdup, and pressure drop for any gas-liquid system in upward vertical flow. A correlation is presented of data obtained on the upward vertical flow of air-water mixts. in a smooth bore tube 1.025 in. inside diam. for 9 water rates from 0.00040 to 0.0421 cu ft/sec and for air-water vol. ratios under flow conditions from 0 to 348. The const. av. flowing pressure was 36.0 lb/sq in. abs.; the temp., 70°F. The correlation enables the prediction of flow pattern, pressure drop, and holdup ratio for gas and liquid rates within the range tested, but is restricted as to tube diam. and liquid- and gas-phase properties.

2156. Govier, G. W., and Short, L. W.

THE UPWARD VERTICAL FLOW OF AIR-WATER MIXTURES. II: EFFECT OF TUBING DIAMETER ON FLOW PATTERN, HOLDUP AND PRESSURE DROP, Can. Jour. Chem. Eng. 36, 195-202 (1958).

Results of visual observation and measurements of holdup and pressure drop are reported over a range of air-water ratios for the vertical upward flow of air-water mixts. in 4 tubes with diams. ranging from 0.630 to 2.50 in. Tests were conducted under conditions of const. air d. corresponding with an av. pressure of 36 lb/sq in. abs. and at 10 const.

superficial water velocities ranging from 0.0695 to 7.35 ft/sec. Tubing diam. was found to have little effect on the transition from the bubble to the slug flow pattern. Tubing diam. has a marked effect on the transition from the slug flow to the froth flow pattern and from the froth flow to the ripple flow pattern. Tubing diam. has an important effect on the superficial friction factor and on the holdup. The pressure drop data for each diam. were correlated in a friction factor-Reynolds no. chart.

2157. Halbronn, G.

ETUDE DE LA MISE EN REGIME DES ECOULEMENTS SUR LES OUVRAGES A FORTE PENTE, Houille Blanche 7, 3-5 (Jan.-Feb. 1952).

Setting up flow regime on high gradient structures; theoretical study of viscous fluid flow over long spillway; calculation of velocities and depths in laminary and turbulent flow; existence of critical point where turbulent action becomes noticeable on surface and air entrainment becomes possible.

2158. Kawaratani, Tsutomu

TRANSITION BEHAVIOR OF TWO-PHASE TWO-COMPONENT FLUID FLOW IN TUBES, University of California, M. S. Thesis, 1951.

The co-current-vertical upward flow of air and water in a 0.0268 foot diameter pyrex tube was investigated experimentally.

A visual and photographic study of the flow patterns was made. The several types of flow patterns were classified as steady, bullet flow, unsteady bullet flow, pulsating annular flow, steady annular flow and mist flow. At low water rates all of these patterns occurred. At the high water rates the transition regions are less pronounced, and the trend of the curves indicate that at higher liquid rates the transition would be directly from steady bullet flow to steady annular or mist flow.

The correlation of Lockhart and Martinelli was used to plot the data. Their correlation for the pressure drop was substantiated for the annular flow regions.

The apparent friction factor for two-phase flow plotted against the Reynolds modulus based on the tube diameter resulted in a curve which resembled "rough pipe" flow and approached the single phase friction factor curve asymptotically at the high gas rates.

With the water rate as a parameter the air rate varied over the range of the apparatus.

2159. Kelakos, M. G., and Crowley, A. H.

TWO-PHASE FLOW OF FLUIDS THROUGH A HORIZONTAL PIPE, MIT, BS Thesis (1935).

This work reported here is a continuation of the work performed by Reichart which was conducted at MIT in 1934. Reichart carried out an investigation on the subject of two-phase flow of fluids using 25 mm. glass tube. He identified the various types of patterns existing in two-phase flow and determined the critical conditions of changes of type. The first object of this study is to repeat this work on 25 mm. tube in an attempt to verify his work. The tube will then be changed for one of larger diameter and also for one of smaller diameter and the above work repeated. An attempt to correlate the data thus obtained is made.

2160. Kozlov, B. K.

TYPES OF FLOW OF GAS LIQUID MIXTURES AND STABILITY OF BOUNDARIES IN A VERTICAL TUBE, Zhur. Tekh. Fiz., 24, 2285-2288 (1954), Translated in: AEC-tr-2258.

2161. Krasiakova, L. Yu.

SOME CHARACTERISTICS OF MOVEMENTS OF TWO-PHASE MIXTURES IN HORIZONTAL PIPE, Zhurnal Technical Physics (Russian) 22, 656-669, AERE Lib/Tr 695, (1952)

This article discusses the qualitative aspects of gas-liquid flow in horizontal pipes at various velocities of both gas and liquid. The visual and mechanical aspects of the various types of flow and the boundary conditions as one form changes into another are discussed in some detail, and figures are presented embodying the pictures taken and descriptive graphs. The dynamic pressure head, the film thicknesses, and the carry over of water into the gas phase were measured for various types of two-phase flow and suitable graphs are presented. The types of flow discussed are slug (cork-like), laminar (two regions - very small air velocities, turbulent region-medium air velocities), annular, and mist.

2162. Melikyan, R. A.

THE HYDRODYNAMIC CONDITIONS PRESENT WHEN A GAS FLOATS UP THROUGH A LAYER OF LIQUID, Zhurnal Prikladnoi Khimii, 30, 38-44 (1957).

When a gas floats up through a layer of liquid, various conditions of flow make their appearance (bubbling, foaming, wavy, etc.) depending on the volume of gas released. Qualitative descriptions of these regimes are given and also some elementary concepts in regard to the establishment of this or that regime in relation to the volume of gas released and the height of the layer of liquid.

2163. Molochin, M. A.

FLOW PATTERNS OF A GAS-LIQUID MIXTURE IN HORIZONTAL TUBES, Dokl. Akad. Nauk, S.S.S.R. 94, No. 5 (1954).

2164. Mologin, M. A.

TYPES OF FLOW OF GAS-LIQUID MIXTURES IN HORIZONTAL PIPES, Dokl. Akad. Nauk. S.S.S.R., 94, 807-810, AERE-Lib/Trans. 479 (1954) (Translation available in AERE-Lib/Trans. 479).

Detailed visual observations and cinematographic photos were made of the flow of air/water mixtures in horizontal pipes of diameters ≈25, 50, 75 and 100 mm, and in the range of gas contents, C_{op}, from 0 to 1. Velocities of the mixture ranged from 0.2 to 6 m/sec, and up to 20 m/sec for the pipe of

diameter ≈50 mm, with pressures of ≈1.8 to 2 atm. at the entry and ≈1.3 atm. at the outlet. This investigation made it possible to construct the first accurate charts of the ranges of the flow types of gas/liquid mixtures, and to draw a number of conclusions as to their behavior.

2165. Mologin, M. A.

WAVE MOTION ON THE SURFACE OF SEPARATED FLOW IN HORIZONTAL PIPES, Zhurnal Tekhnicheskoi Fiziki, 26, pp. 1823-1835, (Aug 1956) (In Russian).

The "wavy" flow regime for 2-phase (air-water) pipe flow is investigated in detail (for background, see lead article, AMR, v. 11, p. 10, 1958). In earlier paper (Doklady Akademii Nauk SSSR, v. 51, No. 3, 1946) author classified 7 flow regimes in terms of, for each pipe diameter, ratio (0 to 1) of gas volume flow to mixture flow volume and mixture velocity (0.15 to 20 m/sec). Flow regimes of interest here are: I-Separated (stratified or wavy); II-Plugged without froth; III-Plugged with froth between bubbles. Author found that transition from I to II, III or IV could be given by an empirical formula involving above flow variables and pipe diameter. In this paper, author reported detailed measurements of wave amplitude, period and propagation speed with the same pipes (25, 50, 75, or 100 mm). For wave amplitude and period, empirical formulas are found which include the effect of pipe diameter. Author's detailed description of wavy regime appears to be new and useful. The usefulness of his particular choice of flow variables and empirical formulas should be investigated for extension to other fluids. (AMR, 1959, #1361)

2166. Radovcich, N. A., and Moissis, R.

THE TRANSITION FROM TWO-PHASE BUBBLE FLOW TO SLUG FLOW, NP 11845 (June, 1962) 81 p.

The process of transition from bubble to slug flow in a vertical pipe was studied analytically and experimentally. An equation is presented which gives the agglomeration time as a function of void fraction, channel diameter, initial bubble diameter, and liquid purity. A dependent function which also appears in the equation was evaluated using experimental data. A reasonably good correlation of the data was achieved. (NSA-62-29086)

2167. Schneider, F. N.

SOME ASPECTS OF SIMULTANEOUS HORIZONTAL TWO-PHASE FLUID FLOW, University of Oklahoma, M. S. Thesis (1953) 63 p.

In summarizing the results of this investigation, the following conclusions and recommendations may be made.

A tentative flow pattern chart is presented for a kerosene-natural gas system. For such a combination of fluids it allows the type of flow which would exist to be predicted under a given set of mass rates. The limits of the various types of flow are somewhat indefinite for the following transitions; wave semi-annular, slug-cresting and semi-annular cresting. Until more data are available, it is not possible to predict the effect variables such as viscosity, surface tension, and density would have upon the flow patterns. A correlation is presented which allows the two-phase static pressure drop to be predicted if the flow rates, physical properties and pipe diameter are known. It is not known to what extent pipe roughness might affect the two-phase pressure drop. Additional data obtained with the commercial grades of tubing would be helpful.

2168. Schneider, F. N., White, P. D., and Huntington, R. L.

HORIZONTAL TWO-PHASE OIL AND GAS FLOW, Pipe Line Industry (October 1954).

A tentative flow pattern chart is presented for kerosene-natural gas system. For such a combination of fluids this chart makes it possible to predict the type of flow for a given set of mass rates. The limits of the various types of flow are somewhat indefinite for the following transitions; wave-semi-annular, slug, cresting, and semi-annular cresting. Until more data are available, it will not be possible to predict the effect variables such as viscosity, surface tension, and density might have upon the flow pattern.

A correlation is presented which allows the two-phase pressure drop to be predicted if the flow rates, physical properties, and pipe diameter are known. This correlation is limited to those steady-state flows which exhibit uniform patterns throughout the tube length thus excluding slug and stratified flow. It is also limited to systems where evaporation and kinetic energy changes are small. Where these factors are significant, a step-wise solution would be necessary. Whether this correlation obtained in low pressure systems would be valid for high pressure work is not known.

2169. Vohr, J. H.

FLOW PATTERN OF TWO-PHASE FLOW, A SURVEY OF LITERATURE, TID-11514 (1960), 59 p.

A survey was made of the literature on flow patterns occurring in simultaneous gas-liquid flows through ducts. Description of gas-liquid flow patterns and the terminology used in denoting them are presented. The experimental investigations from which the descriptions are taken are surveyed. The relations between flow pattern and pressure drop in gas-liquid flows are discussed. Horizontal, vertical, and vertical boiling flows were investigated.

2170. Wace, P. F., Burnett, S. J.

FLOW PATTERNS IN GAS-FLUIDIZED BEDS, Trans. Instn. Chem. Engrs. 39, 168 (1961).

The following methods were used to detect the direction and velocity of gas streams moving through fluidized beds: injection of a visible trace of nitrogen dioxide, and measurement of pressures round an artificial gas bubble. It was found that pressure gradients exist toward the base of void spaces in fluidized beds. The gradients give rise to horizontal drag forces on particles and, because of their transitory nature, to rapid changes of direction of the local gas flow. The observations indicate the

order of magnitude of gas channeling effects in fluidized beds and the mechanism by which solids reform in the wake of bubbles.

2171. Yagi, Sakae, et al.

VERTICAL TUBE REACTOR. I. FLOW PATTERN AND HOLDUP IN GAS LIQUID TWO-PHASE FLOW, Chem. Eng. (Japan) 15, 317-22 (1951).

Several states of gas-liquid 2-phase flow were observed, and holdup was measured in a vertical glass tube (inside diam = 10.25 mm., length = 2 m.) with air as the gas phase and water and 3 types of oils as the liquid. By changing rates of gas and liquid 3 types of flow were distinguished: unsteady, climbing-film, and mist flow. The liquid holdup, ϕ, is correlated with other variables as follows: $\phi/(1-\phi) = 700\ (u_l/u_g)^{0.88}\ L^{-0.6}\ \mu_l^{0.2}$, where u_l and u_g are apparent velocities of liquid and gas, resp., L and μ_l refer to mass velocity and viscosity of the liquid, resp.

2172. TWO-PHASE FLOW PATTERNS WITH HEAT ADDITION, Progress Report, Jan.-Mar. 1962, UNC-5009 (EURAEC-316) (Apr. 15, 1962), 23 p.

Design of the apparatus for the two-phase flow patterns experiment was completed with the exception of the test strip insulators and the instrumentation connection details. Purchase orders were placed for all the major equipment, except the cooler coil and power control package. Fabrication of the mixer and test section electrical components is about 60% complete; the loop area was cleared and structural material ordered. Insulating materials for the test section heating strip are being screened in 50-hr corrosion tests in water at 600°F. A satisfactory material has not yet been tested.

2173. TWO-PHASE FLOW PATTERNS WITH HEAT ADDITION, Progress Report, April 1, 1962 to June 30, 1962, UNC-5025 (July 15, 1962).

Activities in a program to investigate two-phase flow patterns with heat addition from one wall of a rectangular flow passage are reported. Design of the test strip connectors and support was changed to utilize flame-sprayed aluminum oxide as electrical insulation. The loop framework and test section shielding were installed; the mixer is complete except for final assembly. All of the major equipment for the apparatus was received except the water pump, steam pump, pressure vessel, and quartz windows for the test section. Corrosion tests of phenolic-laminated asbestos were unsatisfactory because of contamination of the water by decomposed phenolics. Thermal shock tests of flame-sprayed aluminum oxide were successful. Photographic techniques are being developed using air-water mixtures in the brass model of the test section. Predictions of critical heat fluxes in the dispersed flow regime were made for this specific test section from a theory based on turbulent diffusion of droplets. According to the model, the critical heat flux occurs when the walls are no longer kept wet by the impingement of droplets. A graphical presentation of the predictions is included. (NSA 62-31799)

2174. TWO-PHASE FLOW PATTERNS WITH HEAT ADDITION, Progress Report, Sept. 5-Dec. 31, 1961, UNC-5001 (EURAEC-257) (Jan. 15, 1962), 18 p.

The experimental system consists of a test section with an electrically heated test strip connected to water and steam loops to provide the desired mixed flow. Coolant flow patterns near the heated strip in the test section will be observed visually and photographed through observation ports. Design of the experimental apparatus is about 65% complete. Vendors were requested to submit bids for the pumps, valves, pressurizer-separator, pressurizer heater, cooler, and high-speed motion picture camera. The designs of the test section, mixer, electrical and controls systems remain to be completed.

Annular

2175. Abramson, A. E.

INVESTIGATION OF ANNULAR LIQUID FLOW WITH CONCURRENT AIR FLOW IN HORIZONTAL TUBES, J. of Applied Mechanics, 19, 267-74 (1952).

For annular liquid flow with concurrent gas flow, the liquid flow is relatively smooth until the liquid-flow rate is sufficient for the thickness of the liquid annulus to enter the flow region where the turbulent forces predominate over the viscous forces; disturbances then develop on the liquid film. The approximate liquid-flow rate for this transition can be predicted.

2176. Anderson, J. D.

GAS-PHASE CONTROLLED MASS TRANSFER IN ANNULAR, CO-CURRENT TWO-PHASE FLUID FLOW IN HORIZONTAL PIPES, M. S. Thesis Univ. of Delaware (1959).

2177. Bennett, J. A. R., and Thornton, J. D.

PRESSURE DROP DATA FOR THE VERTICAL FLOW OF AIR-WATER MIXTURES IN THE CLIMBING-FILM AND LIQUID-DISPERSED REGIONS, Trans. Instn. Chem. Engrs. (London) 39, 101-126 (1961).

Relevant to petroleum production and refining operations, steam generation, and performance of climbing film type evaporators; analysis of film thickness and entrainment data and pressure drop measurements; present results confirm, qualitatively, B. G. Mantzouranis pressure drop analysis.

2178. Brown, D. H., Lustenader, E. L., and Neugebauer, F. J.

CRITERIA FOR UPWARD ANNULAR TWO PHASE FLOW, AECU-3934 (1958) 19 p.

A direct theoretical analysis was undertaken of upward annular two-phase flow. Inadequacies in experimental correlations indicate that the present theoretical models are either in error or are incomplete. Application was made of modern knowledge in the fields of boundary layer theory and film condensation. It was established that correlations and analytical methods that superimpose force fields, such as that of gravity, on the flow result in unrealistic patterns for flow distribution, fluid shear, and local pressure drop. Success with such methods

may be attributed to grossly compensating errors. The analysis was carried to the point of determination of the interface wave phenomenon. A further program of investigation of wave phenomenon for inclinations from horizontal to vertical is recommended.

2179. Budd, J. T.

MEASUREMENT OF ENTRAINMENT IN TWO-PHASE ANNULAR FLOW OF AIR AND WATER IN ONE INCH HORIZONTAL COPPER TUBE, B. S. Thesis, Univ. of Delaware (1950).

2180. Calvert, S.

VERTICAL, UPWARD, ANNULAR, TWO-PHASE FLOW IN SMOOTH TUBES, PhD Thesis, Univ. of Michigan (1952), 113 p.

This thesis is a study of the regime of co-current, two-phase flow, which is characterized by the liquid running as a film along the tube wall. This investigation involved the application of the concept of flow mechanisms to the case of film-flow, an experimental study of the flow of air and water, and an analysis of the momentum exchange between the two fluids. Data were taken for a range of air rates from 10-75 ft/min. and water rates of 0 to 300 lbs/hr for one inch ID tubes; and over a range of air rates from 55 to 112 cubic feet per minute and water rates from 0 to 2000 lbs/hr for the 2-inch ID tube.

Using fundamental principles of fluid dynamics, a relationship was developed which predicts film thickness and velocity for any liquid flowing in an annular film as a function of pressure drop, flow rate, tube radius and kinematic viscosity. The theoretical predictions agree with data for air-water systems. Pressure drop as a function of gas rate is predicted for air-water systems by an empirical correlation of the drag coefficient for the liquid surface, based upon reported pressure drops for an air-water, annular flow system. Using these two relationships pressure drops are predicted which agree well with those measured over the experimental range studied.

A general criterion of turbulence in liquid films is developed.

2181. Calvert, S., and Williams, B.

UPWARD CONCURRENT ANNULAR FLOW OF AIR AND WATER IN SMOOTH TUBES, AIChE Jour. 1, 78-86 (1955).

Two-phase fluid flow is distinguished from single-phase flow in two respects: (1) the cross section for flow of either fluid is not defined by the conduit alone and (2) not only the extent but the manner of frictional energy exchange for each fluid depends on the individual rates of flow for both fluids. It was believed therefore that an empirical approach would not adequately describe the various situations encountered in two-phase flow, and so study was undertaken to obtain some understanding of the mechanisms of the flow of liquid with a free surface and the momentum exchange between fluids at that surface. It resulted in the development of a method of predicting liquid holdup and pressure drop for flowing systems in which the liquid, lifted by the gas flowing as a central core, moves upward as an annular film along the pipe wall.

In order to clarify the relationship of annular flow to the entire range of vertical two-phase flow modes, a discussion of vertical two-phase flow is presented, followed by an analysis of the special case of vertical, upward, annular flow; a description of the experimental work; and a comparison of experimental data with predictions.

2182. Charvonia, D. A.

A REVIEW OF THE PUBLISHED LITERATURE PERTAINING TO THE ANNULAR, TWO-PHASE FLOW OF LIQUID AND GASEOUS MEDIA IN A PIPE, TM-58-1 (1958).

A literature study on two phase-flow was conducted with the emphasis on annular flow patterns of gas-liquid systems in a pipe. The theoretical and semi-empirical analysis of two-phase flow by various investigators is reviewed, and it is pointed out that analytical methods are generally characterized by procedures such as analysis of the interfacial structure of the flow. Experimental investigations are reviewed, and data pertinent to the annular flow pattern in two-phase flow are emphasized. Experimental results of pressure drop experiments are compared as well as data on liquid film thickness. A discussion of the stability of annular two-phase flow is also presented. 55 refs.

2183. Charvonia, D. A.

A STUDY OF THE MEAN THICKNESS OF THE LIQUID FILM AND THE CHARACTERISTICS OF THE INTERFACIAL SURFACE IN ANNULAR TWO-PHASE FLOW IN A VERTICAL PIPE, Jet Propulsion Center, Purdue University, Interim Report No. 50-1, JPC I-59-1 (1959).

The influence of the rates of flow of the two fluid media upon the mean thickness of the liquid film and the characteristics associated with the interfacial surface were studied experimentally and analytically. Pressure drop data for the gas stream in annular two-phase flow were obtained. A brief experimental study was conducted to determine unstable flow regions when entrainment occurs.

Fully developed air stream flows downward in a vertical pipe along with water film introduced through a circumferential injection slot.

2184. Collier, J. G., and Hewitt, G. F.

DATA ON THE VERTICAL FLOW OF AIR-WATER MIXTURES IN THE ANNULAR AND DISPERSED FLOW REGIONS. PART II: FILM THICKNESS AND ENTRAINMENT DATA AND ANALYSIS OF PRESSURE DROP MEASUREMENTS, Trans. Instn. Chem. Engrs. (London) 39, 127-136 (1961).

Relevant to petroleum production and refining operations, steam generation, and performance of climbing film type evaporators; analysis of film thickness and entrainment data and pressure drop measurements; present results confirm, qualitatively, B. G. Mantzouranis' pressure drop analysis.

2185. Foure, C., et al.

STUDY OF TWO-PHASE FLOWS (AIR-WATER) WITH VORTEX CYLINDRICAL AND ANNULAR FLOWS, Special Report No. 3, EURAEC-144 (1961).

The results of measurements of two-phase water-air, fall of pressure and vacuum fractions, both in conventional cases and with types of flow likely to produce an effect on the heat transfer characteristics at boiling point, are presented. The experimental equipment used during the tests is described. The falls in pressure in cylindrical annular flow, with and without twisted tape, were compared. Tests carried out with two-phase flow enabled the gradients in the falls in pressure and vacuum fraction to be studied with and without twisted tape. The influence of the water flow speed, the shape of the flow, the hydraulic diameter, and the thread of the twisted shape in the case of single and bracketed vortices was also demonstrated. The vortices induced by jets were also investigated.

2186. Fritzlen, A. F.

A STUDY OF LIQUID ENTRAINMENT IN ANNULAR CO-CURRENT, TWO-PHASE FLUID FLOW, MS Thesis, Univ. of Delaware (1951), 44 p.

Liquid and vapor phases can be brought into contact to provide for efficient reaction or transfer of mass or heat between phases if the fluids are caused to flow cocurrently through a straight pipe. The pressure drop that must be overcome to cause flow may sometimes be excessive, however, especially if the gas flow rate is high enough to keep the liquid flowing smoothly as a film on the pipe wall.

Measurements of pressure loss accompanying two-phase flow of water and air through a horizontal, 1-inch diameter tube have shown that the frictional effect is larger than would have been expected from previous work. An empirical equation has been found to relate the pressure drop to the air and water velocities.

Rates of transport of entrained liquid in the gas stream have been measured in order to find the operating conditions for which the liquid flows smoothly as an annular layer instead of unsteadily in "slugs." The measurements were made by inserting $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$-inch diameter sampling nozzles into the center of the 1-inch pipe, withdrawing a mixture of liquid and gas at a velocity approximately equal to the velocity of flow of the main stream. It was found that at the highest liquid rates the mass velocity of entrained liquid spray was equal to almost half the mass velocity of air. By comparing the rates of liquid collection by the three nozzles it was found that the spray mass velocity increased linearly with distance from the axis. The rate of increase and, consequently, the tendency of the liquid and vapor to be segregated, was found to be greater at the higher gas velocities.

2187. Gill, L. E., and Hewitt, G. F.

FURTHER DATA ON THE UPWARDS ANNULAR FLOW OF AIR-WATER MIXTURES, AERE-R 3935 (1962).

Data are presented for film thickness, film flow-rate and pressure gradient for upwards co-current air-water annular two-phase flow in a $1\frac{1}{4}$ in. bore perspex tube. Two injectors - a multijet type and an annular slot type - were used and a much wider range of phase flowrates was investigated than had previously been reported. The range of water flow over which film thickness was measured was increased from 10-100 to 20-300 lb/hr.

Film flowrates, film thicknesses and pressure gradients were all observed to be lower with the multijet injector than with the annular slot. The results for pressure drop were compared with the Lockhart and Martinelli and homogeneous correlations and the former was found to predict the values closest. The Lockhart and Martinelli hold-up correlation generally over-predicted the film thickness - this is due to the presence of entrainment. Very different patterns of entrainment were observed for the two injectors.

For higher liquid rates the entrainment results were found to agree with the correlating line obtained previously for vertical flow using the correlation method of Dukler and Wicks - provided the appropriate "critical Weber numbers" were used for the two types of injector. As in earlier work at lower liquid rates, the entrainment is over-predicted by the correlating line extrapolated from high liquid rates, and is a function of the gas flowrate. It transpired that the transition to the correlation occurs at values of y_1^+ of 16-18 and is related to the formation of large roll waves on the film surface.

The inter-relation of film thickness, pressure drop and film flow rate by velocity profile theories has been studied and is discussed; systematic deviations from simple theory are found.

2188. Hall-Taylor, N., and Hewitt, G. F.

THE MOTION AND FREQUENCY OF LARGE DISTURBANCE WAVES IN ANNULAR TWO-PHASE FLOW OF AIR-WATER MIXTURES, Chem. Eng. Div. Atomic Energy Research Establishment, Harwell, Berks.

In annular two-phase flow large disturbance (or "roll") waves are nearly always observed. These waves travel rapidly along the surface of the liquid film and have a "milky" appearance as a result of light scattering by their extremely ruffled surface. The ranges of air and water flow rate over which these waves are observed in low-pressure air-water flow have been investigated and are reported. The formation of the waves appears to coincide with the transition in entrainment observed in earlier work.(2,7)

Measurements of wave velocity and wave separation (in time and distance) are reported. Measurements made by a cine film method and by a conductance probe method are in satisfactory agreement. The mean velocity of the disturbance waves was about 4-10 fps compared with an air velocity of 40-150 ft/sec and a mean water velocity in the liquid film of 1-3 ft/sec. Mean wave velocity increased rapidly with increasing air flow but was insensitive to changes in water rate. The frequency of the waves was insensitive to air rate but increased in proportion to the liquid rate thus suggesting that the waves are transporting the liquid. For any set of conditions the wave velocities measured are not evenly distributed about the mean and a number of peaks occur in the histogram. These peaks appear in the same positions for a number of different flow rates and the existence of "preferred velocities" is therefore possible. Similar, but more equivocal, observations are made with respect to wave separation.

2189. Hewitt, G. F.

ANALYSIS OF ANNULAR TWO-PHASE FLOW: APPLICATION OF THE DUKLER ANALYSIS TO VERTICAL UPWARD FLOW IN A TUBE, AERE-R3680 (1961).

Dukler's analytical treatment of downward, annular two-phase flow is adapted to upward flow. Both fluid dynamics and heat transfer are considered. Diagrams illustrating two-phase flow calculations are presented along with tables of numerical solutions.

2190. Hewitt, G. F.

SOME CALCULATIONS ON HOLD UP, HEAT TRANSFER AND NUCLEATION FOR STEAM-WATER FLOW IN A 0.5 cm BORE TUBE, AERE-3984 (1962), 41 pp.

Using the theory of annular flow reported previously by the author(1) and assuming the Lockhart-Martinelli(2) correlation for frictional pressure drop it has been possible to calculate the holdup and heat transfer coefficient for simple hypothetical cases of steam-water flow in a tube. At zero entrainment the holdup correlation of Lockhart and Martinelli(2) was predicted by the annular flow calculations and the reasons for this prediction are discussed. As entrainment increases the holdup falls and a mass flow rate effect occurs in the correlation. Heat transfer coefficient, on the other hand, is less affected by entrainment, since a large portion of the temperature drop occurs in the boundary layer. The heat transfer calculations reveal a correlation with the Martinelli parameter, X, of the ratio of two-phase to single-phase coefficient; this correlation is some 30% higher than the empirical correlation of Collier et al.(3) Some consideration has been given to the nucleation of steam bubbles in the annular liquid films. Using the theory of Hsu(8) it has been possible to predict the heat flux for the onset of nucleation. Comparison of the nucleation heat flux with heat flux for burnout suggests a possible mechanism for burnout at the lower quality region which successfully explains both the reversal of the mass velocity effect, and the maxima, encountered in plots of burnout flux versus exit quality.

2191. Hewitt, G. F., King, I., and Lovegrove, P. C.

HOLDUP AND PRESSURE DROP MEASUREMENTS IN THE TWO-PHASE ANNULAR FLOW OF AIR-WATER MIXTURES, AER-E R3674 (1961).

2192. Hewitt, G. F., King, R. D., and Lovegrove, P. C.

TECHNIQUES FOR LIQUID FILM AND PRESSURE DROP STUDIES IN ANNULAR TWO-PHASE FLOW, AERE-R 3921 (1962).

Developments are described in the previously reported flush conductance probe method which allow an average value of film thickness to be determined and also the instantaneous value of conductance to be recorded. A generalized calibration for these probes has been obtained. The needle contact method of Brauer has also been considerably improved by the introduction of better counting methods. The application of both these techniques, together with an improved method of measuring two-phase pressure drop, to the study of air/water flow in a $1\frac{1}{4}$ in. bore acrylic resin tube is described. Results for film characteristics and pressure drop are presented for a selected range of air and water rate.

2193. Jacowitz, L. A.

AN ANALYSIS OF GEOMETRY AND PRESSURE DROP FOR THE ANNULAR FLOW OF GAS-LIQUID SYSTEMS, Ph.D. Thesis, Ohio State Univ. (1962), 214 pp.

2194. Laird, A. D. K.

STABILITY CONSIDERATIONS IN VERTICAL ANNULAR TWO-PHASE FLUID FLOW, University of California, Ph.D. Dissertation (1951), 87 p.

The problem of the high pressure drop associated with annular upward gas-liquid flow was attacked analytically and experimentally. It was established that the interface waves could cause the high pressure drop in the gas core. This pressure drop was found to be sensitive to the wavelength, amplitude and frequency of the interface waves. These variables were related to the liquid saturation.

The conditions imposed on the gas column of two-phase flow were simulated by rubber tube models. These tubes were forced to oscillate in the form of a standing wave. The amplitude, frequency and wavelength were varied. Results from these models showed that for any given Reynolds number between 300 and 3000, the pipe friction factor increased as the tube wall oscillation frequency was increased from 0 to 2000 cycles per minute. The rate of increase depended on the ratio of the amplitude of the oscillations to the tube radius. For values of this ratio of 5, 10, and 20 per cent, the friction factor increased to 3, 50, and 150 times, respectively, the friction factor for zero frequency. High pressure drops were shown to accompany a flat velocity distribution in viscous flow. Evidence was given that turbulent flow existed at Reynolds numbers as low as 300.

2195. Laird, A. D. K.

STABILITY OF GAS FLOW IN A TUBE AS RELATED TO VERTICAL ANNULAR GAS-LIQUID FLOW, Trans. ASME 76, 1005 (1954).

A model study of the pressure drop in the gas column of an upward annular gas-liquid flow system is described. The models were two rubber tubes with walls oscillating as axis-symmetric standing waves. Pressure drops were shown to increase rapidly with increase of wave length, wave amplitude, and wave frequency. The mathematical analysis of the system was extended.

2196. Levy, Salomon

THEORY OF PRESSURE DROP AND HEAT TRANSFER FOR TWO-PHASE TWO-COMPONENT ANNULAR FLOW IN PIPES, University of California, M. S. Thesis (1951), 85 p.

The several types of two-phase flow are classified as stratified, wave, slugging, and annular. For each of these types there exist four flow regimes, namely viscous-viscous, viscous-turbulent, turbulent-viscous, and turbulent-turbulent. In this thesis an exact solution of the pressure drop and heat transfer for annular flow is presented. A comparison is made between the predicted pressure drop and Martinelli's correlated experimental results. The two sets of values are shown comparable over a large range, while the flow parameters are proved to be almost identical to the ones derived by Martinelli.

The heat transfer for two-phase annular flow is shown to be determined by the same parameters as the pressure drop if constant weight rate curves are plotted. Finally, the theory indicates that both the pressure drop and the heat transfer are not independent of the flow pattern.

Experimental data were obtained for the heat transfer of an oil-air system flowing in a 4.4 foot heat exchanger 0.0262 foot in diameter. An approximate analysis based on Martinelli's correlation is developed for the heat transfer of two-phase two-component flow in pipes. The calculated values fall within ±15% of the experimental results.

2197. Levy, Salomon

THEORY OF PRESSURE DROP AND HEAT TRANSFER FOR ANNULAR STEADY STATE, TWO-PHASE TWO-COMPONENT FLOW IN PIPES, Ohio State University, Proceedings of Second Midwestern Conference on Fluid Mechanics, 337-48 (1952).

The problem of the high pressure drop and heat transfer associated with steady-state annular horizontal gas-liquid flow in pipes was attacked analytically. Solutions are presented for three gas-liquid flow regimes: viscous-viscous, viscous-turbulent, and turbulent-turbulent. The parameters are identical to the ones obtained semi-empirically by Martinelli. Three additional parameters based on the physical properties of the fluids appear in the solutions, but their effects are negligible in most practical cases. The heat transfer of two-phase annular flow is determined by the same parameters as the pressure drop if constant liquid or gas weight rate curves are plotted. The predicted pressure drop and the experimental data correlated by Martinelli are shown comparable over a large range. The test values of the pressure drop and liquid saturation always exceeded the theoretical results, the maximum deviation for the pressure drop being 20%. This discrepancy can in turn be explained in terms of the simplified geometry of the theoretical system and the neglect of some of the terms in the Navier-Stokes equations.

2198. McManus, H. N.

AN EXPERIMENTAL INVESTIGATION OF FILM ESTABLISHMENT, PROFILE, DIMENSIONS, PRESSURE DROP, AND SURFACE CONDITIONS IN TWO-PHASE ANNULAR FLOW, Ph.D. Thesis, Univ. of Minn. (1956).

2199. McManus, H. N., Jr.

AN EXPERIMENTAL INVESTIGATION OF FILM CHARACTERISTICS IN HORIZONTAL ANNULAR TWO-PHASE FLOW, ASME Paper No. 57-A-144 for meeting Dec. 1-6 (1957), 17 p.

2200. McManus, H. N., Jr.

AN EXPERIMENTAL INVESTIGATION OF LIQUID DISTRIBUTION AND SURFACE CHARACTER IN HORIZONTAL ANNULAR TWO-PHASE FLOW, Cornell University, Sibley School of Mechanical Engineering, Ithaca, N. Y., IR-1 DA-30-115-ORD-992, OOR-R-2117:2 (1959).

A series of tests has been made to measure mean and minimum film thickness, wave height, and pressure drop in horizontal tubes. Three pipe sizes were employed, one, two and three ID, and the film profiles measured at several axial positions. Two fluids, water and a water-glycerine solution, differing in viscosity by a factor of ten were employed.

2201. McManus, H. N., Jr.

FILM CHARACTERISTICS AND DIMENSIONS IN ANNULAR TWO-PHASE FLOW, Cornell University, Sibley School of Mechanical Engineering, Ithaca, N. Y., December, 1959, Interim Report No. 2, OOR Project No. 2117, Contract DA-30-115-ORD-992 (Reprinted from the Proceedings of the Sixth Annual Conference on Fluid Mechanics held at the University of Texas, Austin, September 1959).

Measurements of liquid distribution when undergoing horizontal annular flow have been made in a one-inch and two-inch tube for an air-water system. The air Reynolds number was varied from 59,000 to 285,000; the liquid rates ranged up to 0.6 lb/sec. Measurements were made of mean and minimum film thickness and maximum wave height at five stations in each tube. It was found that the gravity effect is appreciable at all flow rates and leads to the air core experiencing unequal wall roughness around the tube periphery. It is suggested that this effect is responsible for the indifferent success of analytic approaches. A correlation of liquid area fraction with liquid and gas Reynolds numbers for "steady-state" values is given. This correlation also gives data on average mean film thickness.

2202. McManus, H. N., Jr.

LOCAL LIQUID DISTRIBUTION AND PRESSURE DROPS IN ANNULAR TWO PHASE FLOW, ASME Paper 61-HYD-20 (1961).

Empirical correlations are presented for local liquid-film thickness in horizontal annular flow for a wide range of flow conditions. Comparison of measured liquid-area fraction are made with those predicted by the Martinelli correlation. Measured pressure drops are compared with those predicted by the Martinelli and Chenowith-Martin correlations. Separation of pressure drops into component parts was accomplished. Momentum pressure drops were found to depend on gas Reynolds number. Correlations of momentum pressure are presented.

Preprint for the joint ASME-EIC Hydraulic Conference, Montreal, Canada, May 7-10, 1961.

2203. McNutt, C. R.

PRESSURE DROP IN TWO-PHASE ANNULAR FLOW, HW-35065TH (1955).

2204. Magiros, P. G.

ENTRAINMENT AND PRESSURE DROP IN HORIZONTAL TWO-PHASE GAS-LIQUID FLOW, M. S. Thesis, Univ. of Houston (1960).

2205. Magiros, P. G., and Dukler, A. E.

ENTRAINMENT AND PRESSURE DROP IN CONCURRENT GAS-LIQUID FLOW II LIQUID PROPERTY AND MOMENTUM EFFECTS, Presented at the Seventh Midwest Conference of Fluid Mechanics, East Lansing, Michigan, September, 1961.

2206. Quandt, E. R.

MEASUREMENT OF SOME BASIC PARAMETERS IN TWO-PHASE ANNULAR FLOW, WAPD-T-1502 (1962), 38 p.

The experimental results of vertical flow of air-water mixtures in a $\frac{1}{4}$ x 3 in. rectangular channel are presented. It is assumed that annular flow is adequately described by a liquid film on the channel walls flowing concurrently with a central core of vapor and droplets. Dye injection into the liquid film is used as a means of measuring the film velocity and thickness, fraction of liquid entrained in the gas, droplet axial velocity, and rate of droplet interchange between the core and the film. Pressure gradient and liquid volume fraction were also measured. Air velocities from 50 to 200 ft/sec and total liquid rates from 0.04 to 0.60 lb per sec per ft of perimeter were studied. Visual observations indicated that the most important characteristic of this flow regime is the surface waves generated by the gas flow over the liquid film. It is shown that the average values of film thickness and velocity may be used to compute the wall shear stress and that the film flow is laminar. The measured rates of droplet interchange indicate that this flow is too small to account for the film to gas core momentum transfer, but is significant from a heat transfer standpoint. The droplet cross-flow rates behave in the anomalous manner deduced by Isbin and Vanderwater from an analysis of burnout data.

2207. Roberts, D. C.

A CORRELATION OF ADIABATIC PRESSURE DROP DATA FOR TWO-PHASE ANNULAR FLOW IN VERTICAL CHANNELS, Dip. Nucl. Eng. Thesis, Queen Mary College, Univ. of London (1960).

2208. Semenov, P. A.

LIQUID FLOW IN THIN LAYERS, Journal of Technical Physics (USSR) 14, 427-37 (1944).

Water flows along the inner surface of a vertical glass tube and a rapid air current rises in the middle of the tube. According to the rates of flow of water and air six types of flows are observed. A hydrodynamical theory is given to account for the observations; it allows a calculation of the coefficient of friction between water and streaming air. The phenomenon is important for scrubbers, coolers, etc.

2209. Semenov, P. A.

LIQUID FLOW IN THIN LAYERS, PART II, Journal of Technical Physics (USSR) 20, 980-90 (1950).

A study has been made of the upward movement of a thin liquid layer carried along a vertical wall by fast vertical gas currents. As pointed out in Part I, observations show peculiar undulatory movements in the liquid film, unexplainable by a preliminary theory. A more exact theoretical description and analysis of experimental aspects of the phenomenon are given. Besides its bearing on the general problem of the stability of the laminar layer, the subject is connected with several questions concerning practice devices ("choking" of rectification columns, two-phase flow, etc.)

2210. Wicks, M., III.

ENTRAINMENT AND PRESSURE DROP FOR HORIZONTAL TWO-PHASE FLOW OF AIR AND WATER, M. S. Thesis, Univ. of Houston (1958).

2211. Wicks, M., III., and Dukler, A. E.

ENTRAINMENT AND PRESSURE DROP IN CONCURRENT GAS-LIQUID FLOW: I. AIR-WATER IN HORIZONTAL FLOW, AIChE Jour. 6, 463-468 (1960).

2213. Wrobel, J. R., and McManus, H. N., Jr.

ANALYTIC STUDY OF FILM DEPTH, WAVE HEIGHT, AND PRESSURE DROP IN ANNULAR TWO-PHASE FLOW, Develop. Mech. 1, 578-87 (1961).

An analytic investigation of the liquid film characteristics in concurrent, annular gas-liquid flow with interfacial shear is presented. The system studied is that of a turbulent gas moving axially through a circular tube while in contact with an annulus of liquid at the inner periphery of the tube. Heat and mass transfer between phases are not considered. The momentum interchange between phases is likened to that occurring in the flow of a single phase through a hydraulically rough tube, with the interfacial

disturbances representing the equiv. roughness elements. This assumption allows the prediction of the friction factor, i.e., pressure drop, for a given gas-liquid flow system. A comparison of the predicted flow properties with those published in exptl. studies is presented as an evaluation of the analytic solution.

2214. Zhivaikin, L. Ya., and Volgin, B. P.

HYDRAULIC RESISTANCE IN RISING TWO-PHASE FILM FLOW, Zhur. Vsesoyvz. Khim Obshchestva im D.I. Mendeleeva 6, 354-5 (1961).

The effect of the gas rate, w, and the liquor rate, Q, on the coeff. of the hydraulic resistance, $\lambda = A Re^{m} Re_l^{n}$, in an air-$H_2O$ system in a rising film-type app. was studied in a glass column 830 mm high and 13 mm diam. The plots of the pressure drop Δp vs w passed through a min., the value of which increased as Q increased from 0.46 to 4.5 sq cm/sec. In the region of the Δp vs. w curve where Δp decreased as w increased, $\lambda = 4.6 \times 10^{8} Re^{1/3} Re_l^{-5/2}$; in the region in which Δp increased with w, $\lambda = 6.55 Re^{7/12} Re_l^{-3/4}$. Re and Re_l are the Reynolds nos. of the liquid and the gas phases, resp.

Entrainment

2215. Aleksandrov, I. A., and Skoblo, A. I.

ENTRAINMENT OF A LIQUID BY A GAS WITH SCREEN TYPE PLATES, Khim i Tekhnol. Topliv i Masel 5, 42-5 (1960).

Entrainment was studied with an exptl. model of a mesh-type plate column. The water-air system was used with the liquid colored with fluorescein, thereby permitting the use of optical methods for detg. the amt. of entrainment. The data were correlated by the equation: $e \times 10^2 = 0.014 (W/H)^{2.56}$, where e is the ratio of liquid carryover to air in kg/kg, W the superficial air velocity in m/sec, and H the distance between the froth layer and the bottom of the next plate, in mm. The velocity of the air was maintained at 2 m/sec; the space between plates was varied between 250 and 450 mm. The max. deviation from values calcd. from the equation did not exceed ±25%; most points lay within the limits of ±15%. From the value of e obtained from the equation, the optimum value of H may be cald. from: $H = W(0.014/100c)^{0.39}$. Entrainment under the conditions described did not depend on the construction of the plate or on the water rate. Furthermore, the water draining from the upper plate produced a sepg. effect that served to diminish the amt. of entrainment.

2216. Andreevskii, A. A., and Zenkevich, Yu. V.

INVESTIGATION OF THE SALT ENTRAINMENT BY VAPOR UTILIZING RADIOACTIVE ISOTOPES, Teploenergetika, 2, No. 9, 37-42 (1955).

An exptl. steam boiler-condenser loop is described in which aq. solns. of radioactive $Na_2S_{35}O_4$ were vaporized by elec. heating at controlled rates. When an effective entrainment separator was used the coeff. of salt carry over was independent of the boil-up rate. Curves are presented relating carry over to loading with and without a separator for various liquid and vapor space geometries. (CA-50-6715h)

2217. Andrews, J. M.

KINETIC STUDY OF FLUIDIZED SOLIDS ENTRAINMENT, Ind. and Engr. Chemistry, 52 85-88 (1960).

The equations developed here provide a basis for estimating catalyst entrainment in various process designs for both dense phase beds and transfer lines.

2218. Barker, K. R.

REMOVAL OF ENTRAINED GAS FROM SODIUM SYSTEM, Mine Safety App. Co., Tech Report No. 50 MSA-TR-50 (July 1956).

An efficient method for removal of entrained gas in a Na system similar to the S2G primary coolant system is described. A study of the behavior of air-water mixtures in a glass loop showed how gas moved through the system and gave a better understanding of two-phase flow. Air could be held up at various points depending on the velocity: down-stream end of upper horizontal run at 0.25 fps, in the vertical downward leg at 0.25 to 0.50 fps, and at the bottom of the vertical downward run at 0.50 fps. Entrained gas in the Na system caused erratic flowmeter and pump performance and flow stoppage at low velocities. An expansion tank located above the loop will remove gas at any flow condition great enough to transport gas to the vent. If it is necessary to transport gas downward to the expansion tank a minimum velocity must be exceeded. This was found to be between 1.5 and 2.3 fps in a 1 in. line 6 ft long. Gas removal rate is a function of velocity in the expansion tank line, but is independent of the main loop velocity. Entrained gas can be removed if liquid velocities are kept above 2 ft/sec and a normal separator is used in a by-pass line.

2219. Blinov, K. A.

ON THE MODEL PROPOSED BY G. N. KRUZHILIN FOR THE PROCESS OF CARRY-OVER OF MOISTURE, Izv. Akad. Nauk, SSSR, O.T.N., No. 3, p. 467 (1952).

2220. Chernaev, I. I., and Styrikovich, M. A.

PHYSICAL AND CHEMICAL PROCESSES INSIDE BOILERS, Akad. Nauk. SSSR., Moscow (1957).

This monograph contains 40 research papers on the purity of steam, the purity of water, and on corrosion.

2221. Davis, R. F.

THE PHYSICAL ASPECT OF STEAM GENERATION AT HIGH PRESSURES AND THE PROBLEM OF STEAM CONTAMINATION, Proc. of the Inst. of Mech. Engineers, Vol. 144 (1940) pp. 198-216. An abstract appears in the Engineer, Dec. 1940, pp. 399-401, 412-414.

Constitution and physical properties of boiler water investigated with reference to operating pressure; process; process of evaporation at submerged heating surface; effect of bubble size on circulation; mechanical priming and methods of preventing steam contamination by moisture and solids discussed. Bibliography. EI(1940) p. 141.

2222. Dombrowski, N., et al.

LIQUID ENTRAINMENT. I. MECHANISM OF DROP FORMATION FROM GAS OR VAPOR BUBBLES, Trans. Inst. Chem. Engrs. (London) 32, 244-261 (1954)

The paper presents the results of a study of drop formation due to bubbles of gas or vapor travelling upwards through a liquid and collapsing at the liquid-gas interface. The sequence of events associated with the collapse of the bubble has been traced and the sizes, trajectories, and number of drops formed have been determined. Some observations on the function of baffles in entrainment separators are recorded and the conditions giving rise to re-entrainment defined.

2223. Dombrowski, N., et al.

LIQUID ENTRAINMENT; MECHANISM OF DROP FORMATION FROM BUBBLES, Chem. Age. (London) 72, 269-74 (1955)

2224. Eisenklam, P.

FLOW THROUGH POROUS MATERIALS, THE RETARDATION OF LIQUID FLOW RATES IN POROUS MATERIALS. PART II. THE EFFECT OF GASES DISSOLVED OR ENTRAINED IN THE LIQUID, DGGW-EMR-55-6; AD-71864, (Mar 1955) 81 p.

An investigation is carried out of the mechanism of reduced flow rates as experienced during film cooling and liquid filtration processes using micropored materials. Water and kerosene, and sintered steel, bronze, and glass of pore throat diameter from 13 to 47μ are used with pressure gradients up to 80 psi per inch and at room temperature. Gases in the pores by evolution from the liquid or from entrainment cause reduced but steady flow rates. The correlation between the resulting moisture content of the porous material during flow and the corresponding flow rate can be predicted for the majority of conditions examined.

2225. Epstein, G. H.

REPORT OF LITERATURE SURVEY ON LIQUID-GAS ENTRAINMENT PROBLEMS, KAPL-M-GHE-1, (1955)

An exploratory study has been made of literature pertaining to the phenomena of interfacial particles in gas-liquid systems to learn what factors influence the behavior of bubbles or other types of entrainment in both static and dynamic two-phase systems. The aim is ultimately to apply these findings and their corollaries to problems associated with filling and draining Na systems, where gas entrainment appears undesirable, both from heat transfer and hydraulic considerations. 16 references. (NSA-10-10817)

2226. Garner, F. H., et al.

SIZE DISTRIBUTION AND ENTRAINMENT OF DROPLETS, Trans. Inst. Chem. Engrs. 32, 222-35, (1954)

The size distribution and entrainment of droplets in a pilot-plant evaporator and in a 4-in. glass evaporator have been detd. from the evapn. of water and KNO_3 solns. Droplet formation and projection into the vapor space occur under splashing, bursting of vapor bubbles, and foaming. Samples of the entrained droplets were collected in a two-stage cascade impactor and the entrainment was calcd. from the size and total no. of droplets. The cascade impactor consisted of one straight rectangular jet and one tapered rectangular jet in series, each contg. a microscope slide coated with magnesium oxide. A droplet striking the magnesium oxide layer penetrated the surface, giving a well-defined circular impression that appeared as a bright circle of light against a dark background when viewed through a microscope with transmitted light. The ratio of droplet diam. to the impression on the slide is a const. which is independent of the nature of the liquid and the velocity of impact. Entrainment was also detd. by measuring the concn. of salt in the condensed vapor from the KNO_3 soln. Approx. 95% of the droplets entrained in the vapor space of the evaporators were smaller than 20μ, but because of their low mass, they formed only a very small fraction of the total wt. of the entrained liquid. Droplets larger than 100μ contribute the main quantity of the entrainment. A study of the size distribution and entrainment of droplets from bursting air bubbles emerging from water, benzene, and EtOH has shown that droplets are formed both by the collapse of the bubble dome and by the disintegration of the jet of liquid arising from the bubble crater. The relative magnitude of these two effects depends on the size of the bubbles. Droplets from the rupture of bubbles larger than 0.5 cm. in diam. were almost entirely produced from the bubble dome. Stabilization of a bubble by the presence of dissolved or suspended solids and increases in liquid viscosity or surface tension tend to reduce the size and no. of liquid droplets produced upon disintegration of the bubble dome, thus decreasing the entrainment.

2227. Garner, F. H., Ellis, S. R. M., and Shearn, D. B.

ENTRAINMENT IN EVAPORATORS, Trans. Inst. Chem. Engr., 37, 246-54 (1959).

A study was made of the effects of evapn. rate, liquid concn., and liquid level on entrainment from boiling sugar solns. Aq. solns. of granulated sugar (15-72 wt. %) were boiled at 250 mm. Hg in a pilot plant evaporator. Sugar carry-over was measured at different liquid levels at evapn. rates over the range 125-500 lb/hr. Sugar concns. >1% were detd. by refractometer, concns. < 1% colorimetrically by using a 0.05% soln. of anthrone in H_2SO_4 (Morse, C.A. 42, 843i). At sugar concns. < 60%, entrainment increased with increasing evapn. rate and decreasing concn.; between 60 and 72%, the concn. had little influence. Changes in liquid level had no significant effect on entrainment. Size distribution of Pietroboni (by Silvio Pietroboni). Ger. 1,021,288, Dec. 19, 1957 (Cl. 80b). A dry mixt. of 40-65% by wt. of portland cement and 35-60% lime, together with fillers, such as sand with a grain size <3 mm., and dye is worked with H_2O. The latter contains 0.7-1.5% dissolved Me cellulose and 7-15% dispersed poly (vinyl ester), esp. poly (vinyl acetate). From C.Z. 1958, 13612. (CA 54-10355h)

2228. Gaston, E. C.

ELIMINATING CARRYOVER AND BLADE DEPOSITS AT PENSACOLA STEAM PLANT., Southern Power and Industry, 64, 46-6, 136, 138, 140 (Dec 1946).

Good portion of Gulf Power Co. plant outage time was caused by major operating problem of carryover in steam and resulting deposits in turbine; evidence of carry over; procedure for washing out turbine; feed-water treatment prior to washout; changes adopted in feedwater treatment; type of deposits removed during washout; results and conclusions. EI (1947), p. 142

2229. Gelperin, N. I., and Kogan, V. B.

MECHANICAL CARRYOVER BY VAPOR FROM AN EVAPORATOR, Khim. Prom., 96-101 (1958)

The existence of 3 zones in the vapor space of evaporators was confirmed: (1) the zone of boiling liquid, (2) the zone of large amts. of liquid with the vapor, and (3) the zone of sepn. of the liquid drops. The entrainment of large amts. of liquid during the evapn. of non-foaming solns. was caused by a rise of their level during vigorous boiling. The relative velocity of vapor during vaporization was directly proportional to the vapor velocity referred to the total cross-section of the evaporator tubes, and was not related to the physico-chem. properties of the liquids studied (aq. solns. of $K_2Cr_2O_7$, K_2CrO_4, $NaNO_3$, KCl, Na_2SO_4, and MeOH, Me_2O, CCl_4, C_6H_5Me). The level to which the liquid was thrown into the vapor zone was detd. by the pressure at the vaporization level. Equations were derived for the detn. of the dynamic level of the liquid and the limiting height of the vapor space, corresponding to zone 2. (CA 52-16806b)

2230. Gleim, V. G.

ON THE PROBLEM FOR A GENERAL THEORY ON MOISTURE ENTRAINMENT FROM BOILING MIXTURES, Zhur. Priklad Khim., 28, 12-20 (1955) English transl. in: J. Appl. Chem. (USSR) 28, 9-15 (1955)

Aq. solns. of NaOH with a foam inhibitor (4 mg/l distearoylhexamethylenediamine) were boiled at a const. rate at atm. pressure. The humidity of the steam increased at first slowly (0.5%) as the NaOH concn. increased to 700-800 mg/l, then it rose rapidly to 3.5% at 100 mg/l NaOH. The height and the stability of the foam as functions of NaOH concn. are practically parallel curves falling gradually. The laboratory expts. were extended to locomotives and the results led to the conclusion (by elimination of all other sources) that the humidity of the steam was caused by the carry-over of films from burst steam bubbles. Expts. with distd. H_2O showed that the rise of a drop of liquid formed by a broken air bubble was directly proportional to the diam. of the bubble and that there was a crit. diam. (~7 mm for distd. H_2O) at which the rise of the liquid was negligible. For larger bubbles the broken film forms a spray. This was demonstrated photographically. (CA 49-10014c)

2231. Hoffman, B., et al.

EFFECT OF GAS ENTRAINMENT ON THE HEAT-TRANSFER CHARACTERISTICS OF LIQUID MERCURY, BNL-2446 (p. 21-34), (1955).

Mercury, flowing turbulently in circular conduits exhibits small, bubble-like cavities in contact with the tube wall. These cavities, called detachments, impede heat transfer. Wetting the mercury by the addition of sodium produces slightly higher heat transfer coefficients. Reports are given on various attempts to eliminate the entrainment of gases from liquid metals, but as yet no method has been found that is practically feasible.

2232. Ingham, E.

BOILER CARRYOVER TROUBLES, Power and Works Engr., 43, n. 502 p. 121, EI (1948) p. 153, (Apr 1948)

Evils caused by carryover or foreign matter in form of water and solid impurities carried over with steam from boilers into pipes, superheaters, engines, turbines etc.; reducing carryover; inexpensive way of preventing carryover is to fit steam purifier inside boiler, placing outlet fitting in boiler valve stand pipe.

2233. Kirpichev, V. M.

THE CONCLUSIONS OF THE COMMISSION CONCERNED WITH THE SUMMARY OF THE DISCUSSION ON THE MECHANISM OF MOISTURE ENTRAINMENT FROM VAPOR BOILERS, Izvestia Akad. Nauk, Otd. Tech. Nauk, no. 12, 1863 (1953).

2234. Kolokolitsev, V. A.

AN INVESTIGATION OF THE CONDITIONS IN THE STEAM SPACE OF ISV EVAPORATORS, Dissertation, Trans. of the Power Institute, "M. V. Molotov," 10, (1952).

2235. Lamb, O. P.

AIR ENTRAINMENT IN FLOWING WATER, A SUMMARY AND BIBLIOGRAPHY OF LITERATURE, University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Report No. N60nr-246, Task Order 6, Project Report No. 19, August 1949, 41p.

The physical entrainment of a gas by a liquid and the flow of gas-liquid mixtures are phenomena commonly encountered in engineering practice, but avoided or arbitrarily compensated for in theoretical considerations and in design analysis. The progress toward a satisfactory explanation of these phenomena has been hampered by a lack of accurate experimental observations of entrained flows and by the complexity of the theoretical analysis when certain of the physical forces can no longer be neglected. Flows or liquids with entrained gases may be roughly classified into those occurring in systems enclosed by solid boundaries such as conduits and those occurring in open channels where a boundary of the liquid stream is gaseous. Gas is often entrained in a liquid of a closed-conduit system in an easily understood manner, but the entrainment in an open channel remains

a natural and imperfectly understood process. Although liquids and gases often flow as physical mixtures in closed-conduit systems, the only gas-liquid mixture of great practical importance in open-channel flows is that of water and air. The published literature indicates that an awareness of the special problems involved in the design of structures and systems where entrained flows may be expected has been present throughout the last century. During the past 20 years the demand for a more comprehensive definition of these flows has been intensified in proportion to the progressive limitation of uncertainty in other factors of hydraulic design. This report is in partial fulfillment of Task Order 6, dated April 16, 1948 under terms of Contract N60nr-246 between the University of Minnesota and the Office of Naval Research. The specification stated in part "...review the existing literature relating to the problem (of air entrainment), prepare a selected bibliography of collected papers..." A general limitation has been placed on the examination of the literature pertaining to flows of entrained fluids in vertical conduits and in open channels. In addition there is included an abbreviated account for the related problems of the rate of rise of air bubbles in water and the unsteadiness of flow in open channels in as far as they may concern the study of entrained flows. The review also includes selected reports of research and analysis relevant to determining the importance of surface-tension and viscosity forces in the flows of gas-entrained liquids. The report is divided into 2 sections. The first is intended to act as an introduction to the problems of entrained flows and is subdivided into the following groups: (1) Physical Properties of Gas-Liquid Mixtures, (2) Entrained Open-Channel Flows, (3) Entrained Closed-Conduit Flows, and (4) Experimental Methods. Reasonably substantiated results of the various investigation are listed in this section, although no common exposition was found that could be used for the purpose of comparing results. The second section consists of a bibliography with abstracts of the pertinent literature.

2236. Margulova, T. H., Katovskaia, K., and Borodulina, L.

NOMOGRAMS FOR COMPUTATION OF STEAM PURITY, Teploenergetika, V. 5, no. 1, p. 6, (1956)

2237. Mitsuishi, N.

STUDIES ON LIQUID ENTRAINMENT. EVAPORATION OF RADIOACTIVE LIQUID WASTE. Translated from: Kagaku Kogaku 22, 680-6, AEC-tr-4225 (p. 19-36), (1958).

The bursting of gas bubbles was experimentally studied, using air, distilled water, and solutions of butyric acid and glycerin. Large drops were caught on a slide coated with a mixture of vaseline and light mineral oil, and the diameter of the drops were measured through a microscope. The relations between the diameter of the gas bubble and the height which the drops entrained above the gas-liquid interface, and the diameter of the drops are shown. The velocity of the rising drops was calculated. A general theoretical formula was derived for the case in which several drops were formed from a single bubble:

$$\sum_{i=1}^{N} v_i = K \left(\frac{\sigma}{\rho_w}\right) \frac{1}{r^{1/2}}$$

where, N is the number of drops. Comparison of the theoretical values of the velocity of drops with the experimental data may verify the adequacy of the equation, except for the case of liquids with high viscosity. A natural circulation type evaporator for radioactive liquid waste disposal was constructed, and the over-all decontamination factor was obtained. The factor ranged over 10^5 to 10^7 for vapor mass velocities of 200 to 3000 kg/m^2hr. (NSA 15 16768)

2238. Mitsuishi, N., et al.

THE LIQUID ENTRAINMENT AND ITS REMOVAL IN A LARGE-SCALE EVAPORATION UNIT. EVAPORATION OF RADIOACTIVE LIQUID WASTE. Translated from: J. At. Energy Soc. Japan, 1, 363-9, AEC-tr-4225 (p. 1-18), (1959).

A large scale evaporation unit consisting of evaporator, cyclone, and packed tower was constructed, with which studies were made of the liquid entrainment and its removal. The results obtained are as follows: (1) the decontamination factor of the evaporator lies between 10^4 and 10^5; (2) that of the cyclone is in the range of 10 to 10^2; (3) the over-all decontamination factor of the evaporation unit lies between 10^6 and 10^7; (4) the optimum vapor mass velocity in the vapor space of the evaporator is about 200 kg/m^2hr. With this optimum vapor mass velocity, the maximum over-all decontamination factor is obtained. The results obtained by the large scale evaporation unit were compared with that obtained by the small scale evaporation unit. (NSA 14-8319)

2239. Mitsuishi, N., Yamamoto, Y., and Oyama, Y.

ON LIQUID ENTRAINMENT AND ITS REMOVAL. DECONTAMINATION CHARACTERISTIC OF EVAPORATION UNIT. Translated from: Kagaku Kogaku, 23, 647-54, AEC-tr-4225 (p. 37-52), (1959)

Considerations are given for the decontamination factors in an evaporator, a pipe line, and a cyclone, pertaining to the pilot plant. The decontamination factor in the evaporator proves to be mostly independent of the height of vapor space (0.6 m and 1.1 m, respectively). Theoretical calculation from the jet velocity at which a single gas bubble bursts demonstrates the results obtained experimentally. The over-all decontamination factor is found to be between 10^7 and 10^8. The drag coefficient of the glass-fiber-packed bed proves to obey the Langmuir and Iberall's equation. The decontamination factor without downtake indicates approximately the same value as in a natural circulation type evaporator, when the mass velocity is large. The mass velocity at the maximum decontamination factor is larger than in the natural circulation type. Considering the presence of demisters which are usually installed in industrial scale equipment, the mass velocity at the

optimum over-all decontamination factor may be set within 2000 to 3000 kg/m^2hr. (NSA 15:16769)

2240. Newitt, D. M., Dombrowski, N., and Knelman, F. H.

LIQUID ENTRAINMENT. I. MECHANISM OF DROP FORMATION FROM GAS OR VAPOR BUBBLES, Trans. Inst. Chem. Engrs. (London) 32, 244-61 (1954)

A study of drop formation owing to the upward motion of bubbles of gas or vapor through a liquid with the collapse of the bubble at the liquid-gas interface is reported. The mechanism of bubble collapse was detd. from high-speed motion pictures to be as follows; the bubble coming to rest at the liquid surface forms a hemispherical dome with its internal pressure producing a depression of the interface. Liquid drains from the dome until the upper part is so weakened that the internal pressure causes the formation of a secondary cap. This cap subsequently disintegrates perforating the bubble dome and giving rise to liquid droplets of a few μ's in diam. These droplets are carried away by the high-velocity gas issuing from the perforated dome. A system of standing waves is set up on the liquid surface surrounding the crater left by the collapsed bubble. As the crater fills in, the momentum of the inflowing liquid produces a jet which rises at high velocity and detaches one or more comparatively large droplets from its apex. These drops, which may have a diam. as great as 0.1 cm, are responsible for the main losses by entrainment. The jet then retracts and the surface of the liquid returns to rest. The exptl. work was performed with the air-water system, generating the bubbles from a glass capillary oriented in a horizontal plane at various depths below the water-air interface. The size of the bubble was controlled by varying the diam. of the capillary. Drop sizes were detd. by allowing the drops to impinge on plates coated with MgO and situated at predetd. levels above the interface. Five bubble sizes ranging from 0.31 to 0.53 cm. diam. at temps. of 25°, 35°, and 45° were studied at a frequency of formation of one per sec. Bubble-size observations were made at heights of 0.64, 1.91, 3.17, 4.44, and 5.71 cm. above the interface. Visual counts indicate that the no. of large drops formed per min, is approx. const. at all depths of the capillary tip greater than 1 in. As the depth is reduced below 1 in. there is a sharp decrease in the no. of drops to a min. at 0.64 cm. after which the no. again increases. At depths less than 0.32 cm., a continuous channel forms. An increase in bubble diam. reduces the no. of small drops. It also increases the size of the large drops while reducing the size of the small drops. In wind tunnel studies of the removal of liquid entrainment from gas streams with baffles, it has been noted that there is a min. baffle thickness at which the detaching drop attains a max. diam. For water drops, this thickness is 1.9 cm. and the corresponding water drop detached is 0.78 cm. in diam. Drops from a bevelled edge baffle are smaller than those from a square edge and, therefore, if excessive pressure drop is not involved, entrainment baffles should have square leading edges. (CA-49-12047e)

2241. Newitt, D. M., et al.

MECHANISM OF DROP FORMATION FROM GAS OR VAPOR BUBBLES, Chemistry and Industry; 74, 165-6 (February 12, 1955)

Discusses the mechanism at which entrainment can occur from a liquid surface at which bubbles are bursting.

2242. O'Connell, H. E., and Pettyjohn, E. S.

LIQUID CARRY OVER IN A HORIZONTAL TUBE EVAPORATOR AIChE Trans., 42, 795-814 (1946)

Carry-over of liquid droplets was studied in a semicom. horizontal-tube evaporator for 10 and 20% NaCl, 20 and 24% Na_2SO_4, and 23% $MgSO_4$ solns. Carryover was caused by entrainment of small liquid droplets by the rising vapor, splashing of liquid from the evaporator directly into the condenser, and foaming of the soln. into the overhead condenser. Entrainment losses were low, the max. loss was about 180 lb. of liquor/1,000,000 lb. of vapor. Entrainment in lb./1,000,000 lb. decreased with increased heat-flux density and increased b.p. A relationship between entrainment and the over-all heat-transfer coeff. was attributed to the fact that both were functions of the size and no. of the vapor bubbles formed. Splashing occurred at the high heat-flux densities, and a higher heat-flux density was required to cause splashing at the higher b.ps. than at the lower. This study showed that splashing did not occur if 1 cu ft of vapor space was provided for every cu ft/sec of vapor evapd. Since splashing losses are large, attention should be given to splashing in the design of evaporators. Foaming occurred with the NaCl solns. in concns. below 10% and over 25%, with the Na_2SO_4 solns. below 20%, and with the $MgSO_4$ solns. below 10%. There was a greater tendency for foaming at higher b.ps. (CA 41 320c)

2243. Panasenko, M. D., Timofeev, V. N., and Filimonov, A. I.

ON THE INTERPRETATION OF EXPERIMENTAL DATA FOR ANALYZING THE CARRYOVER OF MOISTURE, Izv. Akad. Nauk, SSSR, O.T.N., no. 5 p 615, 1952.

2244. Panasenko, M. D., and Antonov, A. Ya.

GENERAL PRINCIPLES OF MECHANICAL CARRYOVER WITH STEAM, Teploenergetika, 6, no. 10, (Oct. 1959) pp 44-9.

Generalized treatment of experimental data, obtained in bubblers on carryover of boiler feedwater admixtures by steam; formulas for determining coordinates of transition point from second into third region of carryover; calculation formulas for value of carryover coefficient at critical point.

2245. Pannickar, P. K. N., et al.

ENTRAINMENT OF WATER DROPLETS BY AIR BUBBLES RELEASED FROM SINGLE NOZZLES, Trans, Indian Inst. Chem. Engrs. 12, 18-22, (1959-60)

The entrainment of H_2O, by air forced through a 2.680 mm nozzle at a bubble rate of 500-2000/min, at heights of 2-7 cm above the H_2O level was studied. The size of the droplets was measured by the MgO technique of May [J. Sci. Instr. 22, 187 (1945)]. At a given frequency, the no. of droplets entrained and their mean diam. decreases with the distance above the liquid surface. At a given height above the surface, the no. of droplets and their diam. increases with bubble frequency. The entrainment as a function of droplet diam. is given by log $E = 0.015\ D^{0.8} - 4.40458$ where E is the entrainment in g. of liquid/g. of air and D the mean diam. in microns defined by $\Sigma nd^3/\Sigma nd^2$ where n is the no. of entrained droplets and d the diam.

2246. Rey, George

ENTRAINMENT FROM A SUBMERGED COMBUSTION EVAPORATOR, A.I.Ch.E. J. 7, 299-302, (1961)

Sodium ion was used as a tracer. By measuring the ratio of the sodium concentration in the pot to that in the condensate the entrainment removal performance of the evaporator system was studied under various conditions. It was observed that the log of the concentration ratio decreases with an increase in the temperature of the gaseous products of combustion as they emanate from the combustion chamber into the solution. This is attributed to the fact that a greater amount of fine ($< 5\mu$) droplets of entrainment are formed in the evaporator as the temperature of the gases increases.

2247. Seniff, R. W.

STEAM CONTAMINATION BY AQUAGLOBEJECTION, Amer. Railway Engr. Assoc., v. 46, p. 446, (1944).

2248. Shor, A. J., et al.

RADIOACTIVE CARRY-OVER FROM BORAX-III AND TEST SYSTEMS, Nuclear Science and Engineering, 2, 126-142 (1957).

Data obtained from three systems are presented and discussed in reference to the problem of radioactive carry-over in boiling reactors. Measurements of droplet carry-over have been made on a small scale laboratory boiling test unit and on a 600-psia loop under high purity water conditions using Cs^{137} tracer. Measurements have also been made on the Borax-III boiling reactor under actual operating conditions. Activation products present in the steam and condensate served as an indication of the radioactive carry-over. Analysis of the decay curves of the samples provided a means of differentiating activities carried as droplets from volatile radioactive carry-over.

2249. Sterman. L. S.

ON SOME RELATIONS CONCERNED WITH THE CARRYOVER OF MOISTURE FROM A VAPOR BOILER, Izv. Akad. Nauk, SSSR, O.T.N., no. 3, p. 464, (1952)

2250. Stiushin, N. G.

ON SOME RELATIONS CONCERNED WITH THE CARRYOVER OF MOISTURE AND OF SALT FROM VAPOR BOILERS, Izv. Akad. Nauk, SSSR, O.T.N., no. 4, p. 620, (1952).

2251. Straub, F. G.

STEAM TURBINES BLADE DEPOSITS, Bull. 364, Univ. of Illinois Eng. Exp. St., Urbana, Ill., EI (1947) p. 1109, (1946) 90 p.

Causes of deposits of water soluble and insoluble type; salts normally found in boiler water are not appreciably soluble in saturated steam below 2000 psi but are soluble in superheated steam at pressures as low as 600 psi; silica, possibly as silicic acid, distills off from boiler water in appreciable amounts above 600 psi. Silica as low as 0.2 ppm in steam will cause deposition in turbine. Bibliography.

2252. Styrikovich, M. A.

ON THE PROBLEM CONCERNED WITH A THEORY OF CARRYOVER OF MOISTURE, Izv. Akad. Nauk, SSSR, O.T.N., no. 2, p. 281, (1952).

2253. Styrikovich, M. A., Khaibulin, I. Kh., and Khokhlov, L. K.

THE INFLUENCE OF SOLUBILITY UPON THE PERFORMANCE OF A WATER BOILER, Problemi Energetiki Anad. Nauk. SSSR, p. 483 (1959).

2254. Styrikovich, M. A., Serov, E., Smirnov, D. K.

INVESTIGATION OF THE STEAM QUALITY OF A UNIFLOW BOILER AT SUPERCRITICAL PRESSURES AND FOR DIFFERENT FEEDWATER COMPOSITIONS, Teploenergetika, 7, no. 1, (1960).

2255. Tatarinov, B. P.

ON SOME RELATIONS CONCERNED WITH THE CARRYOVER OF MOISTURE AND OF SALT FROM VAPOR BOILERS, Izv. Akad. Nauk, SSSR, O.T.N., no. 4, p. 620, (1952)

2256. Uvarov, G. A.

ENTRAINMENT OF LIQUID BY GAS OR STEAM, Translated from Sbornik Nauch. Trudov, Kuibyshev, Ind. Inst. im V. V. Kuibysheva, no. 5, 196-203, TIL/T-5028, (1955), 8 p.

Calculations were made of the quantity of liquid entrained by gas or steam during its movement in a free space. The equation for the motion of a bubble of the gas in a sufficiently large space is given. For examining phenomena in liquid disturbed by the motion of a body immersed in it, the assumption was made that the body remains at rest while the flow of liquid takes up the motion. Determination of the thickness of displacement for a bubble of gas is discussed. Equations are given for determining the volume of the body of rotation. (AD-235547)

2257. VanRossum, J. J.

EXPERIMENTAL INVESTIGATION OF HORIZONTAL LIQUID FILMS, WAVE FORMATION, FILM THICKNESS, Chem. Eng. Sci. 11, 35-52 (1959)

The entrainment wave formation and atomization of horizontal films of H_2O aq. solns., and oils have been investigated in a 15 x 15 x 310 cm wind tunnel. Air passed over the film of liquid at rates of 2-65 m/sec. Liquid flows varied from 2.5 kg/hr to 1500 kg/hr. Film thicknesses were derived from elec. resistance measurements between 2 electrodes glued to the bottom of the tunnel. Crit. velocities for onset of waves and atomization were detd. Atomization onset conditions were correlated 2 ways, one involving the Weber no. and the other the Reynolds no. The film thickness is correlated in terms of the film Reynolds no., properties of the liquid, and shear stress.

2258. Walker, V.

PROBLEM OF CARRY-OVER FROM HIGH PRESSURE BOILERS, Elect. Times, 101, n. 2635, 946-8, EI (1942) p. 138, (Apr. 23, 1942)

Mechanical means of control of carry-over includes changes in water level maintained in drum, improved design of drum baffling and dry pipe, and use of steam purifiers or scrubbers; chemical methods of control include chemical treatment of feed and boiler water to counteract effect of substances conducive to foaming and priming and control of concentration of dissolved and suspended solids in boiler water which promote carry-over.

2259. Wilson, J., and McDermont, M.

MOISTURE DE-ENTRAINMENT TESTS IN TWO AND FOUR INCH DIAMETER TEST SECTIONS, Rep. ACNP-5921, Allis Chalmers Mfg. Co., Milwaukee 1, Wisc., Nov. 15, 1959

2260. Zenkievich, Yu. V., and Turnovski, A. P.

ON SOME BASIC FACTORS WHICH INFLUENCE THE EFFECTIVE SCRIBING OF VAPOR, Energomashinostroenie, no. 10, p. 18, (1956)

2261. Zenkievich, Yu. V.

ABOUT THE FORMATION OF SALT DEPOSITS IN TURBINES, Teploenergetika, 7, no. 4, 62-7, (Apr. 1960)

Mechanism of deposit formation in high pressure equipment; methods for determining admissible limits for steam quality. EI (61), p. 1640

2262. Zenz, F. A., and Weil, N. A.

A THEORETICAL-EMPIRICAL APPROACH TO THE MECHANISM OF PARTICLE ENTRAINMENT FROM FLUIDIZED BEDS, A.I.Ch.E. Journal, 4, 472-479, (1958)

A means of calculating the rate of entrainment of solids from commercial-size continuously operating fluidized beds was developed from the combined results of a theoretical and an empirical approach which through different channels arrived at the same fundamental mechanism. The calculation method shows agreement with data obtained from an apparatus simulating flow characteristics in large-scale equipment and compares favorably with smaller scale tests reported in the literature at pressures up to 200 lb/sq in. gauge.

2263. Zhivaikin, L. Ya. and Volgin, B. P.

DETERMINATION OF THE ENTRAINMENT OF LIQUID BY A GAS STREAM FROM THE SURFACE OF A FILM, Inzhener.-Fiz. Zhur., Akad. Nauk Belorus, S.S.R. 4, 114-16 (1961)

Z. and V. consider the possibility of calcg. the amt. of spray entrained by 2-phase film processes. The effect of gas velocity, fluid flow rate, and phys. properties of the liquid (d., surface tension) on the amt. of spray entrained was found. Equations are proposed for the detn. of entrainment of liquid in the dimensionless and explicit form. The conclusions are confirmed by expts. on different liquids (H_2O, 35 and 55% glycerol soln., H_2O with addn. of a surface-active substance).

Film Flow (see also Annular Flow)

2264. Benjamin, T. B.

WAVE FORMATION IN LAMINAR FLOW DOWN AN INCLINED PLANE, Journ. Fluid Mech. 2, 554-574 (1957)

This paper deals theoretically with a problem of hydrodynamic stability characterized by small values of the Reynolds number R. The primary flow whose stability is examined consists of a uniform laminar stream of viscous liquid running down an inclined plane under the action of gravity, being bounded on one side by a free surface influenced by surface tension. The problem thus has a direct bearing on the properties of thin liquid films such as have important uses in chemical engineering.

Numerous experiments in the past have shown that in flow down a wall the stream is noticeably agitated by waves except when R is quite small; on a vertical water film, for instance, waves may be observed until R is reduced to some value rather less than 10. The present treatment is accordingly based on methods of approximation suited to fairly low values of R, and thereby avoids the severe mathematical difficulties usual in stability problems at high R. The formulation of the problem resembles that given by Yih (1954); but the method of solution differs from his, and the respective results are in conflict. In particular, there is disagreement over the matter of the stability of a strictly vertical stream at very small R. In contrast with the previous conclusions, it is shown here that the flow is always unstable: that is, a class of undamped waves exists for all finite values of R. However, the rates of amplification of unstable waves are shown to become very small when R is made fairly small, and their wavelengths to become very large; this provides a satisfactory explanation for the apparent absence of waves in some experimental observations, and also for the wide scatter among existing estimates of the "quasi-critical" value of R

below which waves are undetectable. In view of the controversial nature of these results, emphasis is given to various points of agreement between the present work and the established theory of roll waves; the latter theory gives a clear picture of the physical mechanism of wave formation on gravitational flows, and in its light the results obtained here appear entirely reasonable.

The conditions governing neutral stability are worked out to the third order in a parameter which is shown to be small; but a less accurate approximation is then justified as an adequate basis for an easily workable theory providing a ready check with experiment. This theory is used to predict the value of R at which observable waves should first develop on a vertical water film, and also the length and velocity of the waves. These three predictions are compared with the experimental results found by Binnie (1957), and are substantially confirmed.

2265. Benjamin, T. B.

SHEARING FLOW OVER A WAVY BOUNDARY, Jour. Fluid Mech. 6, 161-205 (1959)

A theoretical study is made of shearing flows bounded by a simple-harmonic wavy surface, the main object being to calculate the normal and tangential stresses on the boundary. The type of flow considered is approximately parallel in the absence of the waves, being exemplified by two-dimensional boundary layers over a plane. Account is taken of viscosity; but, as the Reynolds number is assumed to be large, its effects are seen to be confined within narrow "friction layers," one of which adjoins the wave and another surrounds the "critical point" where the velocity of flow equals the wave velocity. The boundary conditions are made as general as possible by including the three cases where respectively the boundary is rigid, flexible yet still solid, or completely mobile as if it were the interface with a second fluid.

The theory is developed on the model of stable laminar flow, although it is proposed that the same theory may usefully be applied also to examples of turbulent flow considered as "pseudo-laminar" with velocity profiles corresponding to the mean-velocity distribution. Use is made of curvilinear co-ordinates which follow the contour of the wave-train. This admits a linearized form of the problem whose validity requires only that the wave amplitude be small in comparison with the wavelength, even when large velocity gradients exist close to the boundary. The analysis is made largely without restriction to particular forms of the velocity profile; but eventually consideration is given to the example of a linear profile and the example of a boundary-layer profile approximated by a quarter-period sinusoid. In Sec. 7 some general methods are set out for the treatment of disturbed boundary-layer profiles: these apply with greatest precision to thin boundary layers, but are also useful for the initially very steep but on the whole fairly diffuse profiles which occur in most practical instances of turbulent flow over waves.

The phase relationships found between the stresses and the wave elevation are discussed for several examples, and their interest in connexion with problems of wave generation by wind is pointed out. It is shown that in most circumstances the stresses are distributed in much the same way as if the leeward slopes of the waves were sheltered. For instance, the pressure distribution often has a substantial component in phase with the wave slope, just as if a wake were formed behind each wave crest - although of course actual separation effects are outside the scope of the present theory. In this aspect, the analysis amplifies the work of Miles (1957). (CA 59-60)

2266. Benjamin, T. B.

THE DEVELOPMENT OF THREE-DIMENSIONAL DISTURBANCES IN AN UNSTABLE FILM OF LIQUID FLOWING DOWN AN INCLINED PLANE, Jour. Fluid Mech. 10, 401-419 (1961)

On the basis of results from a previous paper, expressions are found for the phase velocity and amplification rate of a wave travelling obliquely to the direction of flow. This wave comprises the general harmonic component of three-dimensional small disturbances, and accordingly a double Fourier integral is introduced to represent a bounded disturbance whose initial distribution over the free surface may be arbitrarily prescribed. Hence an asymptotic approximation is derived for a disturbance which is initially concentrated around a point on the free surface. Several distinctive properties of a localized unstable disturbance are noted: for instance, it lies mainly within an elliptical region whose area increases linearly with time as it moves downstream and which is modulated by long-crested waves. An experimental observation of a growing disturbance on an unstable film is recorded, and its main features are seen to be in agreement with the theory.

In so far as linearized perturbation theory remains applicable, the effects investigated are common to a wide class of parallel and nearly parallel laminar flows. In the final part of the paper the method used to analyse the instability of a film is generalized in order to reveal the connexion between this and other problems; this aim is achieved by demonstrating collective properties of the complete class of flows in question, but particular reference is made to the example of laminary boundary layers and Poiseuille flow between parallel planes. (CA 61)

2267. Brauer, H.

FLOW AND HEAT TRANSFER OF FALLING LIQUID FILMS, VDI-Forschungsheft, n. 457, 40 p, Suppl. to Gebiete Ingenieurw. 22b, (1956)

The flow mechanism of falling liquid films was investigated by using a vertical tube on which water and (or) glycol water mixts. resp., were forming the film under various conditions. Special attention was paid to the wave pattern of the film surface leading to the conclusion that three main regions of flow laminar and can be described essentially by Nusselt's theory. Waves occur in the 2nd region, and these were related to the Reynolds no. and the length of the tube. The 3rd region is characterized by turbulent flow at Reynolds nos. of the film above 400. Accurate measurements of film thickness, wave-pattern including frequency spectrum, surface velocity of the film, and shear stress at the tube wall led to results which

allow for correlating the flow parameters of falling liquid films in the form of power functions of the initially given quantities.

2268. Corkill, J. M., et al.

THE THICKNESS AND COMPOSITION OF THIN DETERGENT FILMS, Trans. Faraday Soc., 57, 821-828 (1961)

The composition of thin detergent films was investigated by making some of the film components radioactive and by determining the thickness of these films by optical methods. The results obtained strongly support a sandwich model, consisting of two surface layers and an inner core of solution, for the structure of the film. The structure of the black film resembles that of a neat (smectic) mesophorphic phase, and it is postulated that the forces governing the formation of this film are exactly those which are important for mesomorphic phases generally. For non-ionic detergents these are believed to be primarily the forces between the water molecule around the polar heads of the surface-active molecules. With ionic detergents, a term is introduced by the electrical repulsion between the charged surface layers on either side of the film, and only when sufficient electrolyte is added to reduce this electrical term do the equilibrium thicknesses of these films approach those formed by non-ionic molecules of about the same total length.

2269. Drouhin, R.

LA FORMATION DES LITS DE MOUSSE ET LEUR APPLICATION AU TRANSFERT DE CHALEUR ET DE MATIERE, Genie Chimique 85, 23-9 (Jan 1961)

Formation of foam beds and their application to heat and mass transfer; gas passing through a liquid with formation of continually renewed foam bed exhibits certain industrial interest. Before la Societe de Chimie Industrielle and la Societe Hydrotechnique de France, Paris, Mar. 1960. English, German and Spanish summaries.

2270. Dukler, A. E.

HYDRODYNAMICS OF LIQUID-FILM IN SINGLE AND TWO-PHASE FLOW, University of Delaware, Ph. D. Thesis, June 1951.

In this study, energy loss data were obtained for the two-phase, co-current flow of air and liquids of varying density and viscosity in a vertical, one-half wetted wall column. In order to evaluate the contribution of the liquid film to the energy loss, the flow of liquid alone down a vertical plate was studied in detail. An electronic apparatus was constructed for the measurement of liquid film thickness and wave profile under various flow conditions and high-speed flash photographs of the wave motion were obtained to further clarify the nature of the turbulence. A single theoretical equation was developed from fundamental concepts which predicts the liquid film thickness for both viscous and turbulent flow states. Although this equation received experimental verification for the case where the liquid flows alone it can also be applied to the case of two-phase flow. Using this equation the data for two-phase flow were analyzed. It was shown that the primary cause for increase energy loss in two-phase flow over the case for the single phase flow is due to the wave motion on the surface of the liquid which presents a rough appearance to the faster moving gas stream. The profile of the liquid surface undergoes severe changes over the range of liquid and air rates investigated and the points of transition are shown to be independent of liquid rate and physical properties, indicating a universality which should permit extension to other types of equipment. Increasing liquid rate always increases the wave magnitude but does not effect the spacing or form of the wave appreciably. Increasing viscosity and density likewise increases wave magnitude but leaves the wave profile essentially unchanged. The effect of physical property is less pronounced at high rates of flow where the inherent instability of the liquid film due to flow is so large that variations in physical properties have only a small influence.

2271. Dukler, A. E., and Bergelin, O. P.

CHARACTERISTICS OF FLOW IN FALLING LIQUID FILMS, Chem. Eng. Progr. 48, 557 (1952)

By use of the von Karman velocity distribution theory new equations are developed which relate liquid-film thickness in concurrent gas-liquid flow to the flow rates, phys. properties of the fluids, and to the energy loss. For the case of no gas flowing, the equations reduce to give the film thickness as a function of flow rate and phys. properties over the complete viscous to turbulent-flow range. The transition from laminar to turbulent film flow occurs at a Reynolds no. of 1080. Equipment is described for the measurement of liquid-film thickness and wave profile based on a capacitance technique and this equipment is capable of measuring film thicknesses to an accuracy of 0.001 in.

2272. Dukler, A. E.

DYNAMICS OF VERTICAL FALLING FILM SYSTEMS, Chem. Eng. Prog. 55, 62 (1959)

Study of flow and heat transfer in thin films; new equations are developed for velocity and temperature distribution in thin vertical films; results are then used to calculate local and average heat transfer coefficients as well as local film thickness; geometry similar to that found in falling film evaporators, vertical condensers and film cooling equipment.

2273. Dukler, A. E.

FLUID MECHANICS AND HEAT TRANSFER IN VERTICAL FALLING-FILM SYSTEMS, CEP Symp. Ser. No. 30, 56, 1-10, (Heat Transfer-Storrs) (1960)

New equations are developed for velocity and temperature distribution in thin vertical films. The geometry is similar to that found in falling-film evaporators, vertical condensers, and film-cooling equipment. These equations utilize the expression proposed by Deissler for the eddy viscosity and eddy thermal conductivity near a solid boundary, thus introducing turbulent fluctuations close to the wall. The differential equations are solved numerically with an IBM-650 computer. From the velocity and temperature distributions, liquid film thickness and

point heat transfer coefficient are calculated. Results, which are presented graphically, include laminar and turbulent flow conditions and account for different liquid properties and the presence of concurrent (or countercurrent) gas flow. From the point coefficient data, average condensing heat transfer coefficients are developed. Results are shown to agree with the classical Nusselt relationships at low Reynolds numbers and no interfacial shear. In the turbulent region agreement is obtained with the empirical relationships of Colburn for fully developed turbulent flow in the absence of interfacial shear and with recent experimental data at high pressure drops. These results now provide reliable values in the commercially important region between these two extremes. Graphs are included which present both local and average heat transfer coefficients and liquid film thickness for Reynolds numbers from 100 to 50,000 and Prandtl numbers from 0.1 to 10.0 for a wide range of vapor loadings. (CA 60-61)

2274. Friedman, S. J., and Miller, C. O.

LIQUID FILMS IN THE VISCOUS FLOW REGION, Ind. and Eng. Chem. 33, 885-891 (1941)

In the case of flow of liquid films bounded by solid and essentially static air interfaces, a third type of flow called "pseudo-streamline" has been found to exist between Re 25 and Re 1500. This type of flow is characterized by the appearance of waves in the liquid film and by a much higher interfacial velocity than that predicted by streamline flow equations. However, the Reynolds number-friction factor correlation for true streamline flow is applicable in this region.

2275. Greenberg, A. B.

THE MECHANICS OF FILM FLOW ON A VERTICAL SURFACE, Ph.D. Thesis, Purdue Univ. (1956)

2276. Hahnermann, H. W.

HEAT TRANSFER TO FALLING LIQUID FILMS, VDI Z. 104, No. 24, 1236 (1962)

Dimensionless heat transfer equations relating the mean Nu no., the Re no. and the Pr no. were established through a series of heat transfer measurements on falling liquid films of H_2O, ethylene glycol, and mixts. of the two. Measurements of the velocity and temp. profiles at different heights provided information on variation of local heat flux d. with distance from the wall, as well as the effect of turbulence at the film surface on heat transfer. By using a simplified model, a theoretical heat transfer equation was established. The effect of evapn. at the film surface on the heat transfer between pipe wall and film is discussed. (CA 62 16354h)

2277. Hanratty, T. J., and Hershman, A.

INITIATION OF ROLL WAVES, AIChE Jour. 7, 488-497 (1961)

The theory proposed by Jeffreys to explain roll-wave transition on a liquid surface is applied to the concurrent flow of a gas and liquid. Data are presented for the concurrent flow of air with water-glycerine solutions, water-butanol solutions, and water-sodium lauryl sulfate solutions. Agreement is obtained between theory and experiment.

2278. Hartley, D. E.

HEAT TRANSFER ACROSS A TURBULENT LIQUID FILM IN A TURBULENT VAPOUR STREAM, Memorandum Q2, Queen Mary College Nuclear Engng. Laboratory (1959)

2279. Hershman, A.

THE EFFECT OF LIQUID PROPERTIES ON THE INTERACTION BETWEEN A TURBULENT AIR STREAM AND A FLOWING LIQUID FILM, Ph.D. Thesis, U. of Ill. 191 pp. (1961)

2280. Howkins, J. E., and Davidson, J. F.

COUNTERCURRENT GAS LIQUID FLOW. STABILITY OF A SPHERICAL LIQUID FILM IN AN INFINITE AIRSTREAM. Chem. Eng. Sci. 7, 235-40 (1958)

A liquid film flowed downward by gravity over a string of spheres with air flowing upward over the spheres. The spheres were 1.0 or 1.5 in. in diam. and inserted in a 5.75-in. tube. Three liquids, water, water plus 1% Lissapol, and liquid paraffin were used in the expts. A standing wave formed on the film covering the lowest hemisphere at about 30° to the vertical at air velocities of about 20 ft/sec. This kind of wave formation is thought responsible for loading in packed towers of high voltage.

2281. Kapitza, P. L.

UNDULAR FLOW OF THIN LAYERS OF A VISCOUS FLUID. I. FREE FLOW, J. Exp. Theor. Phys., 18, 3-18 (Jan 1948) In Russian.

This paper deals with the flow of thin layers of a viscous liquid under the action of a constant volume force, allowing for surface tension. An approximate solution of the equation of flow was found which showed that the undular flow established experimentally by a series of workers had a more stable character than the laminar flow. Wave shape, phase velocity, and amplitude are given. The theoretical values of the critical factors Re_K characteristic for the inception of the undular flow agree with the experimental data. The rapid dispersion of colouring matter along the flow observed by Friedman and Miller is quantitatively explained by the undular character of the flow.

2282. Kapitza, P. L.

UNDULAR FLOW OF THIN LAYERS OF A VISCOUS LIQUID. II. FLOW IN CONTACT WITH A GAS FLOW AND WITH HEAT TRANSFER. J. Exp. Theor. Phys., 18, 19-28 (Jan 1948) In Russian.

This paper deals with the interreaction of a gas flow with the flow of a liquid. On the assumption of an interruption in the gas flow occurring where it makes intimate contact with the wave surface of the liquid it becomes possible to explain and define numerically the increased pressure drop in a gas streaming through pipes with moist walls. The expression for

the critical velocity at which the gas current is "chocked" in a vertical pipe along the walls of which there is a liquid counterflow is in good agreement with test results. Finally, the increase of the thermal conductivity of thin layers of a liquid in an undulating condition is estimated.

2283. Kapitza, P. L., and Kapitza, S. P.

UNDULAR FLOW OF THIN LAYERS OF A VISCOUS LIQUID. III. EXPERIMENTAL STUDY OF WAVE FLOW CONDITIONS. J. Exp. Theor. Phys., 19, 105-20 (1949) In Russian

A method of taking photographic skiagrams of a lamina of a viscous fluid with a view to studying the free flow on the outer wall of a cylindrical tube. The necessary conditions for the existence of a 2-dimensional wave-flow of a lamina were found. Quantitative determinations of the amplitudes, phase velocities and wavelengths were carried out for a number of flow types of water and alcohol. A series of photographs of sections of flow laminae are given. The results are compared with the theory worked out in the foregoing part of the paper. Experimentally it could be shown that the wave flow due to a certain critical efflux is more stable than the laminar one. The magnitude of the critical efflux, as found by experiment for water and alcohol, is in good agreement with theory. Two distinct types of undular flow were established; the first, in close agreement with theory, with a wave shape nearing a sinusoid, was called periodic regime, while the second is a new type, consisting of single waves moving independently of each other. The empirically found dependence for the periodic regime of amplitudes, phase velocity and wavelength on the efflux again corresponds to the theoretical predictions within the limits of accuracy of the approximations made.

2284. Kress, B. A.

FALLING FILM HEAT EXCHANGER, (1945) 21 p.

In order to determine the possibilities of using a falling film heat exchanger in a homogeneous reactor, the optimum size of a falling film tube with regard to heat transfer and hold-up and an investigation of the possibility of gas release by the film were studied. An apparatus was designed and built which would give rates of flow for various types of inlets in gravity-flow and in forced flow falling film. Some heat removal calculations were made. CE-3503.

2285. Lacey, P. M. C., Hewitt, G. F., and Collier, J. G.

CLIMBING FILM FLOW, AERE-R-3962 (Presented to the Thermodynamics and Fluid Mechanics Group of the Inst. Mech. Eng. on 7th Feb. 1962)

Climbing film flow is shown to embody a large number of superimposed phenomena which make it one of the most complex forms of two-phase flow: it becomes particularly important to distinguish the various mechanisms when considering the breakdown of the regime to the liquid deficient condition, leading to so-called "burn-out," but only very recently have measurements been made of a kind which allow any assessment of the relative importance of these mechanisms in different parts of the regime, and the picture is still very incomplete. The paper considers the mechanisms in turn: simple film motion induced by gas-phase shear, ripples and Helmholz instabilities, the role of Helmholz waves in spray production, rates of spray growth and deposition, depletion of the film through entrainment and breakdown of the film through surface tension forces and dewetting, and the possible effects of nucleation: and attention is drawn to inconsistencies and gaps in the experimental data and in the theories adduced to correlate them.

2286. Mahrenholtz, O.

TRANSPORT OF FLUID FILM ON VERTICAL WALL BY GAS STREAM, Kaeltetechnik 10, 150-6 (May, 1958)

Transport of fluid film on vertical wall by gas stream; trials using annular tube and 4 liquids with different viscosities show transport by rising gas stream is possible; data for pressure loss of gas flow, mean thickness of liquid film, and range of transportation of liquid film; example of such transport would be where oil of refrigerating evaporator is returned to compressor.

2287. Michaud, F.

THEORY OF LIQUID FILMS, J. chim. phys. 41, 147-59 (1944)

The classical theory of capillarity can be extended for phenomena observed in the formation and destruction of liquid films. One is lead to the notion of film pressure which is similar to that of surface tension in that it requires the dimensions of energy. The effect of one or more dissolved substances can be predicted. It can be proved that the thickness of the capillary layer is smaller in a soln. of a substance that lowers the surface tension than in a soln. of a substance that elevates it. The theory predicts and expt. verifies the fact that two bubbles within the body of a soln. of a substance lowering the surface tension attract each other before forming a film that will sep. them. The sudden variation in thickness observed at the border of the black spot in a film of soapy water can be accounted for. Finally the failure of scientists who attempted the verification of Gibbs' adsorption formula is explained. (CA-40-263-3)

2288. Miles, J. W.

ON THE GENERATION OF SURFACE WAVES BY SHEAR FLOWS, Jour. Fluid Mech. 3, 185-204 (1957)

A mechanism for the generation of surface waves; by a parallel shear flow U(y) is developed on the basis of the inviscid Orr-Sommerfield equation. It is found that the rate at which energy is transferred to a wave of speed c is proportional to the profile curvature - U"(y) at that elevation where U = c. The result is applied to the generation of deep-water gravity waves by wind. An approximate solution to the boundary value problem is developed for a logarithmic profile and the corresponding spectral distribution of the energy transfer coefficient calculated as a function of wave speed. The minimum wind speed for the initiation of gravity waves against laminar dissipation in water having negligible mean motion is found to be roughly 100 cm/sec. A spectral mean value of the sheltering coefficient, as defined by Munk, is found

to be in order-of-magnitude agreement with total wave drag measurements of Van Dorn. It is concluded that the model yields results in qualitative agreement with observation, but truly quantitative comparisons would require a more accurate solution of the boundary value problem and more precise data on wind profiles than are presently available. The results also may have application to the flutter of membranes and panels.

2289. Miles, J. W.

THE HYDRODYNAMIC STABILITY OF A THIN FILM OF LIQUID IN UNIFORM SHEARING MOTION, Jour. Fluid Mech. 8, 593-610 (1960)

The stability problem for a thin film of liquid having a linear mean-velocity profile and bounded by a fixed wall and free surface is solved asymptotically for large values of the Reynolds number R. The analysis is similar to that for plane Couette flow, but instability occurs for sufficiently large values of R in accordance with Heisenberg's criterion that neutral disturbances having finite wave numbers and phase velocities for $R = \infty$ are necessarily unstable as $R \to \infty$. It is found that a sufficient condition for stability is $W < 3$, where W is the Weber number based on the mean speed at the free surface and the depth of the film. The minimum critical Reynolds number, also based on free surface speed and film depth, is found to be $R = 203$. This last figure is in order of magnitude agreement with observation, but there remains considerable uncertainty as to whether the observed instability corresponds to that considered here. Neutral stability curves are presented in an R vs α (= wave-number) plane with W as the family parameter. Brief consideration also is given to the time-rate-of-growth of unstable disturbances and to the lighter fluid that, in actual configurations, is responsible for the shear in the film. An appendix gives extended and more accurate results for the function F(z), introduced and calculated previously by Tietjens (1925) and Lin (1955).

2290. Norman, W. S.

HEAT TRANSFER TO A LIQUID FILM ON A VERTICAL SURFACE, Trans. Instn. Chem. Engrs. (London) 38, 301-7 (1960)

Measurement of heat transfer coefficients and minimum wetting rates; heat transfer to liquid films in laminar flow region (Re lower than 2000) is affected by instability of film which eventually results in film breakdown and appearance of dry patches on wall; relation of minimum liquid rate, film thickness function, and surface tension function.

2291. Oosterhout, K. C.

THE SURFACE STRUCTURE OF A FLOWING WATER FILM, M.S. Thesis, Univ. of Illinois (1958)

2292. Ranz, W. E.

SOME EXPERIMENTS ON THE DYNAMICS OF LIQUID FILMS, J. Appl. Phys. 30, 1950-5 (Dec, 1959)

Experiments and theory are described concerning the rupture of soap films and the continuous formation, by impinging jets, of quasi-stationary liquid sheets.

2293. Saveanu, Th., Ibanescu, I., and Mariana, V.

INFLUENCE OF THE NATURE OF THE WALL ON MASS TRANSFER IN LIQUID WAVE FILM FLOW, Acad. rep. populare Romine, Filiala Iasi, Studii cercetari stiint., Chim. 11, 139-48 (1960)

In thin-layer wave flow, the nature of the material on which the liquid flows has no great influence on mass transfer when the wall has the usual roughness. Two exptl. methods were used: evapn. of water into air and absorption of NH_3 vapor from an air mixt. in water. Roughness due to working the surface is distinguished from roughness produced by treating with chemicals.

2294. Sinek, J. R.

HEAT TRANSFER IN FALLING-FILM LTV EVAPORATORS, Ph.D. Thesis, U. of Mich., 175 pp (1962)

2295. Squire, H. B.

INVESTIGATION OF THE INSTABILITY OF A MOVING LIQUID FILM, Brit. Jnl. Appl. Phys. 4, p. 167-169 (1953)

The stability of a thin layer of liquid moving in still air is studied theoretically with the object of throwing light on the break-up of films during atomization. It is found that instability occurs if $W = T/\rho_1 U^2 h < 1$ and that the wavelength for maximum growth factor, for $W \ll 1$, is

$$\lambda = (4\pi T/\rho_2 U^2)$$

where ρ_1 is the liquid density, ρ_2 is the air density, U is the film velocity, 2h is the film thickness and T is the surface tension of the liquid. Comparison with experimental data shows fair agreement with the observed wavelengths.

2296. Tailby, S. R., and Portalski, S.

THE HYDRODYNAMICS OF LIQUID FILMS FLOWING ON A VERTICAL SURFACE, Trans. Instn. Chem. Engrs. (London) 38, 324, (1960)

Experimental study of critical Reynolds number of wave inception, and increase in surface area due to rippling; theory of P. L. Kapitza modified and extended has been used to predict quantitatively Reynolds number of wave inception and enlargement of surface area due to rippling; improved measurement of holdup and wave profile.

2297. Tailby, S. R., and Portalski, S.

THE OPTIMUM CONCENTRATION OF SURFACE ACTIVE AGENTS FOR THE SUPPRESSION OF RIPPLES, Trans. Instn. Chem. Engrs. (London) 39, 328-336 (1961)

Extends previous preliminary investigations of other workers and examines the effect of surface-active agents in damping waves and ripples by direct observation and recording of the state of the surface on a flowing film. In each of the cases considered an optimum concentration of wetting agent has been found for the attainment of a smooth surface.

2298. Tailby, B. S. and Portalski, S.

DETERMINATION OF THE WAVE LENGTH ON A VERTICAL FILM OF LIQUID FLOWING DOWN A HYDRODYNAMICALLY SMOOTH PLATE, Trans. Inst. Chem. Engrs., 40, 114-22 (1962)

The onset of wave formation was detd. for liquid flowing down hydrodynamically smooth, 7 ft high by 21 in. wide, vertical, stainless steel plates, with water, 27%-82% glycerol solns., MeOH, and iso-PrOH at 19-25°C. The wave formation and the wavelength (λ) were recorded photographically and over a range of liquid flow rates having Reynolds nos. (Re) of 4-4000. λ theoretically should be a function of Re, but was found to vary complexly with the height of the wetted column. Only at the front of wave formation was there a region where the train of waves was sufficiently regular for detn. of λ. These λ values were larger than those predicted from theory, which neglects the natural coalescence of waves. The various theories of wave formation are crit. reviewed; exptl. results are presented. (CA 62 12282a)

2299. Tailby, S. R. and Portalski, S.

WAVE INCEPTION ON A LIQUID FILM FLOWING DOWN A HYDRODYNAMICALLY SMOOTH PLATE, Chem. Eng. Sci. 17, 283-90, (1962)

Wave formation as a function of liquid flow rate, liquid viscosity, and air flow over the liquid film was studied by using a photographic technique. The plate carrying the film was 21-in. wide and 7-ft high. Waves appear over the entire column above the crit. Reynolds no.

The stretch of film, free of wave motion, increases with liquid flow rate and viscosity, and decreases with increase in air Reynolds no. (CA 62 13582i)

2300. Tananaiko, Yu. M.

HEAT TRANSFER FROM A DOWNWARD FLOWING FILM OF BOILING WATER, Izvest. Kiev. Politekh. Inst. 17, 75-82 (1956) (Translated from Referat. Zhur. Fiz. No. 3, 1957. Abstract No. 6333)

When water boils in a flowing film with thickness δ = 0.25 mm, one observes two modes of heat transfer, in which the heat transfer coefficient may be calculated from the following empirical equations: $\alpha_2 = 22q^{0.527}$ and $\alpha_2 = 8.15q^{0.6}$ (q is the specific thermal load). It was established that upon boiling in a film (δ = 0.25 mm)α_2 is 10 to 15% lower than in an ordinary tube. This is caused by the particular conditions in the flowing film (action of gravity forces, surface tension, supporting action of the moving steam, etc).

2301. Wilke, W.

HEAT TRANSFER AT FALLING LIQUID FILMS, VDI (Ver. Deut. Ingr.)-Forschungsheft 490, 36 p. Suppl. to Forsch. Gebiete Ingenieurw. 28B (1962)

The effect of the tube length, Reynolds no., and Prandtl no. on the heat transfer between tube wall and falling liquid film was studied in a vertical tube, 2.4 m long. Measurements of the temp. and velocity profiles across the film helped to explain the heat transfer mechanism for falling liquid films with wavy flow pattern and led to the development of a theoretical heat-transfer equation based on simple assumptions. The equation takes into account the effect of the waves on the heat transfer and is in good agreement with exptl. results. The theory of Nusselt, which holds for small Reynolds nos., was further extended to consider the heat transfer at the free surface of the film. The heat transfer equations established in the investigation may be applied to the design of falling liquid film app. 25 references.

Foams and Froths

2302. Abe, T.

FOAMING OF SEA WATER - ANALOGY BETWEEN THE COAGULATION PROCESS OF COLLOIDAL PARTICLES AND THAT OF BUBBLES IN THE FOAM LAYER OF SEA WATER, Papers Meterol. and Geophys. (Japan) 6, 56-62 (1955)

Bubbles in a foam layer are considered to have elastic properties and are accumulated in the form of a layer, packing most closely in 3 dimensions under the influence of capillary forces. They are attracted by these forces and are kept apart by the pressure at the interfaces where they touch. When the membrane between any 2 bubbles is broken, the bubbles coagulate. During the period when the coagulation process is dominant, the processes are fairly well treated by analogy with that of colloidal particles. The max. diam. of bubbles is calcd. from $\rho(x) = AB^x$, where $\rho(x)$ = frequency of a bubble, x = (bubble diam)^2, and A and B are consts. Values of d_{max} at 14° are 1.79 for time = 2 sec to 3.17 for t = 14 sec, whereas at 5° d_{max} = 1.58 for t = 2 and 2.95 for t = 16.

2303. Brown, D. J.

PARTICLE TRAJECTORIES, COLLISION AND ATTACHMENT IN FROTH FLOTATION, Aerodyn. Capture Particles, Proc. Conf., Leatherhead, Surrey, 35-43 (1960)

Collisions of 0.3-mm-diam pyrite, coal, and galena particles with, and attachment to, 1.4 mm diam air bubbles in water was studied by rapid photography. Comparison of measured horizontal deviation of the particle path with the calcd. shows good agreement for galena and pyrite, but actual deviation for coal is much greater than theoretical. Efficiency of attachment decreases with increasing distance between the point of collision and the vertical axis, and does not depend on the relative velocity. The model of 2 circular planes moving toward each other gives a value of the equil. distance too high for spontaneous attachment to occur.

2304. Cassel, H. M.

PHYSICAL ASPECTS OF FOAMING IN STEAM GENERATION, J. Appl. Phys. 15, 792-798 (1944)

Vaporization of pure liquids is reviewed as a problem of heat transfer and the rate of vapor bubble creation. Applying an idea of Gibbs, the influence upon the activation energy of nucleus formation exerted by the contact angle at the vapor/liquid/solid phase

boundaries as well as by the shape and size of submerged solids is quantitatively expressed by the reduction in the volume requirement of the nucleus. Possible effects of solutes in superheated liquids upon steam bubble creation and growth are discussed. The stabilization of foam in boiling electrolyte solutions is explained by the thermoelectric potential differences originating from the temperature gradient around growing bubbles. The effect of foam inhibiting agents (e.g., castor oil) is interpreted as a change in the rate of bubble creation caused by surface conditioning of heating elements and suspended particles.

2305. Chang, R. C.

AQUEOUS FOAMS; BUBBLE SIZE AND BUBBLE SIZE DETERMINATION, Ind. Eng. Chem. 48, 2035-9 (1956)

Bubble size and distribution were detd. photomicrographically on frozen foams made from 1.5-6% solns. of heptadecylbenzimidazole (I), saponin (II), Na heptadecyl sulfate (III), Na dodecyl sulfate (IV), and a protein hydrolyzate (V). Sliding-vane and centrifugal pumps were used to generate foam. For III and V with sliding-vane pumps at steady flow the bubble size is inversely proportional to the expansion ratio. Bubble diams. of 50-300 μ over an expansion ratio of 10-35 were obtained for V and 30-70 μ at 7-19 expansion for IV. (CA 51:3235d)

2306. Deryagin, B. V., and Titievskaya, A. S.

THE WEDGE EFFECT OF FREE LIQUID FILMS AND ITS IMPORTANCE FOR THE STABILITY OF FOAM, Kolloid. Zhur. 15, 416-25, (1953)

From microscopic observations, 2 gas bubbles (e.g., of H) coalesced immediately when brought in contact under pure H_2O (e.g., in a quartz vessel). In the presence of glass or paraffin wax the film between the bubbles was stable for a few sec. The persistence τ of such films (of approx. 1 sq mm) of 2% PrOH in H_2O decreased from 50 to 20 sec when the "wedge pressure" P increased from 400 to 1000 dynes/sq cm; $P = \gamma[(1/R_1) + (1/R_2)]$; γ is surface tension and R_1 and R_2 are the radii of the bubbles. In 2% PrOH in 0.1N KCl, τ was approx. 5-10 sec and depended little on P. In 0.2M AcOH, τ was 16 sec at P = 470. In 0.00025M caprylic acid in H_2O or 0.001N HCl the films were stable with the thicknesses h of 110 and 40 mμ, resp, at P = 550-560.

Films were produced between 2 bubbles connected to the same source of compressed gas, so that the pressures in the bubbles were equal and the films were plane. If P is the pressure difference between the liquid in the film and the liquid in the vessel at the film level, then P is the "wedge pressure." When P increased from 580 to 2110 dynes/sq cm, h decreased from 150 to 105 mμ in 0.0006% undecylic acid (I); in 0.00006% I, h was 150 and 100 at P = 560 and 1860, resp; in 0.00002% I, h was 110 and 80 at P = 770 and 1280, resp; etc. According to D.'s theory (CA 32, 3232[9]) $P = D\psi^2/[8\pi d^2 \cosh(h/2d)] = 2\pi\sigma^2/[D \sinh^2(h/2d)]$; D is dielec. const., and ψ, σ, and d are the potential, the surface charge d, and the thickness of the elec. double layer. Assuming $d = 10^{-5}$ cm, ψ becomes 0.05-0.09 v and σ = 54 e.s.u. in 0.00002% and 84 in 0.0006% I. Solns. of I in 0.001N HCl or 0.01N KCl gave unstable films, whereas those in 0.001N KCl gave stable films that were thinner than in H_2O. Presumably, soap formation is needed for film stability. No stable films could be obtained in 0.02% pelargonic acid solns. Saponin films were stable also in more concd. NaCl solns, in which they were black.

2307. de Vries, A. J.

FOAM STABILITY. A FUNDAMENTAL INVESTIGATION OF THE FACTORS CONTROLLING THE STABILITY OF FOAMS, Mededel Rubber-Sticht., Delft. No. 326, (1957) 91 p.

Real foams are unstable dispersions of gases in liquids. The excess pressure in each gas bubble is an inverse function of the bubble size. Consequently, with time gas should diffuse from small to large bubbles. Furthermore, liquid drainage occurs with time. When the lamellas reach a crit. thickness, collapse generally occurs resulting in coalescence of bubbles. Bubble-size distribution thus changes with time. The rate at which small bubbles decrease in size as a result of diffusion is shown to be a function of bubble radius, surface tension, lamella thickness, and permeability of the gas in the liquid. The pressure differential is assumed to be detd. essentially by the radius of the smaller bubble. By observing the rate of shrinkage of small bubbles in various foams, values for the av. lamella thickness are calcd. These values are reasonable and support the contention that gas diffusion is at least one factor in limiting foam stability. Expressions are derived for bubble-size distribution as a function of time. The author exams. a second factor (liquid drainage) by high-speed photography of liquid films in wire frames. When held vertically, drainage occurs. Actual rupture is preceded by the formation of black areas whose thickness is under 1000 A. Rupture is due to hole formation followed by rapid enlargement. The rate of enlargement (hundreds of cm/sec) is in rough agreement with the values calcd. by Dupre's equation ("Mechanical Theory of Heat," Paris, 1869). The rate is inversely proportional to the square root of the film thickness. The actual formation of a hole may require an activation energy. At the moment a hole forms, a subsequent enlargement involves an increase in interfacial energy because of the prominence of the contribution due to the inner surface of the hole.

2308. Heinrich, G.

ÜBER STRÖMUNGEN VON SCHÄUMEN. Z. Angew. Math. Mech. 22, 117-18 (1942) (Translated by L. J. Goodlet, R.T.P. Translation No. 2239 British M.A.P.)

The problem of foams is studied by the author under the following assumptions: (1) The mixing of the liquid, which is considered as incompressible, and the gas is very thorough and stable, so that the mixture can be considered as one fluid with properties representing the average of liquid and gas. (2) The gas is a perfect gas. The author then calculates the density ρ, the equation of state and the adiabatic relation between pressure p and density ρ for the fluid, all involving the weight ratio μ of gas and liquid as a

parameter. The computation of the velocity of sound a, defined as $a^2 = dp/d\rho$, shows the interesting fact that, for the mixture of a heavy liquid and a light gas, the sound velocity is a minimum when the volume of liquid and the volume of gas in the mixture are equal. This minimum is only a fraction of the velocity of sound of the gas alone.

2309. Kitchener, J. A. and Cooper, C. F.

CURRENT CONCEPTS IN THE THEORY OF FOAMING, Quart. Revs. 13, 71-97 (1959)

A review with 39 references.

2310. Mukhlenov, I. P., and Tumarkina, E. S.

HEAT TRANSFER IN A FOAM APPARATUS, Zhur. Priklad, Khim. 28, 135-44, J. Appl. Chem. (USSR) 28, 125-32 (1955) (English Translation)

Heat transfer between air at 23-28° satd. with H_2O and H_2O at 15-18° was detd. in a foam column of 1 and 3 plates with a range of air velocities w of 0.4-3.5 m/sec, H_2O rates L of 2-40 cu m/m hr, and a spillway H of 0-30 mm; 20 different plates with perforations from 2 to 8 mm (9-25% free cross section) were used. The overall coeff. of heat transfer K vs w gives a family of curves (L = 20 cu m/m hr, perforations 6 mm at 4-mm distances between centers) which are expressed by the empirical relation $K = a + b w^n$. The const. n = 2.4 is independent of H; the consts. a and b are: 5400 and 420 for H = 0; 5600 and 445 for H = 10 mm; and 5600 and 600 for H = 20 mm. For w > 3 m/sec the calcd. K is lower than the exptl. This is ascribed to the formation of spray below the foam at high values of w. The plate efficiency η is given by $\eta = (I_i - I_f)/(I_i - I_t)$, where I_i, I_f, I_t are the heat contents of air entering and leaving the plate and of that satd. with H_2O at the mean temp. of H_2O on the plate. η reaches 94.7% at w = 2.5 m/sec, L = 32 cu m/m hr (K = 16,500 kcal/sq m hr degree); and 92.9% at w = 3 m/sec, L = 25 cu m/m hr (K = 18,600 kcal/sq m hr degree).

2311. Mukhlenov, I. P.

DYNAMICS OF A SUSPENDED LAYER OF A LIQUID IN A GAS, Translated from Zhur. Priklad. Khim. 30, 1750-5, AEC-tr-3252 (1957)

The kinetics and dynamics of a suspended layer of an active foam are treated and a general criteria equation is derived which describes the hydrodynamics of the foam layer and which is basic for a treatment of experimental data in order to obtain the calculated formulas.

2312. Nikolaev, L. A.

EFFECT OF THE NATURE OF THE HEATING SURFACE ON FOAM FORMATION, Trudy Moskov. Inst. Inzhener. Zhelez.-Dorozh. Transporta 1955, No. 82-3, 84-7.

Bubbles formed on a hydrophobic surface (graphite, paraffin) are larger than those formed on a hydrophilic surface (glass, porcelain). Increased bubble size decreases foam formation.

2313. Nikolenko, I. A.

FOAMING OF BOILER FEEDWATER OF DIFFERENT COMPOSITION, Teploenergetika, 7, no. 8, (Aug 1960)

Laboratory tests with water of different salinity; effect of salinity is shown to be nonadditive.

2314. Pozin, M. Ye., and Temarkina, Ye. S.

SUPPRESSION OF FOAM BY HIGHLY SOLUBLE GASES, Zhur. Priklad. Khim 27, 1180-3 (1954)

Slightly sol. gases, such as CO_2 and SO_3, 0.5-30 vol %, do not affect H, the structure, nor the back pressure of a foam formed by H_2O, whereas NH_3, HCl, and SO_3 depress H and this depression is not affected by a change in σ or η.

2315. Pozin, M. Ye., and Tumarkina, Ye. S.

EFFECT OF THE PHYSICAL PROPERTIES OF A LIQUID ON THE FORMATION OF MOVABLE FOAM, Zhur. Priklad. Khim 27, 1170-9 (1954)

A foam formed by sucking a gas at a given linear velocity w through a depth of a liquid held on a perforated plate is defined as a dynamically stable foam and is distinguished from a static foam formed by solns. of surface-active substances. The height H of such foams decreases as the surface tension σ and the viscosity η increase. This rule holds in aq. solns of electrolytes in the range of 70-85 dynes/cm and 0.99-7 centipoises and in soaps and glycerol in the range of 42-70 dynes/cm and 1-16 centipoises; aq solns of 0.4M $Al_2(SO_4)_3$ form an exception. The concn. affects H only in so far as it affects σ and η. The effect of w was detd. on monoethanolamine (12.5-25%) and triethanolamine (10, 20, and 30%). The plot H vs w shows a sharp min at w = 2.25 m/sec. With w > 2.25 m/sec the effect of phys. properties is masked by hydrodynamic forces.

2316. Pozin, M. E., et al.

CHARACTER OF GAS LIQUID DISPERSED SYSTEMS, Zhur. Priklad. Khim 30, 45-52 (1957)

The conditions in a sieve-plate app. are detd. primarily by the flow rate of the gas stream, and the bubbling process passes into a foaming process. Photographic examn. shows that the structure of the foam changes. The processes of heat- and mass-transfer proceed more vigorously in the layer of dynamically fluidized foam consisting of films and liquid mixed with gas bubbles. The criteria suggested by Melikyan are untenable for sieve plates, and the concept of 3 streams is not always accurate.

2317. Rennie, J., and Smith, W.

FORMATION OF AIR WATER FROTHS, Nature 192, 419-20 (1961)

A mechanism for the breakup of air bubbles emerging from an underwater orifice (diam. $\frac{1}{16}$ - $\frac{3}{8}$ in.) was observed. The air bubbles are observed to break up when hit by a small trailing bubble, or when penetrated by the small trailing "neck," which connects the bubble to the orifice when the bubble is forming.

2318. Ruyssen, R., et al.

FOAM FORMATION AND SURFACE ADSORPTION, Mededel. Koninkl. Vlaam. Acad. Wetenschap., Belg., Kl. Wetenschap. 22, No. 8 17 pp. (1960)

Foams were obtained by bubbling a N stream from either 3 capillaries (59 μ in diam.) or a filter (100 holes 50 μ in diam.) through a soln. of dodecyl sodium sulfate (I) or sodium laurate (II). The foams were formed in a cylinder of which a part was removable. In this part, the surface of the bubbles (closely packed pentagonal dodecahedra) was detd. by photomicrography and measurement with a micrometer of the edges of the dodecahedra on a projected image. Concn. of the surfactant was measured (1) by drying and weighing, (2) by interferometry, and (3) by radioactive tracers. The mol. surface was 11.0-10.4 $A.^2$ for I and 12 $A.^2$ for II. Therefore, every bubble is surrounded by a double unimol. layer. In a foam, rapidly formed on a glass filter, the surface contains a single unimol. layer. (CA 55:17123f)

2319. Savitskay, E. M.

ANALYSIS OF THE DISPERSITY OF FOAMS, Kolloid Zhur. 13, 309-13, (1951)

The foam is placed in a tray whose bottom is cooled with liquid O; the foam solidifies within a few sec and is then photographed through a glass cover. Freezing and thawing did not affect the dispersity. In a foam produced by bubbling air through a sintered glass membrane into a 0.125% soln. of Na 6-butylnaphthalene-1-sulfonate (I) the most frequent bubble radius r was 50 μ, and there were almost no bubbles with r greater than 150 μ. The frequency distribution of bubbles was the same in the surface layer and in any section of the foam. The most frequent r (in μ) and the total area (S sq cm) in 1 cc of another I foam depended on concn.; for 2%, 0.5%, 0.25%, 0.125%, and 0.06% solns. they were 80-90 and 360; 90-100 and 330; 100-110 and 270; 100-110 and 250, and 120-130 and 210, resp. The surface tension (γ ergs/sq cm) of these solns. was 30, 32, 38, 52.5, and 60, resp., and the product γS was almost const., i.e. the work necessary to disperse 1 cc of gas was almost independent of the soln.

2320. Seniff, R. W.

FOAMING AND CARRYOVER IN BOILERS, Am. Water Works Ass. Jour., 40, no. 9, 961-70, EI (1948) p. 153 (Sept. 1948)

Review of some carryover problems; effect of water treatment, locomotive boiler design and carryover in presence and absence of foam; steam separators, steam washing and maintenance of low boiler water concentrations appear to reduce carryover problems. Bibliography.

2321. Stenuf, T. J.

A STUDY OF THE VARIABLES AFFECTING THE FLUID DYNAMICS OF FOAM, Syracuse University, Ph. D. Thesis, (1953) 270 p.

The first phase of this work consisted of a study of the flow characteristics of foam by means of theological consistency curves, apparent viscosity correlations and a study of the degree of dispersion of the foam flowing thru $\frac{1}{2}$, $\frac{3}{4}$ and 1 in. pipe.

The foam was found to display pseudoplastic characteristics at low flow rates at which it passes through a pipe in laminar plug flow. At higher velocities a gradual transition to turbulent flow was found. This transition occurred at lower velocities with denser foams. The transition period for dense foams was short while lighter foams displayed an extremely long transition period. The results showed good agreement with those of a previous investigator who studied the lower flow rates of the same foam in $\frac{1}{2}$ and 1 in. pipes.

2322. Sterman, L. S.

FOAMING IN WATER BOILERS, Elektricheskie Stantzii, no. 9, (1949)

2323. Wise, G. E., Jr.

FLOW PROPERTIES OF MECHANICAL FIRE FIGHTING FOAMS, Syracuse University, M. S. Thesis, (1950) 66 p

In this investigation, the resistance to flow of the non-Newtonian mechanical foams used in fire fighting was studied. This work is one of a series of investigations of the fluid dynamics of the foam system. These flow data are of value in the design of pipeline systems to transport fire fighting foams from a generating station to predetermined scenes of possible outbreak of fire.

This study involved series of experimental measurements of pressure drops encountered by foams flowing through 1 in. and $\frac{1}{2}$ in. commercial iron pipe under various flow conditions. These data cover the usual viscous range of flow with measurements on foams of expansion ratios from 27.7 to 16.7 flowing under 20 psig to 70 psig pressure at velocities up to about 13.5 ft/sec at 74°F.

Families of consistency curves corresponding to various flow densities have been defined for flow through 1 in. commercial iron pipe. Likewise data were determined for flow through $\frac{1}{2}$ in. pipe. Apparent viscosities have been calculated over a range of flow densities and velocities, and are presented by curves of constant flow densities on a plot of apparent viscosity versus linear velocity.

The critical region of transition from viscous to turbulent flow was estimated to Reynolds' number values of 1800 to 2200.

Consistency curves obtained from this study provided the pseudoplastic behavior exhibited by foams in flow. There was no evidence of any yield value characteristic of plastic flow of a Binham body at expansion ratios up to 16.7.

The variation of apparent viscosities with pipe size at the same linear velocity and flow density was demonstrated by flow through 1 in. and $\frac{1}{2}$ in. pipe. The evaluation of this scaling up factor is necessary to enable the design of large scale piping systems for the flow of foams.

2324. Wise, G. E., Jr.

FLUID DYNAMICS AND OTHER STUDIES OF MECHANICAL FIRE FIGHTING FOAMS, Syracuse University, Ph.D. Thesis, (1951) 178 p.

The primary phase of the investigation treated the resistance to flow of proteineous mechanical foams through commercial iron pipe lines. Pressure drop data were obtained to express the flow of Mearlfoam proteineous foams of various expansions in the range of 2.7 to 16.7 through an 18 foot test section of 1 in. commercial iron pipe at velocities between 1 and 5 ft/sec and average pressure of 20 to 70 psig. Similar data were acquired for flow of these foams of expansions in the range of 3.0 to 14.4 through an 18 foot test section of $\frac{1}{2}$ in. commercial iron pipe at velocities between 1 and 18 ft/sec, and average pressures of 16 to 100 psig.

Theological shear diagrams were determined to express the flow data. Families of consistency curves corresponding to various flow densities have been defined and have demonstrated the non-Newtonian behavior of these proteineous mechanical foams. These plots have failed to indicate any Bingham yield value and have demonstrated that these foams are pseudo-plastics.

The consistency plot demonstrating flow through the $\frac{1}{2}$ in. conduit yielded sharp breaks in the various specific gravity parameters, indicating transition to a turbulent flow mechanism at high rates of shear. At low rates of shear, the pseudoplastic consistency parameters suggested a laminar-plug type mechanism.

Mist

2325. Adler, C. R., et al.

A SCANNING DEVICE FOR DETERMINING THE SIZE DISTRIBUTION OF SPRAY DROPLETS, Ch. Eng. Prog., 50, 15-24 (1954)

An instrument is described which utilizes a scanning technique to count and classify spray droplet images on photographic negatives. These negatives mounted on a rotating drum are projected by an optical system and focused at the plane of a mask containing a small aperture and located directly in front of a photomultiplier tube. As the droplet images rotate past this aperture they are simultaneously advanced a small distance each revolution by the rotating drum. In this manner the phototube receives through the aperture a series of light pulses whose durations correspond to the lengths of the chords created when ever a drop image passes across the aperture. These light pulses of various time durations are converted into electrical pulses and fed into electronic sorter counter circuits which classify the chords into fifteen size classes. A statistical treatment of this chord distribution is then made to give drop size distribution. Tables of coefficients have been computed to permit rapid conversion of the chord distribution to drop-size distribution. The statistical theory on which these coefficients are based is presented. Results of tests on actual spray samples and on special test negatives demonstrated that the device will rapidly count and classify drops with acceptable accuracy. The scanning rate can be as high as 10,000 drops in 15 min at maximum drum speed. Advantages of the instrument are that it removes the human element from the counting process, scans all drops in a single complete travel of the drum, simultaneously counts and classifies drops into fifteen size classes or less, and it counts much faster with greater accuracy than a human operator. Its principal limitation is that it is restricted to the analysis of transparent images on photographic negatives, which requires the sampling of sprays by the collection of droplets in cells on greased or soot-coated slides and photographing them.

2326. Alexander, L. G., and Coldren, C. L.

DROPLET TRANSFER FROM SUSPENDING AIR TO DUCT WALLS, Ind. Eng. Chem. 43, 1325 (1951)

Deposition rates of small H_2O droplets (av. diam. 27 μ), from a turbulent air stream onto the walls of a straight duct, were measured. The major resistance to transfer from the air stream to the duct wall, as deduced from the shapes of the radial profiles of mass velocity of suspended matter, resided in a relatively thin layer of gas adjacent to the wall. This hypothesis led to the relation, $K_g = 0.00335\ \bar{u}^{1.17}$, for the film coeff. $\bar{u}$ being the velocity. The coeff. was found to be from 10 to 20 times greater, on a mass basis, than estd. coeffs. for NH_3 and CO_2 under comparable conditions.

2327. Amelin, A. G., and Belyakov, M. I.

ON THE DEPOSITION OF DROPLETS FROM A STREAM OF GAS, Dokl. Akad. Nauk SSSR, 108, 31-33 (1956)

The coefficient of droplet capture $\epsilon = M/NvsT$ (where M = the number of droplets of a given diameter deposited on an object, s = the projection area in the direction of flow, N = the number of droplets of the given diameter per unit volume of the stream, v = the stream velocity, and τ = time) is a function of Stokes number S: $\epsilon = mS^n$. Experiments gave the following values for the leading edge of a cylinder: $m = 7 \times 10^{-6}$, $n = 3.5$ (within the range of S from 0.6 to 10); and for the trailing edge: $m = 2.66 \times 10^{-4}$, $n = 0.54$. At $S = 2.9$ equal amounts were deposited on both sides of the cylinder.

2328. Aziz, K., and Govier, G. W.

HORIZONTAL ANNULAR MIST FLOW OF NATURAL GAS WATER MIXTURES, Can. J. Chem. Eng. 40, 51-9 (1962)

The pressure drop data for const. mid-point d. are presented as a function of the superficial velocities of the 2 phases. Possible mechanisms of the flow in the annular-mist region are discussed.

2329. Bagotskaya, I. A.

FALL VELOCITY OF MERCURY DROPS IN A VISCOUS MEDIUM, Zhur. Fiz. Khim. 24, 1-9 (1950)

When the distance d between 2 consecutive drops was less than, say, 50 r, the rate u of fall increased with the ratio r:d; e.g., at r:d = 0.12, u sometimes was 1.15 u_0 (u_0 is the rate of fall of a single drop). When u_0/u_s (u_s = the rate calcd. from Stokes' equation) was

large (e.g. 1.47), u/u_0 was near 1 and sometimes even less than 1. The ratio u_0/u_s had a max. (about 1.4) when the drops carried a charge ϵ of about 3 x 10^{-6} coulomb/sq cm; this max. was steep in 0.01 N KBr and shallow in 0.5 N KBr. The dependence of u_0/u_s on ϵ is accounted for by the earlier theory. In an acidified (with HNO_3) 0.38 N $HgNO_3$ soln. in glycerol u_0/u_s was 1.37. This high velocity cannot be explained by the effect of ϵ, which was about 7 x 10^{-5}; there must have been transfer of Hg ions across the drop/soln. boundary. In 0.1 M $C_{10}H_7NH_2$ + 0.7 N KBr in glycerol the greatest u_0/u_s was 1.24; surface-active substances reduce the tangential movements in the drop (as in suppressing polarographic max.) and hence increase the friction between drop and soln. AmOH, octyl alc., and $PhNH_2$ had less effect. The values of u_0/u_s near 1 found by the previous experimenters, e.g., Silvey [Phys. Rev. 7, 106(1916)] were due to low elec. cond. of the medium and the presence of O and surface-active impurities.

2330. Brown, R.

SPRAYS FORMED BY FLASHING LIQUID JETS, Ph.D. Thesis, Univ. Mich. 130 pp. (1961)

2331. Cadle, R. D., and Magill, P. L.

PREPARATION OF SOLID- AND LIQUID-IN-AIR SUSPENSIONS FOR USE IN AIR POLLUTION STUDIES, Industrial and Engineering Chemistry, 43, 1331-1335 (1951)

Artificial smogs have been found useful in verifying the accuracy of current knowledge of the composition of natural smogs. The preparation of atmospheres containing gaseous additives is usually relatively simple, but the preparation of atmospheres containing dispersed liquids and solids is much more difficult. This paper describes techniques for preparing such atmospheres on a continuous basis. Aerosol generators were developed, which disperse liquids by an aspirating action and can also be used for dispersing certain solids. In a device for continuously dispersing powders at a uniform and easily controllable rate, the powder is spread on a long brass trough which is drawn beneath an air-operated glass aspirator. Chambers in which the atmospheres are blended and tested are described. The methods and equipment developed have been very useful in air pollution studies, and should be useful in many more studies of dispersion in air.

2332. Castleman, R. A., Jr.

THE MECHANISM OF THE ATOMIZATION OF LIQUIDS, U. S. Bureau of Standards, J. of Research, 6, 369-376 (1931)

A discussion is given of the general problem and of some applications of the phenomena of liquid atomization, with especial reference to fuel preparation in internal combustion engines. It is pointed out that both "air" and "solid" injection seem to have physical backgrounds quite similar to that of air stream atomization, and the discussion is limited to the latter.

Some previous work which seems to bear either directly or indirectly on this problem is reviewed, and it is assumed that a necessary step in atomization is the tearing of ligaments from the unatomized mass, these ligaments being of such sizes that they will eventually break up into drops of the sizes observed in the spray.

Brief discussions are given of the applicability of Rayleigh's work on the rate of collapse of liquid columns to the collapse of these ligaments, and of what values of the length/diameter ratio and of the degree of instability may be expected to be effective. It is then shown how the sizes of the ligaments can be determined from those of the drops in the spray. Finally, combining (a) measurements of the sizes of drops, (b) geometrical and physical considerations, and (c) Rayleigh's work, it is shown that these ligaments will collapse so quickly at sufficiently high air speed - that is, when true "atomization" sets in - that the droplets will then appear to be picked directly from the main mass, as has been observed.

Certain other observations are shown to be in qualitative agreement with this theory.

2333. Consiglio, J. A.

THE EFFECT OF OPERATING VARIABLES ON SPRAYS PRODUCED BY A PRESSURE-TYPE NOZZLE, Ph.D. Thesis, U. of Mich., (1953)

2334. Eisenklam, P., Dombrowski, N., and Hasson, D.

DROP FORMATION FROM RAPIDLY MOVING LIQUID SHEETS, Imper. Coll. of Sci. and Tech., South Kensington, London, Report JRL No. 44, (1959)

2335. Fedoseev, V. A.

DISPERSION OF A STREAM OF SUPERHEATED LIQUID, Kolloid. Zhur. 20, 493-7 (1958)

When a liquid boiling under a pressure P atm. above the atm. is let out of the vessel through a nozzle, it forms a stream (which may be several meters long) of droplets. The radius r of the droplets is greater the smaller P; it was, e.g., equal to 15/P for H_2O between r = 2 and r = 16 μ. The r increased linearly with the diam. of the nozzle between 0.5 and 2.5 mm. This device for spraying is more efficient than the usual mech. devices; the initial drops "explode" because vapor bubbles form in them; hence, the average r is smaller further from the nozzle.

2336. Gordon, G. D.

MECHANISM AND SPEED OF BREAKUP OF DROPS, J. Appl. Phys., 30, 1759-61 (1959)

A mathematical analysis has been made of the breakup of liquid drops in an air stream; only the mechanism in which the drops flatten, become bowl-shaped, inflate like a parachute, and finally burst is considered. The analysis provides an understanding of this process of breakup and the conditions for which the viscosity and surface tension become important factors. An estimate of the breakup time for a wide range of conditions is obtained as a function of the

drop diameter, surface tension, viscosity, drop density, air density, and velocity difference. The results are compared with the available experimental data.

2337. Gregory, C. L.

MASS TRANSFER BETWEEN FORMING DROPS AND A CONTINUOUS LIQUID PHASE, Massachusetts Institute of Technology, Department of Chemical Engineering, (Cambridge, Mass.)

2338. Grigoriu, A., et al.

INFLUENCE OF AIR MOVEMENTS ON COALESCENCE IN CLOUDS AND MISTS. I. THE CASE OF ACCELERATED MOTION, Rev. de Physique (Bucharest), 3, 247-54 (1958) (In French)

Theoretical considerations are given of the processes of drop coalescence in clouds and mists for the cases of paths in a pure gravitational field and subjected to uniformly accelerated air motion. For the latter, it is found that the region where the coalescence is increased as the result of the air motion is more extended than that in which it is hindered, leading to a net intensification of coalescence. These results are clearly important in considering the role played by interior macroturbulence in clouds, and also in possible acoustical means of dissipating fog or artificially stimulating rainfall.

2339. Grober, H., and Erk, S.

FUNDAMENTALS OF HEAT TRANSFER, 3rd rev. ed. New York, McGraw, 1961

2340. Haenlein, A.

DISINTEGRATION OF A LIQUID JET. Forschung auf dem Gebiete des Ingenieurwesens, 2, no. 4, 139-149 (1931)

Investigation of phenomenon occurring with decomposition of liquid jet at different degrees of density, viscosity and surface tension for different jet diameters and speeds; tests were carried out on water, gas oil, glycerine, and castor oil; subject has bearing on how fuel in combustion chamber of compressorless Diesel engine is atomized, and how it mixes with surrounding air.

2341. Hagerty, W. W., and Shea, J. F.

A STUDY OF THE STABILITY OF PLANE FLUID SHEETS, Jour. Appl. Mech. 22, 509 (1955)

Study of system in which flat sheet of fluid is produced by slender orifice, which may be subjected to waves of any desired frequency; analysis developed expressions for growth rate of waves in terms of surface tension, frequency, sheet thickness, and velocity, based on Rayleigh's analysis of one-sided sheet; pertinence to system for producing sprays.

2342. Hinze, J. O.

FUNDAMENTALS OF THE HYDRODYNAMIC MECHANISM OF SPLITTING IN DISPERSION PROCESSES, A.I.Ch.E. Journal, 1, 289-95 (1955)

The splitting of globules is an important phenomenon during the final stages of disintegration processes. Three basic types of deformation of globules and six types of flow patterns causing them are distinguished.

The forces controlling deformation and breakup comprise two dimensionless groups: a Weber group Nwe and a viscosity group Nvi. Breakup occurs when Nwe exceeds a critical value (Nwe) crit. Three cases are studied in greater detail: (a) Taylor's experiments on the breakup of a drop in simple types of viscous flow, (b) breakup of a drop in an air stream, (c) emulsification in a turbulent flow.

It is shown that (Nwe) crit depends on the type of deformation and on the flow pattern around the globule. For case (a) (Nwe) crit shows a minimum value ~0.5 at a certain value of Nvi and seems to increase indefinitely with either decreasing or increasing ratio between the viscosities of the two phases. For case (b) (Nwe) crit varies between 13 and ∞, depending on Nvi, and on the way in which the relative air velocity varies with time, the lowest value refers to the true shock case and Nvi $\rightarrow$ 0. For case (c) (Nwe) crit, which determines the maximum drop size in the emulsion, amounts to ~1, and the corresponding values of Nvi, appear to be small. A formula is derived for the maximum drop size.

2343. Hughes, R. R., and Gilliland, E. R.

THE MECHANICS OF DROPS, Chem. Eng. Prog. 48, 497-504 (1952)

Preliminary to general study of mass transfer in fluid particle systems; review of gross motion of drops and detailed motion in and around individual drops; new concepts and correlations in connection with effect of acceleration on drag, equilibrium distortion, and internal circulation caused by skin friction.

2344. Ingebo, R. D.

DRAG COEFFICIENTS FOR DROPLETS AND SOLID SPHERES IN CLOUDS ACCELERATING IN AIRSTREAMS, NACA-TN-3762 (1956)

2345. Ingebo, R. D., and Foster, H. H.

DROP SIZE DISTRIBUTION FOR CROSSCURRENT BREAKUP OF LIQUID JETS IN AIRSTREAMS, NACA-TN-4087 (1957)

2346. Jenkins, D. C.

THE ACCELERATION OF WATER DROPS BY AN AIRSTREAM OF CONSTANT RELATIVE VELOCITY, Ministry of Aviation, London, C.P. No. 539 (1961)

2347. Kolmogorov, A. N.

DROP BREAK-UP IN TURBULENT FLOW, Doklady Akad. Nauk SSSR, 66, 825-828 (1949)

2348. Krichevskii, I. R., and Khazanova, N. E.

MIST FORMATION AT HIGH PRESSURES, Zh. Tekh., Fiz. 26, 422-429 (1956) (In Russian)

Supersaturation and precipitation of a mist in a liquid-gas system can be achieved at high pressures by isothermal expansion, making use of the phenomenon of minimum solubility of the liquid in the gas corresponding to a certain pressure. Study of mist

formation in systems benzene-nitrogen, methanol-nitrogen, and carbon tetrachloride-nitrogen at pressures up to 900 kg/cm^2 shows that critical supersaturation at high pressures is much lower than at atmospheric pressure. The results are in qualitative agreement with the Volmer-Farkas theory. The apparatus is described in great detail.

2349. Lane, W. R.

SHATTER OF DROPS IN STREAMS OF AIR, Ind. and Eng. Chem. 43, 1213-17 (1951)

Electronic flash and spark photography were used to study the shatter of drops in steady and transient air streams in the atomization of liquids. Various stages of shatter of individual drops were identified and interpreted in terms of fluid mechanics. The secondary droplets were progressively smaller as the velocity of the air stream was increased, but at supersonic velocities they were not so small as would be predicted by extrapolating the relationship established for breakup in a steady air flow.

2350. Lane, W. R. and Green, H. L.

SYMPOSIUM OF SURVEYS IN MECHANICS, (THE MECHANICS OF DROPS AND BUBBLES), G. I. Taylor 70th Anniversary Volume, Cambridge University Press, New York, N.Y., (1956)

The mechanics of drops and bubbles are discussed, considering not only their dynamics but also the motion of fluid within and around them. The behavior of these systems presents problems not encountered in other branches of mechanics. By contrast to rigid spheres they may experience deformation, and then the two physical properties, surface tension and viscosity, exert a dominant influence. Internal circulation within the fluid of a drop or bubble may alter appreciably its dynamics and reaction with the surrounding medium.

The mechanics of drop formation is discussed first, and this is followed by an account of the motion of falling drops, their deformation and disruption. An important aspect is the deposition on obstacles of drops from a moving stream and the related problem of the collection of droplets in a cloud by a falling drop. The treatment is largely restricted to drops of macroscopic size formed in gas, leaving out of consideration such systems as mists, fogs and liquid aerosols in general, and fine liquid-liquid dispersions, commonly called emulsions.

Some chapter headings are: Shape of a pendant drop; Detachment of drops from tips; Production of drops; from tips, from spinning disk, and from swirl chamber; Behavior of falling drops; terminal velocity of spherical empirical equations for terminal velocities, shape of falling drops, circulation in drops; Break-up of drops; Deposition of drops on obstacles from a moving stream; Collection efficiency of drops.

The section on bubbles deals with their formation, the dynamics of rising bubbles, and, finally, the bursting of bubbles. With the exception of the last topic, the behavior of bubbles bounded by a liquid film (soap bubbles, foam, etc) is not discussed. Bubbles can remain stable in sizes which are many orders of magnitude greater than the limiting size of drops. Chapter headings are: Productions of Bubbles: from orifices, from capillaries, "bubble rafts"; Behavior of rising bubbles, terminal velocity, vertical motion of large bubbles, large bubbles rising in tube. (AMR, 1958, No. 30)

2351. Lang, R. J.

ULTRASONIC ATOMIZATION OF LIQUIDS, J. Acoust. Soc. Amer., 34, 6-8 (1962)

An experimental study was made of the mechanism by which the ultrasonic vibration of liquid surfaces causes atomization. At exciting frequencies in the range of 10 to 800 kc/s, uniform patterns of crossed capillary waves were found on the liquid surface when atomization occurred. The number-median diameter of the particles produced was found to be a constant fraction, 0.34, of the capillary wavelength; the capillary wavelength is calculable by Kelvin's equation using the exciting frequency and properties of the fluid being atomized. The evidence is strong that the mechanism of ultrasonic atomization involves the rupture of capillary surface waves and the subsequent ejection of the wave peaks from the surface as particles.

2352. Lapple, C. E., and Shepherd, C. B.

CALCULATION OF PARTICLE TRAJECTORIES, Industrial and Engineering Chemistry, 32, 605-617 (1940)

Equations are developed for calculating the paths taken by bodies or particles undergoing accelerated motion, taking into account the effect of fluid friction. In several cases curves have been prepared to simplify the computation and eliminate graphical integrations. The equations are summarized in Tables IV and V. Available experimental data on particle trajectories show excellent agreement with calculated values. Applications to spray cooling or crystallization, cyclone dust collection performance, classification, dust sampling, and ventilation are presented and discussed, together with illustrative numerical calculations.

2353. Limper, A. F.

ATOMIZATION OF LIQUIDS BY INJECTION INTO HIGH VELOCITY GAS STREAMS, University of Illinois, M.S. Thesis (1947)

The object of this investigation was to study the design and operating characteristics of a venturi atomizer in which the liquid is injected into the high speed gas stream in the throat of the tube. The performance of the unit is judged by the amount of pressure loss incurred by the atomization, the drop size and drop size distribution in the spray, and the amount of wall wetting which occurs.

2354. McIrvine, J. D.

ATOMIZATION OF VISCOUS LIQUIDS WITH SWIRL-CHAMBER PRESSURE NOZZLES, Ph.D. Thesis, U. of Wisc., (1957)

2355. Mugele, R. A. and Evans, H. D.

DROPLET SIZE DISTRIBUTION IN SPRAYS, Industrial and Engineering Chemistry, 43, 1317-1331 (1951)

General features of size distribution are reviewed for dispersed systems. The concepts of "mean diameter" and "distribution parameter" are clarified and generalized. Previously applied distribution equations (Rosin and Rammler, Nukiyama and Tanasawa) (log-probability) are examined critically in regard to theoretical soundness, and application to spray data. A new equation, called the upper-limit equation, is formulated and proposed as a standard for describing droplet size distributions in sprays. It is based on the differential equation of the "normal" or Gaussian distribution, the distributed quantity being $y = \ln ax/(x_m - x)$ where a is a dimensionless parameter, x is droplet diameter, and x_m is maximum stable diameter. The upper-limit equation is applied to a wide variety of experimental data on sprays and more limited results on other dispersoids. It is concluded that the new equation fits the available spray data accurately, calculates the mean diameters accurately, applies also to emulsions and aerosols when the mechanism of formation is not too different from that of sprays, and indicates the type of distribution function that may be derivable from the basic mechanism of dispersion, when this mechanism is better understood. For a mechanical spray, the relation of the parameters of the distribution equation to physical properties and design variables is indicated.

2356. Nelson, P. A.

DROP-SIZE DISTRIBUTIONS FROM CENTRIFUGAL SPRAY NOZZLES, Ph.D. Thesis, Northwestern Univ. 102 pp. (1958)

2357. Nicholson, P. J.

AN INVESTIGATION OF DROPLET SIZE AT HIGH QUALITY IN A BOILING COLUMN OF WATER, M.S. Thesis, M.I.T., (1957)

2358. Parker, J. D.

WALL TEMPERATURE VARIATION FOR MIST FLOWING THROUGH TUBES WITH CONSTANT HEAT FLUX, American Society of Mechanical Engineers, Preprint Paper No. 62-HT-47, New York, (1962) 8 p.

A study was made of the flow of a mist through a circular tube having a constant wall heat flux. The simple analytical model developed showed that severe wall temperature variations should be expected when an annular-mist flow changes, due to evaporation, to a true mist flow. In true mist flow two distinct types of heat transfer should be expected, depending upon whether the spheroidal state exists for the droplets striking the heated wall. Experimental data showed that the model qualitatively describes the tube-wall temperature variation with length.

2359. Prokhorov, P. S.

THE EFFECTS OF HUMIDITY DEFICIT ON COAGULATION PROCESSES AND THE COALESCENCE OF LIQUID DROPS, Disc. Faraday Soc., No. 18, 41-51 (1954)

The mechanism of elementary processes of drop coalescence under static and dynamic conditions is considered. It is experimentally demonstrated that the coalescence of two drops, brought into contact, is prevented by the presence of an air-vapour gap between them. The saturation of the atmosphere surrounding the drops with the vapour of the same liquid is favourable for their coalescence. It is shown by theoretical treatment that the principal reason for the failure of drops to coalesce is a surplus pressure arising in the air-vapour gap between the drops due to suction of air into the gap from the exterior by the vapours of the liquid diffusing from the gap. Experiments under dynamic conditions were carried out in order to elucidate the effect of humidity deficit on the efficiency of drop collision. From the results obtained it follows that in considering the growth of water drops due to coagulation the dependence of the efficiency of drop collision on humidity deficit of the surrounding atmosphere should be taken into account. It has been found that the 100% efficiency of drop collision is realizable only under conditions of zero humidity deficit or in presence of supersaturation of the surrounding atmosphere with water vapours.

2360. Ranz, W. E.

SOME EXPERIMENTS ON ORIFICE SPRAYS, Can. J. Chem. Engr. 36, 175-81 (1958)

The theory of spray systems is discussed and expts. spraying Hg and CCl_4 into water are described. Flow patterns, drop size, dispersion angle, and drop-size distribution are considered.

2361. Rasbash, D. J., and Stark, G. W. V.

CONTROL OF THE DISTRIBUTION OF A SPRAY PROJECTED TO AN AREA, J. Sci. Instrum. 34, 75-76 (1957)

Deals with the production of water sprays by nozzles for the purpose of fire extinction. The nozzles consist of a number of radially arranged pairs of jets, the two types considered being arranged to give two different spray angles. In each case it was found that the inclusion of an orifice plate immediately upstream of the jets produced a marked improvement in the spray distribution. A possible explanation is advanced and it is suggested that the use of different size orifices would be a method of spray control.

2362. Schultze, K.

THE BEHAVIOUR OF DIFFERENT LIQUIDS DURING ELECTROSTATIC ATOMIZATION, Z. Angew. Phys. (Germany), 13, 11-16 (1961)

The liquids investigated were classified according to their electrical conductivity, ranging from highly insulating transformer oil to aqueous salt solutions. The liquids were allowed to issue from fine glass or metal jets, a voltage of up to 12 kV being applied with respect to a plane 15 mm below this orifice. The nature of the atomization was observed and the quantity of liquid dispersed per unit time measured. Optimum results were obtained with liquids in the conductivity range 2×10^{-3} to 6×10^{-6} ohm^{-1} cm^{-1}. The effects of hydrostatic pressure, orifice diameter and viscosity of the liquid were also studied.

2363. Schytil, Franz and Krollmann, Herbert

COLLECTION OF LIQUID FROM MISTS, U.S. Patent 2,947,383 (Aug 2, 1960)

A porous filter operation and app. are described. The gas velocities are 1.0-20 m/sec with reference to the free pore area of the filter or approx. 0.3-4 m/sec with respect to the total cross-sectional area of the filter. Preferably, velocities of 0.5-2 m/sec are used. The crit. value of the gas velocity, which must be exceeded, is characterized by the pressure drop-velocity diagram, plotted on a log-log scale, which shows a distinct break with an increase in slope. The crit. velocity above which the process operates is, therefore, detd. by a break point in the pressure drop-velocity diagram. Pore sizes are 20-400 μ.

2364. Short, W. L.

SOME PROPERTIES OF SPRAYS FORMED BY THE DISINTEGRATION OF A SUPERHEATED LIQUID JET, Ph.D. Thesis, Univ. of Mich. 183 pp. (1962)

2365. Smirnov, N. I., and Ruban, V. L.

RELATIVE VELOCITIES OF MOTION OF DROPS, Zhur. Priklad. Khim. 22 (J. Applied Chem.) 1068-77 (1949)

The relation detg. the velocity of rise of liquid drops or gas bubbles in a liquid is expressed by the similitude criteria. Re = Reynolds' no., Ar = Archimedes simplex = $(\gamma_c - \gamma_b)/\gamma_b$ (where γ is the sp. wt. in kg/cu m, and the subscripts b and c refer to the drop and the medium resp.), μ = viscosity, Γ = d/D (where d and D are the diam. of the drop and the vessel, resp.). The form of the function $f[Re, Ar, (\mu_b/\mu_c), \Gamma] = 0$ is detd. by exptl. measurements of the rate of rise of droplets of CCl_4, EtBr, $C_2H_4Cl_2$, $PhNO_2$, $PhNH_2$, $PhNMe_2$, C_6H_6, toluene, iso-AmOH, and C_6H_{14} in H_2O; droplets of H_2O in C_6H_6; and air bubbles in H_2O. Treatment of the exptl. data reveals the constancy of $Re\,\Gamma\,Ar^{-0.5}(\mu_b/\mu_c)^{-1}$, i.e. one has $Re = a\,Ar^{0.5}(\mu_b/\mu_c)\Gamma^{-1}$. For the const. a, the exptl. data yield the relation $a = 0.6\{[(\gamma_c-\gamma_b)/\gamma_b] + 0.21\}^{0.6} + 1.25$; consequently, the final expression is $Re = \{0.6[(\gamma_c-\gamma_b)/\gamma_b + 0.21]^{0.6} + 1.25\}\,Ar\,(\mu_b/\mu_c)\Gamma^{-1}$. In the case of a falling drop, Ar is neg. and Re is neg. When the definitions of the criteria are substituted, then the relative velocity $w = ad^{0.5}g^{0.5}(\gamma_b/\gamma_c)\,[(\gamma_c-\gamma_b)/\gamma_b]^{0.5}\Gamma^{-1}$, i.e., in the investigated range of Re(190-1000) w is proportional to the sq. root of the diam. of the root. A somewhat unexpected result is the independence of w of the viscosities of either the drop or the medium. With Ar formulated $Ar = (d^3\gamma_c^2/\mu_c^2 g)\,[(\gamma_c-\gamma_b)/\gamma_b]$, the equation is written $Re = b\,Ar^{0.5}\Gamma^{-1}$, where from exptl. data $b = 1.4\text{-}0.257\,\{[(\gamma_c-\gamma_b)/\gamma_b] - 0.13\}^{0.248}$. The dimensionless factors a and b allow for deviations of the droplets from spherical shape. The general criterial equation is $Re = \{1.4 - 0.257\,([(\gamma_c-\gamma_b)/\gamma_b] - 0.13)^{0.248}\}\,Ar^{0.5}\,\Gamma^{-1}$. (CA-46-4320b)

2366. Smirnov, N. I.

A SUSPENDED LAYER OF PARTICLES OF DIFFERENT SHAPES, Zhur. Priklad Khim, 24, 439-48; J. Applied Chem. U.S.S.R. 24, 479-87 (1951) (English translation)

With the exptl. method previously described, the equation developed was tested on irregular particles of Al, NaCl, and sand in kerosine, water, air, and CO_2. The definitive form of the criterial equation for the hydrodynamics of a suspended layer for particles of any shape in the region of turbulent flow shows that the value of the shape simplex may be computed from the simple ratio of the surface of a sphere whose vol. is the same as that of the suspended particle to the surface of that particle.

2367. Smirnov, N. I. and Ruban, V. L.

RELATIVE VELOCITIES OF MOTION OF DROPS IN THE INTERMEDIATE RANGE, Zhur. Priklad. Khim, (J. Applied Chem.) 24, 47-55 (1951)

The form of the criterion equation for the motion of liquid drops of $PhNO_2$ and CCl_4 in an aq. sucrose soln. of $PhNH_2$ in H_2O, of H_2O in C_6H_6, PhN-Me_2, and PhMe, of C_6H_6, $PhNMe_2$, and PhMe in an aq. sucrose soln., and of air bubbles in H_2O and in $PhNH_2$ was deted. experimentally at room temp. or below. The empirical relation in the Re range of 10 to 270 is $Re = \{0.24 + 0.008\,[(\gamma_d-\gamma_m)/\gamma_d]\,Ar^{2/3}\,(\mu_d/\mu_m)^{4/3}\,\Gamma^{-1}\}$, where Re and Ar are the Reynolds and Archimedes criterion, resp., γ the d., μ the viscosity, $\Gamma = (d + D)/D$ = criterion of geometric similitude, and the subscripts d and m refer to the substance of the drop and the medium, resp. This can be written $Re = a\,Ar^{2/3}\,(\mu_d/\mu_m)^{4/3}\,\Gamma^{-1}$, and, hence, the velocity of the drop relative to the medium is $w = ad^{2/3}\,(\gamma_m-\gamma_d)^{2/3}g^{2/3}\Gamma^{-1}/\gamma_m\mu_m^{1/3}$. Thus, in this Re range, the velocity of the drop is proportional to its diam. d, and depends only on the viscosity of the medium, and not on that of the substance of the drop. With μ_d eliminated, the criterion equation becomes $Re = \{0.41 - 0.105\,[\gamma_m-\gamma_d]^{0.2}Ar^{2/3}\,(d/D)\}^{1/3} = b\,Ar^{2/3}\Gamma$, which fits the exptl. data. The factors a and b allow for the deviation of the drops from a spherical shape.

2368. Smirnov, N. I. and Ruban, V. L.

MOVEMENT OF BODIES IN A MEDIUM. VII. VELOCITY OF MOVEMENT OF DROPS IN A MEDIUM IN THE LAMINAR REGION, J. Appl. Chem. U.S.S.R. 25, 1357-61 (1952) (English Translation): Zhur. Priklad. Khim. 25, 1305-9 (1952)

Drops of strictly spherical shape, moving in a limitless medium, floating up or settling down in the laminar region of another immiscible liquid, acquire a

velocity of $w = d^2(\rho_m - \rho_s)g\ 3(\mu_m + \mu_s)/18\mu_s(2\mu_m + 3\mu_s)$, where w is the rate of movement, d is the drop diam., ρ_m is the d. of the medium, ρ_s is the d. of the drop, g is the gravitational acceleration, μ_m is the viscosity of the medium, and μ_s is the viscosity of the drop substance. This equation must be modified for nonspherical drops (these form when the difference between the ds. of medium and drop is great) and for movement in a glass-tube column of 13.5 mm diam. as used in these expts., in which were studied cylinder-oil drops in sugar soln., benzene drops in sugar soln., sugar-soln. drops in cylinder oil, toluene drops in sugar soln., nitrobenzene drops in sugar soln., water drops in cylinder oil, dichloroethane drops in sugar soln., kerosine drops in sugar soln., air bubbles in water, air bubbles in aniline. The relation of drop velocity to sp. gr. is complex. The velocity is directly proportional to the drop diam. squared and inversely proportional to the viscosity of the medium; it is independent of the viscosity of the drop substance. Earlier investigations are cited.

2369. Smirnov, N. I. and Ruban, V. L.

MOVEMENT OF BODIES IN A MEDIUM. VIII. DROPLET MOTION IN MEDIA, J. Appl. Chem. U.S.S.R., 26, 95-8 (1953)(English Translation) Zhur. Priklad. Khim., 26, 110-13.

Equations for the rate of motion of drops and air bubbles in liquid media in the turbulent, transition, and laminar flow regions require generalization because of the variation in the equation const., the use of both Galileo and Archimedes criteria, and the use of 2 criteria of geometric similarity. The earlier exptl. data were subjected to analysis, leading to expressions for the Reynolds nos. (Re) applicable from 0.001 to 1000. The new equations for the turbulent, transition, and laminar flow regions are the following: $Re = 1.3\ Ga^{0.5}(\gamma_m\gamma_s/\gamma_m)^{0.4}\Gamma^{-1.5}$, $Re = 0.2025\ Ga^{2/3}[(\gamma_m - \gamma_s)/\gamma_m]^{8/16}\Gamma^{-2}$, $Re = 0.05\ Ga\ [(\gamma_m - \gamma_s)/\gamma_m]\Gamma^{-3}$, where Ga, the Galileo criterion, is equal to $d^3\gamma_m^2/\mu_m g$, γ_m is the medium d. in kg/cu m, γ_s the droplet d. in kg/cc, d the droplet diam. in m., μ_m the viscosity in kg-sec per sq m, Γ is the criterion of geometric similarity $(d + D)/D$, and D is the column diam. in m. The turbulent-flow equation applies when $Ga[(\gamma_m - \gamma_s)/\gamma_m]^{0.8}\Gamma^{-3}$ is greater than 70,000. Motion in the laminar flow region is found for values of $Ga[(\gamma_m - \gamma_s)/\gamma_m]^{0.8}\Gamma^{-3}$ less than 66.5.

2370. Troesch, H. A.

ATOMIZING OF LIQUIDS, Chem. Ing. Tech. 26, 311-20 (1954).

A comprehensive investigation contg. derivations of equations for the largest drop size, and from statistical considerations an equation for a theoretically sound distribution function. A classification of atomizers, exptl. data, and 50 references are given.

2371. Weiss, M. A.

ATOMIZATION IN HIGH VELOCITY AIR STREAMS, Ph.D. Thesis, Columbia, Univ., 302 pp (1958).

2372. Wilcox, J. D. and June, R. K.

APPARATUS FOR STUDY OF THE BREAKUP OF LIQUID DROPS BY HIGH VELOCITY AIRSTREAMS, J. Franklin Inst. (USA), 271, 169-183 (1961).

The use of a blast gun and a shock tube for investigating the breakup of liquid drops, 3-4 mm in diameter, in high velocity airstreams is described. The flow in the shock tube was found to be uniform and predictable, and the pressure and velocities behind the shock front could be regulated to whatever was desired. The preliminary observations were made at an airstream velocity of approximately Mach 1, and a pressure of 1 atm behind the shock front. Photographs show a gradual transition in the breakup mechanism as the forces caused by the high velocity airstream acting on the drop are increased. The "bursting bag" mode is overcome by the violence of forces of the high velocity airstream and the mechanism of "surface stripping" becomes predominant.

2373. Williams, F. A.

SPRAY COMBUSTION AND ATOMIZATION, Phys. of Fluids, 1, 541-5 (1958).

A statistical formalism for describing the behavior of sprays is presented, which includes the effects of droplet growth, the formation of new droplets, collisions, and aerodynamic forces. Criteria for the efficiency of impinging jet atomization are developed. It is shown that if the incident jets have a size distribution of a generalized Rosin-Rammler type, then the resulting spray belongs to the same class of distributions. The size history of evaporating sprays is also obtained from the theory. A spray combustion analysis given by Probert is extended to include more general size distributions and the effects of droplet interactions and the relative motion of the droplets and the fluid. It is shown that the over-all spray evaporation rate is largest for uniform sprays.

2374. Woodward, T.

HEAT TRANSFER IN A SPRAY COLUMN, Chem. Engng. Progr. 57, 52-7 (Jan. 1961).

Pilot-size columns operated as direct liquid-liquid heat exchangers show that the heat transfer coefficient depends on holdup and fluidity of the hydrocarbon exchange medium.

2375. York, J. L., Stubbs, H. F. and Tek, M. R.

THE MECHANISM OF DISINTEGRATION OF LIQUID SHEETS, Trans. ASME 75, 1279 (1953).

Analysis of disintegration of plane sheet of liquid of finite thickness, moving tangentially relative to surrounding fluid; instability and wave formation at interface established as major factors in breakup of sheet of liquid into drops; equation derived relative four significant dimensionless groups; graphs of quantitative relationship among groups.

2376. Ansaldo, S. p. A., Genoa

DESIGN AND CONSTRUCTION OF A FACILITY FOR AIR-WATER MIXING AND SEPARATION EXPERIMENTS. Special Report No. 1 (1960). Work performed under U. S.-Euratom Joint Research and Development Program. 88 p, EURAEC-49 (LAB/STU-1416)

A description is given of the mixers, separators, and allied equipment designed for use in providing fog-cooling by means of steam-water mixtures in dispersed flow for light water moderated power reactors.

Slug

2377. Griffith, P. and Wallis, G. B.

SLUG FLOW, M.I.T. Technical Report No. 15, May 1959.

Slug flow characterized by large bubbles which almost fill the tube and separated by slugs of liquid was studied. Results and conclusions are presented for such a flow in round vertical pipes. Calculation methods are summarized, and procedures and apparatus are described.

2378. Griffith, P. and Wallis, G. B.

TWO PHASE SLUG FLOW, Paper No. ASME 60-HT-28, presented at ASME-AIChE Heat Trans. Conf., Buffalo, N. Y., August 15-17, 1960. J. of Heat Transfer 82, 181-88 (1960).

Entrance effects can persist for great lengths, $L/D = 300$, and long times, in developing two phase flows. Wall shear stresses at moderate and low velocities contribute only slightly to the pressure drop in slug flows. Bubblerise velocities in slug flow are quite sensitive to the velocity profile in the water ahead of the bubbles. The effect of wall shear stress manifests itself primarily through the velocity profiles. Pressure drop, density, slug length, bubble length and fluctuation pressure drops, and frequencies can be calculated for fully developed slug flow with good accuracy.

2379. Kordyban, E. S.

A FLOW MODEL FOR TWO-PHASE SLUG FLOW IN HORIZONTAL TUBES, J. of Basic Engineering 83, 613-18 (1961).

The paper presents a construction of a simplified model approximating the actual observed flow pattern. The resulting expressions for frictional pressure drop are found to agree fairly well with the author's data for steam and water and the data for air and water of other investigators. The similarity with a portion of the Chenoweth-Martin correlation appears to present a logical explanation for the applicability of that correlation to slug flow.

2380. Maissis, R. and Griffith, P.

ENTRANCE EFFECTS IN A DEVELOPING SLUG FLOW, M. I. T. Technical Report No. 18, June 1960.

2381. Nicklin, D. J. and Davidson, J. F.

PAPER 4, THE ONSET OF INSTABILITY IN TWO-PHASE SLUG FLOW (Presented to the Thermodynamics and Fluid Mechanics Group of the Inst. Mech. Eng. on the 7th Feb. 1962).

One of the complicating features of two-phase flow in vertical tubes is the variety of flow patterns which are possible (see Fig. 1). Because the various flow patterns are so different in nature, a single mathematical model would not be expected to represent them all, and so determination of the flow pattern is a preliminary step towards the solution of any problem in this field. Previous work dealing with the prediction or "mapping" of the flow regimes has been very largely empirical. The lack of quantitative criteria for predicting the stability of the different flow patterns is in turn probably due to the very limited amount of theory which has been derived for the individual flow regimes. Certainly no model of two-phase flow, explaining logically the transition from each flow regime to the next, has yet been proposed. This paper deals with the transition from slug flow to annular flow, and is therefore concerned with the nature of the transitional flow pattern, which is here termed "semiannular" flow.

2382. Nicklin, D. J., et al.

TWO PHASE FLOW IN VERTICAL TUBES, Trans. Inst. Chem. Engrs. (London) 40, 61-8 (1962).

Long gas bubbles (slugs) in liquids flowing up vertical tubes and through stationary liquids in them, rise at the same velocity (V_s) as wakeless bubbles. For tubes of diam. (D) of 1 in., $V_s = 0.35\ (gD)^{1/2}$. (g = acceleration due to gravity.) For water at Reynolds nos. (Re) >8000, $V_s = 1.2\ V_L$ (V_L = av. liquid velocity). For downflowing water, slugs become unsym. because of the velocity profile of the liquid stream. Plots of the vol. of liquid around slugs up to 50 in. long, detd. photographically, show that approx. 10% of the cross-sectional area of the slugs is occupied by water. Pressure drop during slug flow is discussed.

2383. Street, J. R.

A STUDY OF VERTICAL GAS-LIQUID SLUG FLOW, Ph.D. Thesis, Univ. of Mich. 228 pp. (1962).

Spray (See Mist)

Stratified

2384. Gazley, Carl, Jr.

EXPERIMENTAL EQUIPMENT AND RESEARCH PROGRAM FOR THE INVESTIGATION OF STRATIFIED TWO-PHASE FLOW, University of Delaware, Report No. TPF-2, March 24, 1948, 10 p.

In spite of the recent information presented in the technical literature on the characteristics of two-phase flow, uncertainties still exist in the prediction of pressure drop. For this reason the present investigation, which is of a more microscopic nature than any heretofore reported, was initiated.

Previous work in these laboratories has been concerned with pressure drop and the limits of the several configurations of two-phase flow. In the current investigation one of these configurations, stratified flow, is being considered in detail. The present report discusses the theoretical approach to the problem of stratified flow and the proposed experimental program. A description of equipment for the determination of pressure drop and velocity distribution in each phase, interfacial height, and interfacial gradient for the concurrent flow of water and air is presented. Preliminary data for the flow of air alone are reported.

2385. Holden, E. K.

TWO PHASE FLOW OF FLUIDS THE EFFECT OF HYDRAULIC GRADIENT ON STRATIFIED FLOW, University of Delaware, M. S. Thesis (1948), 79 p.

The investigation was concerned with the nature of the hydraulic gradient existing in the stratified co-current flow of air and water in a horizontal one-inch tube, and its effect upon the pressure drop. The rates of flow were limited to values which would yield an interface without waves. Measurements were made of the air pressure drop, interfacial gradient, and liquid depth. The air flow rate was varied from 0 to 17.20 lb/hr, and the water flow rate was varied from 129 to 359 lb/hr. A preliminary study was made of water flow with a free surface to determine the characteristics of the surface gradient when it is not affected by the co-current motion of the air at the gas-liquid surface.

FLOW THROUGH POROUS MEDIA

2386. Aboul-seoud, H. H.

EQUILIBRIUM CONSIDERATIONS IN TWO-PHASE FLOW OF HYDROCARBONS THROUGH UNCONSOLIDATED SAND, Thesis, University of California (1950) 62 p.

In this thesis the problem of two phase flow through porous media under adiabatic and steady state conditions is studied. Only the case of horizontal flow is considered. In the introduction the O'Brien-Putnam theory and the Krauklis experiments are analyzed, and the necessity of studying thermodynamic phase equilibrium is indicated.

The two-phase flow problem for a single component is stated. A description of the flow is given with a study of the changes taking place at the boiling point. A general definition of equilibrium is given, from which the conditions for thermodynamic phase equilibrium are obtained. The significance of assuming equilibrium in solving the flow problem is discussed.

A study is made of the temperature variation in a liquid film during vaporization at a given cross section and it is shown that this variation is negligible.

An equation for the rate of evaporation is obtained by the use of classical mechanics, and it is indicated that the same result should be expected if quantum mechanics is used. The rate of evaporation equation is applied to the flow problem, and a scheme for solving the problem without assuming equilibrium is indicated.

A brief description of the experimental equipment and procedure is given. The fluid used in the experiments was propane. Tabulated results of the five runs performed are presented.

Experimental results showed that thermodynamic equilibrium existed between the flowing phases in all the runs. Using the rate of evaporation equation it was shown that equilibirum was to be expected throughout the range of applicability of Darcy's law.

The method used for a single component system was generalized to the case of a multicomponent system, by applying the rate of evaporation equation to each component individually. A scheme for solving the flow problem in this case is proposed.

2387. Botset, H. G.

FLOW OF GAS-LIQUID MIXTURES THROUGH CONSOLIDATED SAND, Transactions of the American Institute of Mining and Metallurgical Engineers, 136, 91-105 (1940).

The experiments described have sufficed to show the nature and magnitude of deviations from the permeability-saturation relations for unconsolidated sands, to be expected as a result of consolidation. They indicate that the methods of analysis developed and general conclusions drawn for unconsolidated sands will be equally applicable to consolidated sands (with some minor corrections, of course). (CA-34-1882[4] (1940))

2388. Elrick, D. E.

TRANSIENT TWO-PHASE CAPILLARY FLOW IN POROUS MEDIA, Phys. of Fluids, 4, No. 5, 572-5 (1961).

The dynamics of two-phase capillary displacement in a finite one-dimensional system following a step change in pressure of one phase at one end is considered. Darcy's law and the equation of continuity for each phase together with the capillary pressure-saturation relation are the fundamental equations describing the flow system. The resulting system of differential equations is linearized by assuming a linear relationship between the capillary pressure and the saturation as well as constant conductivity values of both phases (these assumptions are valid for small step changes in pressure). Solutions of the linearized problem are found and presented in some detail. In the limiting case as the conductivity of one phase becomes much greater than the other, the solution reduces to the (known) single-phase solution.

2389. Krauklis, J. J.

TWO-PHASE FLOW OF WATER THROUGH POROUS MEDIA, University of California, M. S. Thesis (1945).

Adiabatic, two-phase flow of hot water under pressure through unconsolidated sand in a horizontal column was studied. For this purpose an insulated 4-inch iron pipe 7 feet long consisting of 7 flanged sections was packed under pressure with Del Monte beach sand to an average permeability of one darcy.

An electric hot water generator supplied hot water at approximately 65 lb/in.^{2} absolute pressure with

the downstream pressure maintained at approximately 15.5 lb/in.^{2} absolute. Pressure drop and temperature were measured at one foot sections along the flow tube, as well as the discharge rates of liquid and of vapor.

The results were compared with theoretical prediction for the adiabatic flow system as presented by M. P. O'Brien and J. A. Putnam. Their fundamental equation follows:

$$W = Ak_0\left(\frac{k_l/k_0}{\mu_l \nu_l} + \frac{k_g/k_0}{\mu_g \nu_g}\right)\frac{dp}{dx}$$

The results show that the total discharge was about 93 per cent greater than the theoretically calculated flow.

The actual behavior of pressure and temperature along the flow tube was in general similar to the theoretical. However, the point at which two-phase flow began was displaced upstream. In a representative case the beginning of two-phase flow indicated by a sudden increase in the gradients for both temperature and pressure occurred at 4.2 feet downstream, as compared to the theoretical result of 5.6 feet.

The increase of total flow was not consistent with the displacement upstream of the point of boiling, and an explanation for this difference has been attempted. It was concluded that an essential explanation may lie in liquid and vapor segregation. Other factors contributing to the differences consist of a form of complex heat transmission along the flow tube itself, and that the average permeability-liquid saturation relationship for sand of 17.8 to 262 darcys may not hold too well for sand of one darcy. Complete discussion of the results is made in the section "Summary of Results and Conclusions."

2390. Miller, F. G.

STEADY FLOW OF TWO-PHASE SINGLE-COMPONENT FLUIDS THROUGH POROUS MEDIA, University of California, Ph.D. Thesis (1950), pp. 47.

This report presents developments of fundamental equations for describing the flow and thermodynamic behavior of two-phase single-component fluids moving under steady conditions through porous media. Many of the theoretical considerations upon which these equations are premised have received little or no attention in oil-reservoir fluid-flow research. The significance of the underlying flow theory in oil-producing operations is indicated.

In particular, the theoretical analysis pertains to the steady, adiabatic, macroscopically linear, two-phase flow of a single-component fluid through a horizontal column of porous medium. It is considered that the test fluid enters the upstream end of the column while entirely in the liquid state, moves downstream an appreciable distance, begins to vaporize, and then moves through the remainder of the column as a gas-liquid mixture. The problem posed is to find the total weight rate of flow and the pressure distribution along the column for a given inlet pressure and temperature, a given exit pressure or temperature and given characteristics of the test fluid and porous medium.

In developing the theory, gas-liquid interfacial phenomena are treated, phase equilibrium is assumed and previous theoretical work of other investigators of the problem is modified.

Laboratory experiments performed with specially designed apparatus, in which propane is used as the test fluid substantiate the theory. The apparatus, materials and experimental procedure are described. Comparative experimental and theoretical results are presented and discussed.

It is believed that the research findings contributed in this paper should not only lead to a better understanding of oil-reservoir behavior, but also should be suggestive in regard to future research in this field of study.

2391. Muskat, M. and Meres, M. W.

THE FLOW OF HETEROGENEOUS FLUIDS THROUGH POROUS MEDIA, Journal of Applied Physics 7, 346-63 (1936).

The data at present available in the literature on the flow of gas-liquid mixtures all refer to particular experimental arrangements, the individual effects of which have not been abstracted from the numerical results. It is impossible to apply the results quantitatively to systems which are of different geometry of subject to somewhat different physical conditions than those yielding the original data.

This paper gives an analytical formulation of the problem of the flow of heterogeneous fluids through porous media, based upon the fundamental experiments of R. D. Wyckoff and H. G. Potset. Several examples are carried through numerically.

2392. Muskat, M., et al.

THE FLOW OF GAS-LIQUID MIXTURES THROUGH SANDS, Trans. of American Institute of Mining and Metallurgical Engineers, 123, 69-96 (1937).

Curves are given relating the gas and liquid permeabilities to the liquid saturations. The principal features of these curves are: 1) a sharp drop in liquid permeability and a very slow rise in gas permeability for small amounts of free gas dispersed through the sand, 2) the attainment of an almost complete homogeneous fluid permeability for the gas, even with the presence of 10-20% of liquid within the pores of the sand and 3) the property that for a given sand steady-state conditions cannot be maintained until the gas saturation has built up to a certain minimal value. 1) normal or homogeneous fluid permeability as free gas develops in the pores; it shows that there is considerable energy dissipation in the system in addition to that caused by the direct viscous friction. This is due to the composite effect of friction losses in the local eddies in the liquid resulting from the continuous forming and breaking of the interfaces between the gas and liquid phases and the transient Jamin effect exerted by a part of the flowing gas. 2) indicated that these small percentages of liquid are retained in the effectively dead spaces of the system and affect only slightly the main course of the flow. Except for the constant factor involving fluid viscosities, the ratio of K_g/K_l from these curves gives the gas-liquid ratio through the

system. Fundamental equations that govern the flow of heterogeneous fluids through porous media are developed. For the conditions of steady state, analytical solutions of these equations are derived for radial, linear and spherical flow. By numerical methods of solution, curves are derived for the history of pressure decline in a linear reservoir.

2393. Reid, L. S. and Huntington, R. L.

FLOW OF OIL-GAS MIXTURES THROUGH UNCONSOLIDATED SAND, Transactions of the American Institute of Mining and Metallurgical Engineers, 127, 226-239 (1938).

Graphs are presented showing the rate of flow of gas-oil mixtures in sand-packed tubes for various pressure differences under conditions of both steady-state and unsteady-state flow.

2394. Spencer, H. G.

THE TWO-PHASE FLOW OF AMMONIA IN POROUS MEDIA, University of California, M. S. Thesis (1945).

As a result of this research work it was discovered that the rate of flow of ammonia, when flowing in two phases through a porous media, is approximately 20% greater than the rate predicted by theoretical calculation. The reason for this discrepancy, it is believed, is because the assumption that equilibrium exists between the gaseous and liquid ammonia and/or the assumption of permeability-saturation relationship determined by Wyckoff and Botset as applicable to the two-phase flow of ammonia in porous media is not entirely valid.

2395. Wyckoff, R. D. and Botset, H. G.

THE FLOW OF GAS-LIQUID MIXTURES THROUGH UNCONSOLIDATED SANDS, J. of Applied Physics, 7, 325-45 (1936).

A method is described for studying the flow of gas-liquid mixtures through unconsolidated sands. Results are given for experiments on four sands, of widely different permeabilities, with carbon dioxide and water as the fluids. A relation between permeability and liquid-saturation of the sand is found, which permits the correlation of saturation and the steady state flow of the gas and liquid components.

FORCE FIELDS

2396. Askar'yan, G. A.

EFFECT OF EXTERNAL FIELDS ON THE MOTION AND GROWTH OF BUBBLES IN BOILING LIQUIDS, Zhurnal eksperimental'noy i teoreticheskoy fiziki, v. 41, No. 4 (1961), 1231-1232.

To study the influence of motion on the growth of bubbles and to investigate it under very simplified thermodynamical conditions, it is necessary to prevent rising of bubbles to the surface. A freely "falling" bubble chamber fulfills these conditions. Thus, it is also possible to remove convection in liquids and to decrease the track distortion. The drop distance measured several mm, which corresponds to a drop time of 10^{-2} - 10^{-3} sec. Not only gravity, inertia, and buoyancy are acting on the bubbles but also those forces of an inhomogeneous, electric, and magnetic field, which are acting on the dipole moments. The author has studied only such cases where the bubble dimensions are small compared with the characteristic dimensions of the field change and where the surface pressure exceeds by far the pressure of the electric and magnetic field on this surface. For the steady state the following estimation has been made: $\chi_e \nabla E^2 \sim g$, $\chi_m \nabla H^2 \sim g$, where χ_e and χ_m denote the electric and magnetic polarizability per gram of liquid. It has been established that inhomogeneous fields permit the control of both the bubble growth and the boundary conditions during boiling and heat exchange with the wall. If the bubbles are kept to the vessel wall, then the heat exchange between liquid and wall is impeded; otherwise it is facilitated. Local inhomogeneous fields at the vessel walls can be used to improve the storage conditions of liquid gases, the evaporation control, etc. There are 5 references: 3 Soviet and 2 non-Soviet. The two references to English-language publications read as follows: M. S. Plesset, S. A. Zwick, J. Appl. Phys., 23, 95, 1952; 25, 493, 1954; S. A. Zwick, Phys. Fluids, 3, 685, 1960.

2397. Lomer, W. M.

THE FORCES BETWEEN FLOATING BUBBLES AND A QUANTITATIVE STUDY OF THE BRAGG "BUBBLE MODEL" OF A CRYSTAL, Proc. Cambridge Phil. Soc. 45, 660-673 (October 1949).

Bubble rafts, when under sufficient stress, are known to exhibit behavior which is qualitatively similar to that of plastic deformation of single crystals. Present paper has as its aim the development of a quantitative theory of behavior of such rafts when subjected to small stresses. Developed theory is primarily an application of laws of surface tension to this situation and is based in part, according to author, on as yet unpublished work of M. M. Nicholson. Validity of theory is limited to small bubbles where slope of bubble cap is small. It is shown that raft behaves as an isotropic body; expressions for Young's modulus and Poisson's ratio are derived and are computed for various values of $R(pg/T)^{1/2}$, where R is a nominal bubble radius and T is surface tension. Experiments performed by author provide satisfactory agreement with theory within its limitations both for certain geometrical properties of bubbles and for Young's modulus and Poisson's ratio. (AMR-4-296)

2398. Woodrow, J., et al.

FORCES BETWEEN SLURRY PARTICLES DUE TO SURFACE TENSION, J. Nucl. Energy, Pt. B, Reactor Technol., 1,229-37, February 1961).

Equations are derived defining the shape of small bubbles or drops which may form between pairs of slurry particles, immersed in a liquid vehicle; the system considered is axially symmetric. The resultant bubble or drop shapes are also presented graphically. The force which a bubble or drop may transmit between particles is derived and evaluated for some particular cases of interest. In a system with only two components, any bubble must contain the vapour phase of the liquid vehicle, at reduced pressure. Such a bubble can only exist if the contact angle, measured in the liquid phase, exceeds 90° and

it will always exert a cohesive force, holding the slurry particles in contact. Three component systems can be formed with bubbles or immiscible liquid drops joining adjacent slurry particles, provided that the contact angle is greater than zero, and they may transmit a cohesive force. This was demonstrated qualitatively by experiments with glass particles in water which flocculated heavily when shaken in air and dispersed when de-aerated, or when the contact angle was reduced to zero. When a liquid metal slurry is exposed to neutron irradiation, gas may be generated, and may cause flocculation by this mechanism. Degassing may prove to be difficult.

Acoustic

2399. Antonevich, J. N.

ULTRASONIC ATOMIZATION OF LIQUIDS, I.R.E. Trans. Ultrasonics Engng. No. PGUE-7, 6-15 (Feb 1959).

Observations of liquid films excited ultrasonically are described and discussed. These films atomized under ultrasonic excitation, and the rupture of capillary waves in the film is suggested as the prime cause of atomization. The atomization of a paint film by 20 kc/s vibrations was studied qualitatively. High-speed motion pictures show sprays emanating from vibrating gas bubbles in the paint film. The particles produced were from 5 to 500 μ in diameter. Under the best atomizing conditions at 20 k/cs the particle diameters were from 20 to 70 μ.

2400. Bazilevich, V. V. and Tverskoi, N. P.

FREEZING OF DROPS OF A SUPERCOOLED WATER MIST IN AN ACOUSTIC FIELD, Zh. Tekh, Fiz., 27, 1826-9 (1957), In Russian. English translation in: Soviet Physics - Technical Physics (New York), 2, 1696-9 (Aug, 1957).

Experiments to show that supercooled water mists (drop diameters 1.6 to 30 μ) between -4° and -5°C crystallize more rapidly in an acoustic field generated by a siren (frequency: 1 to 15 kc/s; pressure on axis 150 cm from siren: 110 bars at 10.1 kc/s).

2401. Bebchuk, A. S.

THE MECHANISM OF CAVITATIONAL BREAK-UP OF SURFACE FILMS IN A SOUND FIELD, Akust. Zh., 2, 113-117 (Apr-June, 1956).

An investigation of the underlying mechanism of ultrasonic cleaning processes. As a standard film, a blob of resin was used, on a glass plate inclined at an angle above the brass termination of a Ni tube excited ultrasonically by an 8 kw generator. The plate and the upper end of the tube were contained in a parallel-sided glass vessel of distilled water. The plate was photographed at 4000 frames/sec. Two phenomena are involved in the break-up of the film; (1) Bubbles bursting near the surface appear to be associated with strong local break-up. (2) Bubbles penetrate under the film and then break it off.

2402. Derouet, B.

STUDY OF THE DEGASSING OF LIQUIDS UNDER THE ACTION OF ULTRASONIC VIBRATIONS OF 80 AND 17.7 ks/s, Compt. Rend. 234, 71-3 (Jan. 1952).

A study of the formation of air bubbles in water under the action of ultrasonic vibrations. A possible theory for bubble formation is produced and the minimum radius of bubble calculated.

2403. Fox, F. E., et al.

PHASE VELOCITY AND ABSORPTION MEASUREMENTS IN WATER CONTAINING AIR BUBBLES, J. Acoust. Soc. Am. 27, 534-9 (1955).

Measurement of continuous train of sound waves in water having air bubbles as function of frequency in range 10 kc to 1 mc; when bubbles constituted 0.02% of volume, phase velocity varied from 500 m/sec to 2500 m/sec and peak absorption was over 30 db/cm.

2404. Hsieh, D. -Y. and Plesset, M. S.

REPLY TO COMMENTS OF P. W. SMITH, JR., Phys. of Fluids, 5, 254 (1962).

A rebuttal to the comments (see preceding abstract) on the authors' original discussion of sound propagation in a liquid-gas bubble mixture (Abstr. 11813 of 1961). The isothermal behaviour is considered to be due to the assumption of homogeneity and not only to the presence of the liquid. This makes inhomogeneities, such as the bubble size, smaller than the thermal diffusion length and ensures isothermal behaviour.

2405. Kapustin, A. P.

THE DEGASSING OF LIQUIDS IN AN ULTRASONIC FIELD, Zh. Tekh. Fiz. 24, 1008-11 (1954).

Waves of 0-6 Mc/s from a quartz oscillator were used in transformer oil and glycerine. Degassing took place in two stages, formation of bubbles and then their transport to the surface. The time to degas decreased with increasing intensity of the sound waves. (SA-58-3520)

2406. Karal, F. C.

A STUDY OF THE SCATTERING OF SOUND WAVES IN FLUIDS. PART I: SCATTERING OF A PLANE WAVE BY A SPHERICAL BUBBLE, AD-14874 (1953).

Study of rigid sphere moving through incompressible, homogeneous, nonviscous fluid in presence of rigid, infinite plane boundary; direction of motion of sphere is assumed to be parallel to plane boundary; it is assumed that motion is irrotational and that sphere velocity is small; exact treatment is prevented; curves of pressure variation on plane boundary are plotted.

2407. Karin, S. M. and Rosenhead, L.

THE SECOND COEFFICIENTS OF VISCOSITY OF LIQUIDS AND GASES, Revs. Modern Phys., 24, 108-113 (1952).

Up to the present, discrepancies have been noticed in the field of investigation which deals with the transmission of sound energy through liquid and gases.

As far as liquids are concerned no work has been done on the absorption of energy associated with vibrations in the sonic range (20 to 20,000 vibrations per second). In the ultrasonic range experimental values of absorption differ from the theoretical ones by factors ranging from 3 to 1000. In gases, both in the sonic and supersonic ranges, the values differ by a factor whose magnitude lies in the range of 4 to 100.

Most of the work which has been done in this field has been concerned with the passage through liquids of sound energy in the ultrasonic range of frequencies. Here it is clear that the value of μ'/μ deduced from experiment is in good agreement with the value of the ratio deduced from information on excess absorption of energy. The viscosity ratio is never negative; its value ranges from about 1 to about 120 in the cases so far investigated.

The classical theory of the dynamics of viscous fluids is based on the assumption that there is only one fundamental coefficient of viscosity, μ, the coefficient of shear viscosity. The other quantity, μ', the second coefficient of viscosity, is assumed to be equal to $-2\mu/3$ in order that $\kappa[=(2\mu + 3\mu')/3]$, the coefficient of bulk viscosity, should be zero. In making this assumption classical hydrodynamics parts company from classical elasticity, in which two fundamental quantities, the Lamé constants λ and μ, are introduced.

The above assumption seems to have some basis in theory only in the case of ideal monatomic gases; it has, however, been carried over implicitly to both liquids and gases of all degrees of complexity. One might therefore expect some differences to exist between theoretical predictions and experimental results due to this oversimplification. The present review has been undertaken with a view to exploring the existence and the magnitude of any such differences.

2408. Karplus, H. B.

THE VELOCITY OF SOUND IN A LIQUID CONTAINING GAS BUBBLES, COO-248 (June 1958), 41 p.

The velocity of sound in water containing air bubbles is very low. In pure water sound travels with a speed of 1500 m/s; this velocity decreases to 100 m/s in water containing 1% by volume of air. The minimum occurs at 50% volume concentration at which a velocity of 20 m/s is observed. For constant mass concentration the velocity is directly proportional to the ambient pressure over an appreciable pressure range. As a consequence a slow pressure rise in such a medium becomes a shock wave very rapidly. On the other hand, shock waves are expected to be severely attenuated when passing through the medium. The heat exchange between bubbles and the water is very rapid so that there is no adiabatic temp. rise due to the compression. For this reason the results may be readily extended to other gases which do not condense but are inapplicable to vapor (steam) bubbles.

2409. Karplus, H. B.

PROPAGATION OF PRESSURE WAVES IN A MIXTURE OF WATER AND STEAM, ARF-4132-12 (Jan 1961), 89 p.

The velocity of sound in mixtures of water and steam was computed from the slope of the lines of equal entropy over a wide range of ambient conditions up to the critical point. The sound velocity is lower in the mixture than in either constituent. It changes discontinuously on transition to the single phase in wet steam with just a trace of liquid. The velocity is about 10% less than in dry steam. The velocity decreases monotonically with increasing content. In boiling water the velocity is very low. The smallest value occurs at reduced pressure at the triple point (with no solid ice present); the velocity here is as low as 0.012 m/s. Rankine-Hugoniot curves were calculated for the mixture. These show that a shock-like compression in very wet steam or boiling water will condense all the steam, giving rise to a large change in volume with very little rise in pressure. The Hugoniot curve lies very close to a line of constant entropy in this case. For high quality steam the compression will raise the temperature of the vapor and evaporate the liquid phase. This occurs far from constant entropy conditions, indicating a strong loss mechanism. In boiling water the propagation was studied with pressure waves having an amplitude exceeding the minimum necessary to condense all the steam. The velocity decreases monotonically with decreasing driving pressure, approaching the small amplitude acoustic velocity when the driving pressure approaches the minimum necessary to condense all the steam. In a straight pipe of boiling water true shocks were not propagated. The rise time of the compression wave steadily increases as it passes through the medium. On finally reaching a region of no bubbles, high peak pressures are observed. These peaks were an order of magnitude greater than the original driving pressure. This amplitude is apparently due to the formation of a water hammer.

2410. Laird, D. T. and Kendig, P. M.

ATTENUATION OF SOUND IN WATER CONTAINING AIR BUBBLES, J. Acoust. Soc. Am. 24, 29-32 (1952).

Experimental study of very high sound attenuations in water predicted by Foldy theory; attenuation was very large at frequencies where resonant bubbles were present and much smaller at other frequencies, indicating resonance absorption to be principal phenomenon observed.

2411. Meyer, E. and Skudrazyk, E.

ABOUT THE ACOUSTIC PROPERTIES OF GAS BUBBLE CLOUDS IN WATER, Acustica, 3, 434-40 (1953).

On the basis of the known properties of pulsating gas bubbles in water (resonance-frequencies and damping factors) formulae are derived for the complex compressibility and therewith for the phase velocity and attenuation of sound waves in water containing gas bubbles. Numerical computations are made for two cases; for a bubble mixture of constant bubble size and of one with a continuous distribution of bubble

size with equal volume concentration. In a big tank bubble-water mixtures were produced in three different ways: by pressing air through porous plates, by electrolysis, and by means of a pumping device. In these mixtures of bubbles and water, phase velocity and sound attenuation were measured in a wide frequency range. The results agree as well with theory as can be expected.

2412. Rodabaugh, R.

TWO PHASE FLOW AND ACOUSTIC PHENOMENA IN GASES AND LIQUIDS, JPLAI-LS-177 (1960).

Abstracts are presented on 127 papers pertaining to two-phase flow and acoustic phenomena in gases and liquids.

2413. Roll, A.

INFLUENCE OF ULTRASONICS ON ELECTROLYTIC PROCESSES. II. AGITATION PROVIDED BY ULTRASONICS, Z. Metallkunde 41, 339-43 (1950).

Studies of electrodeposition of Ni were extended and the influence of ultrasonics on the mobility of gas bubbles in glycerol-water mixture was investigated. Greater rate of rise of bubbles in the ultrasonic field indicated influence of sound-radiation pressure. Ultrasonics removed gas bubbles at the cathode, and thus improved deposition more than mech. agitation. The agitation effect was further proven in expts. with Cu and Ag deposition. It was shown that ultrasonics of 34 kilocyles and 0.3 w/sq cm was superior to mech. agitation. The effect was independent of frequency and only depended on intensity. (CA-45-4581a)

2414. Silberman, E.

SOUND VELOCITY AND ATTENUATION IN BUBBLY MIXTURES MEASURED IN STANDING WAVE TUBES, J. Acoust. Soc. Amer., 29, 925-33 (1957).

Experimental measurements of sound velocity and attenuation constant in a mixture of air bubbles in fresh water, using a standing-wave tube, are described. Bubble sizes in the mixtures were controlled between about 0.08 and 0.26 in. diameter, concentrations ranged from 0.03 to 1%, and applied frequencies from 60 to 20,000 c/s. Bubbles in each mixture were of a single uniform size except for one series of experiments in which mixtures of bubbles of two discrete sizes were used. Attenuation constants were obtained for each mixture through a range of frequencies, including natural frequencies of the bubbles in the mixture. Velocity measurements were not obtained near the natural frequencies of the bubbles because high attenuation prevented the establishment of standing waves. Data obtained in the tubes were reduced to mean, infinite conditions and compared with available theory. The measurements show that theory gives at least a good estimate of both velocity and attenuation constant in the region investigated.

2415. Smith, P. W., Jr.

COMMENTS ON "ON THE PROPAGATION OF SOUND IN A LIQUID CONTAINING GAS BUBBLES", Phys. of Fluids, 5, 253 (Feb. 1962).

The thermodynamic processes held responsible for adiabatic or isothermal sound propagation in gases or liquid-gas bubble mixtures by Hsieh and Plesset (Abstr. 11813 of 1961) are discussed. The original statement by Laplace is quoted to show the importance of heat conduction to "nearby bodies" (i.e. the surrounding liquid). This makes the sound propagation in a liquid-gas bubble mixture isothermal at low frequencies.

2416. Strasberg, M.

GAS BUBBLES AS SOURCES OF SOUND IN LIQUIDS, J. Acoust. Soc. Am. 28, 20-26 (January 1956).

Author shows that sound generated by small gas bubbles entrained in a liquid is mainly associated with volume pulsations of the bubbles; the sound pressure generated by shape pulsations being negligible. Theory used is a linear approximation and is applied for describing sound pressures and spectra generated in bubble formation at a nozzle, bubble coalescense or splitting, and when bubbles are entrained past bodies and constructions. Limits of the applied theory and the effects of nonlinearities are indicated.

Reviewer believes this article is an important contribution in understanding the phenomenon of sound generated by gas bubbles entrained in a liquid.

2417. Westervelt, P. J.

ADSORPTION OF SOUND BY GAS BUBBLES AT A WATER-METAL INTERFACE, J. Acoust. Soc. Am. 23, 369 (1951).

Electrostatic

2418. Alty, T.

ORIGIN OF THE ELECTRIC CHARGE ON SMALL PARTICLES IN WATER, Proc. Roy Soc. (London), A112, 235-51 (1926).

With the app. previously described (CA-19-198) measurements have been made of the mobility of air bubbles 2.0 to 0.2 mm in diam. in cond. water. If the bubble is assumed to acquire a charge E by ionic adsorption, then E can be calcd. from measurements of the velocity by the application of Stokes' law. The dependence of the charge on the age of the surface of the bubble and on its diam. was studied, and it was found that in very pure, air-satd. water, the charge is extremely small at first, increases to a max. and then falls to a value of about one third of this max., after which it appears to be independent of time. Similar expts. were made in water from which some of the air had been removed, so that the bubble decreased continuously during the expts. A curve of similar type was obtained and when equil. had been reached, the total charge on the bubble remained independent, not only of time, but also of bubble diam. From this it would appear that, after equil. the surface d. of the charge must increase inversely as the square of the bubble radius, since the total charge remains practically const. while the bubble area

decreases. In a theoretical treatment, these results are explained on the basis of adsorption, not of H and hydroxyl ions, but of ionic impurities in the water. This theory is supported by the fact that the greater the purity of the water the lower is the mobility of the bubble. Neg. ions are assumed to be adsorbed on the inner surface of the bubble, and these tend to become covered by the pos. ions in the liquid. Equil. is attained when the no. of pos. ions bound per sec. is equal to the no. removed by thermal collisions in the liquid. From further assumptions, it is possible to calc. the total charge on the bubble at any time after its formation, and the values so obtained agree excellently with the exptl. ones. The p.d. between the surface of the bubble and the interior of the liquid, due to excess of adsorbed neg. ions, can be calcd. by the use of the Boltzmann equation, and the value V = 0.64v is obtained, which agrees well with the values detd. directly by other observers. (CA-21-2595-3)

2419. Bonjour, E. and Verdier, J.

MECHANISM OF BOILING UNDER ELECTRIC FIELD, C. R. Acad. Sci., 251, No. 7, 924-6 (Aug. 17, 1960).

Photographs of the surfaces of heated wires in Freon boiling at atmospheric pressure in the presence of an electric field have established the existence of an electromechanical action on the movement of the bubbles in accordance with the analysis outlined in previous papers (ibid, Vol. 250, 76 (1960); Abstr. 10663 of 1960). (SA-61-2912)

2420. Bonjour, E., Verdier, J. and Weil, L.

IMPROVEMENT OF HEAT EXCHANGES IN BOILING LIQUIDS UNDER THE INFLUENCE OF AN ELECTRIC FIELD, A.I.Ch.E. Preprint 7, New York (1962), 18 p.

It is shown that notable improvements in heat exchange coefficients may be obtained in some cases multiplied by factors ranging from 4 to 10. On a more fundamental basis, mechanisms are described and connected with the physical characteristics of the fluids leading to such improvements. The experimental work used a wire heated electrically, of diameter of 0.1 or 0.2 mm. The electrical field was produced on this wire by means of a parallel linear electrode, an alternating potential being applied between them.

2421. Chapman, S.

INTERPRETATION OF CARRIER-MOBILITY SPECTRA OF LIQUIDS ELECTRIFIED BY BUBBLING AND SPRAYING, Phys. Rev., 54, 528-33 (1938).

2422. Coehn, A.

EFFECT OF THE ELECTROSTATIC CHARGE OF GAS BUBBLES EVOLVED ELECTROLYTICALLY, Z. Electrochem. 29, 306-8 (1923).

It is expected that when employing a cathode of palladium or other metal capable of absorbing hydrogen, the absorption of gas will be affected by the electrical charge on the gas bubbles which is found in the above work to determine the size of the bubbles and their adhesion to the electrode. By means of eudiometer tubes, measurements are made of the volume of hydrogen evolved from palladium cathodes during electrolysis of sulphuric acid of different concentrations with definite currents. It is found that the amount of hydrogen absorbed increases with increasing concentration of the acid up to a certain limit and then falls slightly. The curve giving the relation between the volume of gas absorbed and the concentration of acid is of the same type as that showing the magnitude of the charge on the bubbles with concentration of acid when a stream of gas is bubbled mechanically through the solution, but in the former case, is displaced so as to give a maximum at a higher concentration of acid than in the latter case. This displacement is attributed to the fall in concentration remains around the cathode during electrolysis whereas the concentration remains unchanged during the mechanical bubbling. With potassium hydroxide, a smaller absorption or higher gas evolution occurs in accordance with the observation of the negative charge on the bubbles and consequent lower adhesion to the electrode. Similar absorption relations are observed with other metals such as tantalum, nickel, and iron by using other methods. (CA-17-3446-6)

2423. Coehn, A. and Newmann, H.

ELECTROSTATIC PHENOMENA OF ELECTROLYTICALLY GENERATED GAS BUBBLES. I. ELECTROSTATIC ATTRACTION AND BUBBLE SIZE. II. ELECTROSTATIC REPULSION; THE GAS-JET ELECTRODE, Z. Physik. 20, 54-67, 68-81 (1923).

In a previous paper Coehn and Mozer found that the gas bubbles evolved during electrolysis differed greatly according as the electrolyte was acidic or alkaline the difference being especially pronounced at cathodic hydrogen development; where from alkali the hydrogen rises in fine drops, whereas from acid it adheres to the electrode and only rises when large bubbles are formed. The cause is ascribed to electrostatic effects. It has now been established experimentally that the attraction of gas bubbles at the solid electrode, which is always to hand from capillarity forces, may, for electrolytically produced gases, (a) be increased if the gas bubble and electrode possess opposite signs, (b) be diminished if they have like signs and the potential of the electrode suffices for overcoming the capillary attraction. Bubbles which adhere only by capillary attraction have the same dimensions in all dilute solutions under the same experimental conditions. Those held by electrostatic forces grow with the strength of the electrolyte which has the opposite charge to the electrode. Sense and magnitude of the electrostatic force are derived from another type of phenomena to the bubble effect. The curves giving the connection between the concentration of a solution and the charge on the bubbles travelling through it, give also information on the adherence and magnitude of the electrolytically developed gas bubbles.

Part II Considers Electrostatic Repulsion and the Gas-Emitting Electrode. - When the electrolytically developed gas bubbles and the electrodes have like charges then at a sufficiently high electrode potential the bubbles are repelled and there arises the

gas-emitting electrode. The potential required is lower as the bubble charge is greater, and can be determined like the effect of electrostatic attraction from the curves for the bubble effect showing the dependence of gas charge on concentration. From the emission potential concentration curves the duration of the effect can be obtained. After cessation of the first emission, with very fine bubbles, a second emission with large bubbles appears by increase of potential at both electrodes and for all concentrations. In contrast to the first emission this is traced to the influence of the strong electric field at the electrode on the distribution of the ions in the liquid layer containing the gas bubbles. (CA-18-1081-9)

2424. Coehn, A.

ON WHAT DOES THE ADHERENCE AND SIZE OF ELECTROLYTIC GAS BUBBLES DEPEND, Z. Electrochem. 29, 1-5 (1923).

A series of determinations were made of the discharge potential, and the size of the gas bubbles evolved when solutions of 0.1N H_2SO_4 and 0.1N KOH were electrolysed. Electrodes of nickel and silver were employed. The adhesion of the bubbles to the electrodes was found to be due to the electrostatic attraction of the cathode to the positively charged gas bubbles, aided by capillary forces.

The maximum size of the bubbles was measured by a micrometer ocular, and it was found that the maximum size was a function of the concentration for a given solution. (CA-17-1579-1)

2425. Katti, P. K. and Chaudhri, M. M.

EFFECT OF STRONG ELECTRIC FIELDS ON THE BOILING POINTS OF SOME ALCOHOLS, Nature, 190, 80 (1961).

When a strong alternating electric field is applied to a boiling liquid and its vapour, it is found that the boiling point is reduced. The effect has been studied in the case of methyl, ethyl and isopropyl alcohol.

2426. Krishnamurti, K.

THE EFFECT OF MAGNETIC FIELD ON STREAMS OF CHARGED PARTICLES, Current Sci., 2, 387-8 (1934).

Streams of small gas bubbles, evolved electrolytically, are deflected by a magnetic field; H_2 and O_2 are deflected in opposite directions, at right angles to the field. H_2 evolved from acid-metal reactions is not deflected by the magnetic field; Zn and Cu in contact in H_2SO_4 give deflectable bubbles. Only gases obtained electrochemically are electrically charged. Charged colloidal particles moving in an elec. field are deviated by a magnetic field; the mass of the particle may be detd. from the field strength and the deflection. H_2 bubbles from a point source are deflected by the combined elec. and magnetic fields into 2 streams; apparently H_2 and H_1 are sepd.

2427. Lovera, G. and Pochettino, H.

ELECTRIFICATION BY BUBBLING, Nuovo cimento 14, 393-410 (1937).

When a stream of N_2 was blown through a solution of an organic salt, the droplets of liquid, passed between two electrodes connected to a Lindemann electrometer, were found to be charged both positively and negatively. The magnitude of the charge varied with the rate of flow of the gas and with the concentration of the solution. The form of the curves of charge against concentration is different for positive and negative charges, and has a number of points, characteristic of the salt, at which the positive and negative charges are equal. For methylene blue and quinine bisulphate there are two such points, and for uranin there is one. (CA-32-2406-8)

2428. Lovera, G. and Pochettino, A.

ELECTRIFICATION BY BOILING AND DIPOLE MOMENTS, Nuovo cimento 16, 337-47 (1939).

Tests were made on a series of disubstituted derivs. of aromatic hydrocarbons of different dipole moment dissolved in inactive solvents. Solns. of compds. of zero moment remained inactive but those of compds. with a moment became active. The charge produced increases with the dipole moment of the solute. The solvents were: C_6H_6(I), $C_6H_5CH_3$(II), $C_6H_4(CH_3)_2$(III), dioxane (IV). Data are given for o-, m- and p-$C_6H_4(NO_2)NH_2$ in I and IV, o-, m- and p-$C_6H_4(NO_2)OH$ in IV, o-, m- and p-$C_6H_4(NO_2)Cl$ in III, o-, m- and p-$C_6H_4(NO_2)_2$ in II, m- and p-$C_6H_4(NO_2)_2$ in III, biphenyl in III and IV, o, o'-dinitrobiphenyl in III and IV, p, p'-dinitrobiphenyl in III and IV, naphthalene in IV, 1,5-dinitronaphthalene in IV, 1,8-dinitronaphthalene in IV, bibenzyl in III, Et benzoate in III, crystal violet in II and IV, malachite green in II and IV, diazoamidobenzene in III, amidoazobenzene in III. (CA-34-2662-5)

2429. Lovera, G. and Pochettino, A.

ELECTRIFICATION BY BOILING, Nuovo cimento 17, 161-7 (1940); 18, 269-79 (1941).

The dependence of the charge generated by boiling on the dielec. const. and viscosity was investigated for the mixt. of polar and nonpolar liquids. The effect does not always increase regularly with the concn. of the nonpolar liquid or with the dielec. const. but decreases with H_2O, nitrobenzene and pyridine in high concn. because of the strong influence of assocn. In the mixt. of oleic acid with xylene the electrification at high concns. of oleic acid (40%) decreases to zero because the viscosity is so great that the charge generating surface double layers cannot form rapidly enough with the passage of the gas. The increase in the charge generated coincides with the increase in temp. and the decrease with vigorous boiling. A quant. interpretation of the effect was not attempted. (CA-36-5069-7)

2430. McBain, J. W. and Williams, R. C.

DETERMINATION OF THE NUMBER OF FREE ELECTRIC CHARGES ON AIR BUBBLES AND OIL DROPLETS DISPERSED IN WATER CONTAINING A SMALL AMOUNT OF CETYLSULFONIC ACID, Colloid Symposium Annual 7, 105-14 (1929).

A 0.0001 N cetylsulfonic acid soln. was shaken to produce bubbles, and then poured into a vertical test tube of 7 mm bore, provided with a diagonal side arm sloping to the top of the tube. Electrodes with a p.d. of 110 and 40 v (d.c.) were inserted 3 cm apart, one from the top, one in the side arm. Gases in small quantity due to electrolysis thus escaped without disturbing the field of observation between the electrodes. By timing the small bubbles as they moved over a distance of 1.5 mm and applying Burton's modification of Stokes' formula, the bubble size was calcd. The potential was then applied and its effect observed, in a manner analogous to Millikan's oil droplet expts. By equating the electrical pull $F.e_n$ against the "gravitational" pull mg, the no. of charges per bubble were calcd., air bubbles showing "orthodox" charges of 1.95 to 2.4 x 10^5 and C_6H_6 bubbles 5.9 x 10^5. This represents a surface coverage of 0.0031 to 0.0017 and 0.0006, resp., and shows as Currie and Alty (C.A. 23,2340) pointed out that the conceptions and formulations of Helmholtz are inapplicable. ". . . . . the classical treatment of electrokinetics on the basis of a double layer is invalid. It follows that a more general treatment corresponding to the electrochemistry of electrolytes is necessitated." (CA-24-3414-2)

2431. Murakawa, T. and Nagaura, S.

ELECTRIC RESISTANCE OF GAS BUBBLES FORMED ON THE ELECTRODES. I. EFFECT OF GAS BUBBLES ON CURRENT DISTRIBUTION, J. Electrochem. Soc. Japan 23, 223-6 (1955).

The elec. resistance of the gas film formed on the electrode surface during electrolysis was studied. (a) The difference of current distribution on upper and lower parts of the electrode owing to gas accumulation was measured by using the multiple electrode system and by the distribution of deposited metal. (b) As a result of measurements of the relation between the elec. resistance and the current distribution with a.c. with a so-called 3rd electrode, it was noted that the concn. heterogeneity of the electrolytic soln. was as effective as gas bubbles. In dil. H_2SO_4, the cathode resistance increased with c.d., while the anode resistance decreased. The reverse relation was observed in the dil. caustic soda. This concn. change could be explained qualitatively by the transportation and discharge of ions. (CA-49-14520i)

2432. Whybrew, W. E., Kinzer, G. D. and Gunn, R.

ELECTRIFICATION OF SMALL AIR BUBBLES IN WATER: J. Geophys. Research 57, 459-71 (1952).

Exptl. detns. of the law of resistance to movement of a CO_2-free air bubble along the axis of a H_2O filled (CO_2-free) cond. cell rotating at two angles of tilt from the horizontal yield a surface elec. charge d. (SCD) of approx. 0.080 e.s.u./sq cm, a value 10 or more times that reported previously. The SCD appears to be nearly independent of bubble diams. greater than 0.1 cm. The SCD measured in the same app. by establishing a static balance between the force of the elec. field parallel to the axis of rotation and a component of the force of buoyancy is 0.66 e.s.u./sq cm, in fair agreement with that of the mobility expts. Freely rising bubbles yield a value of the SCD of 0.19 e.s.u./sq cm; the low value is attributed to insufficient time for surface equil. to be attained. CO_2 dissolved in the H_2O in equil. with room air reduces the SCD from 0.80 to 0.22 e.s.u./sq cm. (CA-47-4168f)

HORIZONTAL TUBES

2433. Altman, M., Norris, R. H. and Staub, F. W.

LOCAL AND AVERAGE HEAT TRANSFER AND PRESSURE DROP FOR REFRIGERANTS EVAPORATING IN HORIZONTAL TUBES, Jour. Heat Trans. 82, 189-98 (1960).

A description is given of a test facility for investigating local heat transfer and pressure drop for evapg. or condensing refrigerants. The empirical method of Pierre (Kylteknisk Tidskrift No. 3, 129 May (1957)) for correlating the av. heat-transfer coeffs. of refrigerants evapg. in horizontal tubes is presented in conjunction with published data. Data on local heat-transfer coeffs. and pressure drop are presented for Refrigerant-22 evapg. in two 4-ft-long, 0.343-in. internal diam. straight horizontal tubes, and are correlated by a refinement of the curve proposed by Pierre (loc. cit.). The procedure of Martinelli-Nelson (Trans. Am. Soc. Mech. Engrs. 70, 695-702 (1948)) correlated the data for local pressure drop within 15%.

2434. Baker, M., et al.

HEAT TRANSFER FILM COEFFICIENTS FOR REFRIGERANTS BOILING INSIDE TUBES, Refrig. Eng. 61, 986-91 (1953).

This study deals with heating transfer to boiling refrigerants flowing inside a horizontal tube of 0.545 in. inside diam. the influence of flow rate, boiling temp., mixt. compn., and temp. differential between the tube surface and the fluid were studied for Freon-12 and MeCl. The data are summarized in tabular form.

2435. Davis, E. J. and David, M. M.

HEAT TRANSFER TO HIGH-QUALITY STEAM-WATER MIXTURES FLOWING IN A HORIZONTAL RECTANGULAR DUCT, Can. J. Chem. Eng. 39, 99-105 (1961).

The exptl. data in the region of high vapor fractions and mass-transfer rates, where two-phase convections-controlled heat transfer predominates, were in good agreement with those of other studies, in which circular ducts were used.

2436. Isbin, H. S., et al.

HEAT TRANSFER TO STEAM-WATER FLOWS, 1961 Proc. Heat Trans. and Fluid Mech. Inst. Stanford University Press, Stanford U.S.A., p. 70.

Local heat transfer coeffs. were measured for all H_2O, all steam, and steam-H_2O flows in an electrically heated, horizontal, brass pipe 0.376 in. inside diam. with a heated length of 9.25 in. Two-phase runs were made for total mass flow rates, G, of 52,000-182,000 lb/hr sq ft, pressures 16-90 lb/sq in.abs., and heat fluxes 9350-50200 Btu/hr-sq ft. For the low fluxes used, the heat-transfer coeffs. (for const. G. and heat flux) increased with quality (wt fraction of steam) up to 0.98.

2437. Johnson, H. A. and Abou-Sabe, A. H.

HEAT TRANSFER AND PRESSURE DROP FOR TURBULENT FLOW OF AIR-WATER MIXTURES IN A HORIZONTAL PIPE, Transactions of the American Society of Mechanical Engineers, 74, 977-87 (1952).

The static pressure drop and heat transfer for two-phase, two-component flow of air and water were measured for flow in a horizontal 15-foot length of 1-inch 16-gage brass tubing. Flow rates include the range of 1000 to 15,000 lb per hour for the water and 0 to 200 lb per hour for the air. Tentative correlations are presented from which prediction of pressure drop and heat transfer can be made under restricted flow conditions.

2438. Johnson, H. A.

HEAT TRANSFER AND PRESSURE DROP FOR VISCOUS-TURBULENT FLOW OF OIL-AIR MIXTURES IN A HORIZONTAL PIPE, Trans. ASME 77, 1257 (1955).

The heat transfer and static pressure drop for two-phase, two-component flow of oil and air were measured for flow in a steam-heated horizontal 15 ft length of $\frac{3}{4}$-in. extra-heavy copper pipe. Tentative correlations are presented and used in a comparison of the oil-air and water-air results for heat transfer and nonisothermal pressure drop in the same test system.

2439. Korneev, M. I. and Puganov, B. N.

HEAT EXCHANGE TO A FLOWING VAPOR-LIQUID MIXTURE IN HORIZONTAL TUBES, Teploenergetika 3, 39-44 (1956).

An experimental investigation was made where mixtures of Mg, Hg (liquid), and Hg (vapor) and H_2O-air were led through horizontal pipes. It was found that the coefficient of heat exchange through the wall depends on the amount of heat, the inner diameter of the tubes, and the rate of flow of liquid and vapor. The flow rate at which equilibrium in heat exchange is established depends on the heat, tube diameter, and rate of flow of vapor. It was found that the best results were obtained if the vapor flowed 2-4 m/sec. Two empirical formulas are presented, one for the Mg, Hg; the other for a steam-air mixture. If the tubes are inclined, the maximum permissible rate of flow of the liquid must be decreased.

2440. Lel'chuk, V. L. and Tarasora, I. V.

EXPERIMENTS ON HEAT EXCHANGE WITH BOILING WATER IN A HORIZONTAL TUBE. News of the All-Union Heat Engineering Institute, 10 (1950).

2441. McAdams, W. H., Woods, W. K. and Bryan, R. L.

VAPORIZATION INSIDE HORIZONTAL TUBES, Transactions ASME, 63, 545-552 (1941).

This paper reports an investigation carried out to determine the changes in the coefficient of heat transfer for the evaporation of a liquid flowing inside a heated horizontal tube. For this research, a semi-works apparatus was constructed consisting of 48 ft of standard 1-inch copper pipe, provided with 12 individual steam jackets, steam traps, and condensate lines. In the benzene runs, the velocities ranged from 0.26 to 1 fps at the inlet and 80 to 240 fps at the outlet; in the water runs, the corresponding values were 0.27 to 0.85 and 205 to 540 fps. With moderate temperature differences, as the fluid is progressively vaporized, the local overall coefficient at first increases, goes through a maximum and then decreases sharply toward values typical of superheating dry vapor. Such "vapor-binding" is attributed to insufficient liquid to wet the wall, small droplets of liquid being carried down the center of the tube, as observed at the entrance to the glass return bend. With high temperature differences, the type of vapor-binding previously observed when boiling liquids outside submerged tubes where (due to excessive temperature difference) a vapor film insulates the tube wall from the bulk of the liquid, was encountered.

2442. McAdams, W. H., Woods, W. K. and Heroman, L. C., Jr.

VAPORIZATION INSIDE HORIZONTAL TUBES-II. BENZENE-OIL MIXTURES, Trans. ASME, 64, 193-200 (1942).

This paper reports an investigation carried out to determine heat-transfer coefficients and pressure drops for mixtures of benzene and lubrication oil flowing inside a heated horizontal tube, and also includes an analysis of the pressure drops for the runs previously reported (1) for the flow of benzene and of water. The present data cover the following ranges: velocity, 0.4 to 1.0 ft/sec at the inlet and 16 to 200 ft/sec at the outlet; feed composition, 13 to 94 weight per cent benzene; gage steam pressures, 2 to 120 lb/sq in.; product compositions 4 to 76 wt. % benzene; total pressure drops 1 to 12 lb/sq in. Average overall coefficients of heat transfer, in BTU per hour per sq ft per degree F, range from 50 to 140 in the preheating section, and 45 to 470 in the boiling section. For a given feed composition the average coefficients per pass in the boiling section increase as vaporization progresses, but pass through a maximum and decrease due to depletion of volatile solvent in the liquid phase. When the same data are grouped by composition of the liquid phase, rather than that of the feed, curves are obtained which are very similar to those obtained for pure liquids.

2443. Myers, J. E. and Katz, D. L.

BOILING COEFFICIENTS OUTSIDE HORIZONTAL PLAIN AND FINNED TUBES, Refrig. Eng. 60, 56-9 (1952).

Studies with Freon 12, MeCl, SO_2, and propane show that finned tubes have their max. advantage at low-temp. differences.

2444. Myers, J. E. and Katz, D. L.

BOILING COEFFICIENTS OUTSIDE HORIZONTAL TUBES, Chem. Eng. Progress Symposium, Ser. 49, No. 5, Heat-Transfer (Atlantic City), 107-14 (1953).

Boiling-film coeffs. for several fluids which are used as refrigerants or are potentially usable are presented for both plain and finned tubes of the low-fin integral type. A good compromise is struck between the typical small-surface or short-tube boiling-film coeffs. which have been reported in the literature and the com. applications where the flexibility of the lab. installation is not available and where correlation of data over a range of conditions is attainable only with difficulty. The boiler used contained 4 horizontal active tubes in a vertical row, so that the influence of position and the behavior of the lower tubes might be accurately measured. Boiling-film coeffs. were experimentally detd. for the plain tubes. For the finned tubes, an analytical analysis was made of the over-all coeffs. by using a modified Dittus-Boelter-type equation for the water film coeff. on the inside, the water being used as the heating medium. This modified equation had been found experimentally to apply to the app. and was probably due to the presence of orifice plates located short distances upstream from the entrance to the tube bundle. The fluids used were Freon 12, MeCl, propane, and butane over part of the range of temps. and pressures in which they are likely to be used industrially.

2445. Styrikovich, M. A., Miropolskii, Z. L. and Anakin, N. M.

ON THE INTERRELATION BETWEEN THE HYDRODYNAMICS OF STEAM-WATER MIXTURES, THE TEMPERATURE DISTRIBUTION IN A METAL AND THE DEPOSITION OF EASILY SOLUBLE SALTS IN HORIZONTAL STEAM-GENERATING PIPES, AERE-Lib/Trans.499, Translated from: Izvest. Akad. Nauk S.S.S.R. Otdel, Tekh. Nauk, 432-40 (1953).

Several series of experiments have been performed in a closed circulating system including heated vertical and horizontal portions of steam-generating pipes of various diameters. It was found that deposition of NaCl and Na_2SO_4 took place in the horizontal parts of boiler pipes when the temperatures of the upper part of the pipe wall were higher than those of the lower part. The probability of the occurrence of deposition increases with pressure.

INTERFACIAL SHEAR STRESSES

2446. Ellis, S. R. M. and Gay, B.

THE PARALLEL FLOW OF TWO FLUID STREAMS: INTERFACIAL SHEAR AND FLUID-FLUID INTERACTION, Trans. Instn. Chem. Engrs. (London) 37, 206 (1959).

For flow of air past H_2O in a horizontal, rectangular channel, friction coeffs. at the wall (ϕ_w) and at the surface (ϕ_s) are related to air flow Reynolds No. (Re_g) by: $\phi_w = 0.804\ (Re_g)^{-0.285}$ and $\phi_s = 0.374\ (Re_g)^{-0.111}\ (y_0/h)^{0.0362}$, y_0 is the roughness characteristic and h is the gas phase thickness. Location along the channel is not a significant variable.

2447. Gazley, Carl, Jr.

INTERFACIAL SHEAR AND STABILITY IN TWO PHASE FLOW, PhD Thesis, Univ. of Delaware (1948) 213 p.

The present investigation deals with the air-water interface existing in the stratified flow of the two phases through a horizontal two-inch pipe. Experimental tests were made with water flowing under stationary air, air flowing over stationary water, and the co-current flow of both phases. Measurements of the air pressure drop, the liquid depth, the interfacial gradient, and the gas-phase velocity distribution made possible a rather accurate estimation of the frictional energy lost by each phase at the pipe wall and the energy lost by the gas and gained by the liquids at the common interface.

2448. Gazley, Carl, Jr.

CO-CURRENT GAS LIQUID FLOW. III. INTERFACIAL SHEAR AND STABILITY, ASME, Proc. of Heat Transfer and Fluid Mechanics Inst., June 22-24, 1949, pp. 29-40.

In order to evaluate the energy losses, energy transfers, and exchange phenomena at a fluid-fluid interface, the data previously reported for horizontal stratified flow are used to evaluate interfacial shear and stability. In the case of a smooth interface, the energy lost by the gas at this surface is almost identical with that which would be lost at a smooth solid wall, and is transmitted without loss to the liquid phase. In the case of interfacial waves, the interface exhibits the characteristics of a rough solid surface and there is some energy dissipated at the interface.

Comparison of the present data with those obtained in absorption columns and at air-sea interfaces indicates that at the point of interfacial instability the energy losses and transfer rates at the interface increase sharply. The data for co-current air-water flow in horizontal and vertical tubes and for counter-current flow in packed columns indicate that the formation of interfacial waves is essentially dependent only upon the liquid depth and the relative velocity of the two fluid streams. The effect of liquid depth is slight, and a relative velocity in the range of 10 to 15 ft/sec is required for the formation of waves.

2449. Lilleleht, L. U. and Hanratty, T. J.

MEASUREMENT OF INTERFACIAL STRUCTURE FOR CO-CURRENT AIR-WATER FLOW, Jour. of Fluid Mech. 11, 65-81 (1961).

Method for measuring interfacial structure using absorption of light is described; measurements of rms displacement and frequency spectrum are presented; use of Gaussian model to describe interface is explored.

2450. Lilleleht, L. U. and Hanratty, T. J.

RELATION OF INTERFACIAL SHEAR STRESS TO THE WAVE HEIGHT FOR CONCURRENT AIR-WATER FLOW, AIChE Jour. 7, 548-550 (1961).

Waves at an interface between a concurrent air-water flow cause an increase in the interfacial stress. This increase in stress is correlated with the root-mean-square displacement of the liquid from its average height. The data are compared with Nikuradse's measurements with sand roughness.

JETS (SEE NOZZLES)

LOCAL DENSITY (SEE DENSITY STUDIES)

LIQUID METALS

2451. Avery, G.

EFFECT OF SURFACE ROUGHNESS ON THE BOILING OF MERCURY, M.S. Thesis in Chem. Eng., Columbia Univ. (1960).

2452. Balzhiser, R. E., et al.

LITERATURE SURVEY ON LIQUID METAL BOILING, Final Report-Phase I (1961), ASD-TR-61-594, 157 p.

A survey was made of information pertaining to the current status of liquid-metal-boiling technology. Material pertaining to boiling and two-phase-flow phenomena are also included, and existing correlations for predicting heat transfer coefficients in the nucleate- and film-boiling regimes are summarized. Correlations which predict the critical heat flux (or burnout flux) are presented and compared with experimental data available. The use of liquid metals as fluids in space-oriented Rankin cycles is considered, and interfacial considerations of possible importance are cited and discussed. Particular attention is called to the solid-liquid interfacial energy and its importance in limiting heat transfer across the interface. A summary of physical properties for various liquid metals and water is presented along with 1191 references to books, reports, journals, and theses published from approximately 1930 to 1961.

2453. Balzhiser, R. E., et al.

INVESTIGATION OF LIQUID METAL BOILING HEAT TRANSFER, Quarterly Progress Report, No. 1, AD-270678 (Jan. 1962).

An analytical and experimental study relating to the boiling of liquid metals was initiated. The program will include pool boiling studies of K, Na, and Rb at temperatures up to 2200°F. Hg will be pool boiled at temperatures near its normal boiling point as a preliminary step in studying the effect of radial accelerations up to 20 times normal gravity on the boiling process. A forced circulation loop is being designed to determine the effect of velocity and quality on the heat transfer process. Two-phase flow studies will also be made with this equipment.

2454. Balzhiser, R. E., et al.

INVESTIGATION OF LIQUID METAL BOILING HEAT TRANSFER, AD 275147 (Apr. 1962).

Progress is reported in modification and finalization of equipment design. Equipment specifications are near completion for each phase of the experimental program. K will be boiled in a forced circulation loop where quality and flow rate effects on the heat transfer coefficient will be studied. Pressure drop and void fraction measurements will be made in a second test section to learn more about two phase flow behavior with metallic fluids. A pool boiler will be used to study pressure effects and to increase the temperature and flux levels beyond the 1800°F and 10^6 Btu/hr-ft^2 anticipated in the loop. Film boiling of K will be studied using condensing Na or Li as a heat source. A Nb vessel will be used thus making it possible to increase the range of surface temperatures. Initial agravic experiments will utilize mercury pool boiling from a stainless surface with normal accelerations up to 20 g's. Fabrication of equipment is expected to begin during the next quarter. (NSA-62-33119)

2455. Bonilla, C. P., et al.

BOILING AND CONDENSING OF LIQUID METALS, NYO-3147 (1951), 8 p.

An apparatus has been constructed for study of the boiling of mercury from a horizontal plate up to 300,000 Btu/ft^2/hr. Another apparatus is partially constructed for study of the condensation of mercury vapor on a vertical tube at high heat fluxes. A third apparatus is partially constructed for the comparison of electrical and thermal contact resistances. Preliminary values for thermoelectric potential of the thermocouple mercury-iron have been obtained.

2456. Bonilla, C. F., et al.

BOILING AND CONDENSING OF LIQUID METALS, Progress Report, NYO-3148 (1952), 12 p.

Preliminary data have been obtained on the boiling at atmospheric pressure of a shallow layer of Hg on a horizontal iron-plated surface. The boiling film coefficient of heat transfer, h, ranged from 1600 to 8400 Btu/hr x ft^2 x °F. No film boiling was observed although a heat flow rate of 260,000 Btu/hr x ft^2 was reached. Hg vapor at atmospheric pressure was condensed on a short water-cooled vertical iron tube. Dropwise condensation was obtained, but seemed to impair the heat transfer, if anything, on account of the adherence of the droplets to the surface. Droplets ranged from 1 mm in diameter down to dust, and at intervals a slide would occur of all of the droplets on a given area. The condensing film heat transfer coefficients were very low, ranging from 220 to 530 Btu/hr x ft^2 x °F. They were apparently adversely affected by a mercury oxide film that built

up on the surface, and/or by traces of noncondensable gas. More reliable data on the thermoelectric force of the thermocouple Fe-Hg have been obtained, which are approximately 10% higher than the previous results. The millivolts of a couple with its cold junction at 0°C and hot junction at t°C is given, up to about 400°C, by $E = 0.01939\ t - 8.834 \times 10^{-6} t^2 - 9.675 \times 10^{-9} t^3$.

2457. Bonilla, C. F.

POOL-BOILING HEAT TRANSFER WITH MERCURY, LIQUID METALS TECH. PT 1, CEP SYMPOSIUM SERIES, 1957 (ALSO REACTOR HEAT TRANSFER CONFERENCE OF 1956 (PT 1)(P.324)(Also NYO-7638), TID-7529.

Hg was boiled on a horizontal low carbon steel plate at absolute pressures from 4 mm to 45 lb/in., liquid depths of 2 to 10 cm, heat velocities of 4,000 to 200,000 Btu/hr-ft^2, and with and without wetting-agent additions. The nature of the boiling and the necessary temperature differential were observed. 13 references.

2458. Brooks, R. D.

ALKALI METALS BOILING AND CONDENSING INVESTIGATIONS, Presented at 2nd Annual Meeting Liquid Metal Heat Transfer Technology (May 17, 1962).

The investigation of alkali metal boiling and condensing, sponsored by NASA at General Electric, is now nearing the completion of the first period of work. Preliminary results have been obtained in this program for forced convection for boiling and condensing in single tubes with potassium. Pool boiling data has been obtained in research sponsored at Columbia University as part of this program. Three forced convection experiments have been put into operation with heat transfer capabilities from 50 - 300 kw at the test sections.

To date, a 1600°F stainless steel system has been operated to provide condensing data and instrumentation development. Over 2000 hours of operation have been accumulated for heat transfer purposes. A 300 kw test, constructed of L-605, has been operated at temperatures up to 1850°F and has accumulated, to date, over 700 hours of operation for heat transfer data purposes. Boiling and condensing data have been obtained in this test as well as liquid phase heat transfer coefficients for sodium in an annulus. The 100 kw test, constructed of Cd-1Zr, has recently been put into operation and will be operated at temperatures up to 2200°F. The purpose of this paper is to report on the characteristics of the experimental systems and to review the data being obtained.

2459. Camack, W. G. and Forster, H. K.

TEST OF A HEAT TRANSFER CORRELATION FOR BOILING LIQUID METALS, Jet Propulsion 27, 1104 (Oct. 1957).

2460. Cappel, H. H.

RADIAL TEMPERATURE PROFILE OF SODIUM POOL BOILING HEATER ASSEMBLY, NAA-SR-MEMO-4914, February 1960.

The radial temperature around a sodium reactor heater assembly submerged in water is calculated using a model of the heater cross section found by conformal mapping. Thermocouple readings were also analyzed. When the heat flux is 5×10^5 Btu/hr-ft^2, a radial temperature drop of about 680°C across the center of the thermocouple well is calculated and found to be within 6% of the experimental value. Since most of this drop is across the 0.001-in. helium gap between the heater and its sleeve, it is concluded that the thermocouple will have to be bonded to the sleeve for dependable reading of true sleeve temperature. Drawings of the heater assembly and thermocouple are given.

2461. Cernak, E. A.

BOILING HEAT TRANSFER OF LIQUID METALS. A LITERATURE SEARCH, CNLM-1802-16 (1960), 3 p.

It is a partially annotated bibliography containing references on boiling heat transfer of liquid metals. Emphasis is placed on boiling of sodium, liquid potassium, and liquid rubidium. The period covered is 1950 to October 3, 1960. References are arranged alphabetically by title. Sources used in compiling this bibliography are: Abstracts of Classified Reports and Nuclear Science Abstracts. A total of 16 references are collected.

2462. Chelemer, H.

EFFECT OF GAS ENTRAINMENT ON THE HEAT TRANSFER CHARACTERISTICS OF MERCURY UNDER TURBULENT FLOW CONDITIONS, ORO-139 (1955), 169 p.

Experimental heat transfer data were obtained under wetting and non-wetting conditions for dilute sodium amalgam and pure mercury in turbulent flow inside steel tubes. Investigations were conducted with either of two horizontal test sections having inside diameters of $\frac{3}{8}$ inch and $\frac{3}{4}$ inch. Heat was supplied by passing currents through the wall of the tube resulting in nearly uniform heat fluxes. The fluid was delivered to the test sections by gravity flow from a head tank or by direct pumping. Visual studies of the flowing mercury were carried out using a glass tube in place of a test section. Gas entrainment, indicated by visible bubbles in the mercury, led to low heat transfer rates which were increased by increasing the static pressure. Suitable changes in the flow system resulted in a reduction of this entrainment effect and an increase in heat transfer performance. Operating under wetting conditions and at increased static pressures had no effect on heat transfer rates obtained with reduced entrainment. This behavior was explained by a consideration of the adverse effect of entrained gas bubbles on the thermal conductivity of the liquid. Methanol heat transfer tests were conducted in the system, the experimental results being in excellent agreement with predicted results. The experiments substantiated the accuracy of the operating and calculation procedures used and supported the validity of the mercury heat transfer results.

2463. Drew, T. B. and Hoopes, J. W., Jr.

ADVANCES IN CHEMICAL ENGINEERING, Academic Press, N. Y., V. 1, p. 52 (1956).

In paper on "Boiling of Liquids" Section C, Liquid Metals: Liquid metals have some desirable characteristics as heat transfer media. They have very low viscosities and high thermal conductivities. Thus circulation can be obtained with low power requirements, and temperature gradients through the liquid are rather flat. The high boiling points mean that liquid metals are usable at atmospheric pressure at high temperatures. Other liquids require pressure application if they are to be used at high temperatures. Data (L3) for four liquid metals are shown in Figures 26 and 27. The data of Farmer (F2) for mercury at vacuum are described as "preliminary" and may be subject to revision.

For the region of low ΔT (say below 25°F) the liquid metals give high values of h. For example at a ΔT of 10°F water gave h = 500 Btu/(hr)(ft^2). (F), mercury plus a wetting agent gave a 3000, and NaK gave an extrapolated h of about 20,000, all tested in the same equipment (L3).

Thus liquid metals in nucleate boiling are excellent heat transfer agents, being superior even to water. Water in turn is definitely superior to the other common nonmetallic liquids.

2464. Firman, E. C., Hawes, R I. and Sturge, D. W. G.

EXPERIENCE OBTAINED ON A LIQUID SODIUM HEAT TRANSFER RIG 1954/1956, AERE-RIR-2190 (August 1957), 31 p., (LMFT/P-19).

Heat transfer data for Na flowing at moderately low Reynolds number in a double annulus heat exchanger are reported. Addition of an inert gas to the flowing liquid produced a pronounced lowering of the heat transfer coefficient. After 1400 hours of operation, deposits, mainly of Na_2O, were found throughout the apparatus. General operating experience is described. An investigation was made of the metallurgical changes occurring in dynamic Na in a stainless steel system and the results are compared to static controls.

2465. Gambill, W. R. and Hoffman, H. W.

BOILING LIQUID-METAL HEAT TRANSFER, Paper No. 1737-61, Presented at "Space Nuclear Conf., May 3-5, 1961, Gatlinburg, Tennessee, N. Y. Am. Rocket Society" (May 3-5, 1961), 24 pp.

Nuclear reactors utilizing a boiling liquid metal as the heat carrier provide a method for satisfying the auxiliary-power requirements of a space vehicle at a minimum expenditure in weight. Fundamental heat-transfer data (in particular burnout limitations) needed for effective design are not available, and recourse must be made to estimations based on data for other fluids. Such predictions are evaluated as they apply to potassium and rubidium. It is concluded in view of the wide disparity in the calculated peak-heat-flux values, that no reliable correlation exists. An additive technique that presupposes the independence of the boiling and convective heat-transfer mechanisms suggests that burnout flux levels with the liquid metals could be equivalent to those for water. Experiments on the sub cooled boiling of water in swirl flow show that the peak heat flux is markedly increased over that attained with axial flow at the same pumping power. A similar advantage is indicated for potassium and rubidium. In a bulk-boiling system swirl flow should be particularly effective in maintaining a desirable wetted-wall condition. An experimental program for securing information on burnout fluxes with liquid metals is described.

2466. Greenwood, H. C.

THE INFLUENCE OF PRESSURE ON THE BOILING POINTS OF METALS, Proc. Roy. Soc. A83, 483-91 (1909-10).

B. P. of Bi, Pb, Zn, Ag, at several pressures.

2467. Greenwood, H. C.

THE BOILING POINTS OF METALS, Chem. News 104, p. 31-33, 42-45 (1912).

The app. was arranged so that the surface of the metal could be observed, and the temp. as detd. by a Wanner optical pyrometer, was recorded when vaporization became sufficiently vigorous to cause a projection of drops of metal from the surface. Under atm. pressure the b. ps. of metals which do not combine appreciably with C were Cu, 2310°; Sn, 2275°; Ag, 1955°; Pb, 1525°; Bi, 1440°; Sb, 1420°; and Mg, 1120°. In case of Mg the temp. was detd. by a protected thermocouple immersed in the metal. Metals which readily combine with C were boiled in long C crucibles lined with fused magnesia. The b.ps. of these metals were: Fe, 2450°; Cr, 2200°; Mn, 1900° and Al, 1800°. By placing the furnace in a suitable vacuum the b.ps. at 10 cm of Hg were: Cu, 2000°; Ag, 1660°; Pb, 1430°; Bi, 1200°. Under 26-7 cm of Hg the b.ps. were: Cu, 2200°; Sn, 2100°; Ag, 1790°; Pb, 1430°; Bi, 1310°. Detns. at pressures above atmospheric were made. At 7 atm. the b.p. of Pb is approx. 1880°; Bi, 1730°; Zn, 1120°. At 12 atm. the b.p. of Pb is 2100°; Bi, 1950°; Zn, 1210°. At 17 atm. Bi b. 2080°, and at a pressure of over 50 atm. Zn b. 1500°. By plotting the foregoing values together with those at atm. pressure, curves are traced showing the variations of b.p. under diminished and increased pressures. For the derivation of the latent heat of vaporization from the above experimental results, G. refers to his previous paper (C.A., 5, 2453).

2468. Jansen, G.

BOILING OF LIQUID METAL AMALGAMS. (Motion Picture), HW-61759, September 1959.

2469. Jansen, G.

BEHAVIOR OF A BOILING METAL THERMOSIPHON LOOP, HW-63052 (December, 1959), 34 p.

The boiling characteristics of the system lead-bismuth eutectic-mercury were studied in a one-inch ID quartz tube containing a two-foot column of metal. Uniform internal heat generation was simulated by induction heating. Temperatures of operation ranged from 360 to 550°C as the percentage mercury was

varied from 100 to 5%. Operation with a simple boiling tube resulted in violent surging and slugging of the vapor bubbles. Operation with liquid recirculation by thermosiphon action resulted in stable operation with steady boiling in only the top portion of the column. This type of operation was promoted by the high liquid density, which provided both a high driving force for liquid recirculation and a high static head boiling point rise with liquid depth. A maximum power input to mercury vaporization of 0.3 kw per foot of heated tube length was reached. Although this power input is an order of magnitude below the level desired in a reactor, calculations show that lowering of the resistance to flow in the thermosiphon loop may permit operation at the desired power level. Preliminary results showed that the freezing points for the system were above room temperature with attendant freezing problems.

2470. Johnson, J.

THE VAPOR PRESSURE AND VOLATILITY OF SEVERAL HIGH-BOILING METALS - A REVIEW, Ind. Eng. Chem. 9, 873 (1917).

Values given for metallic elements at various pressures.

2471. Kaufmann, A. R. and Schuhmann, R.

REACTOR COOLED BY BOILING METAL, TID 2504 (Del.)(p.245-6) (1953).

The possibility of cooling a liquid metal fuel alloy by boiling one metal out is discussed.

2472. Kutateladze, S. S., Borishanskii, V. M. and Novikov, I. I.

HEAT TRANSFER TO LIQUID METALS, Atomnaya energ. 4, 422-36 (1958).

A review is presented of basic research on heat exchange between solid surfaces and flowing liquid metals. Results are given from experiments with long or short tubes having flat apertures; on the longitudinal flow of molten metal over rod bundles or plates; on the transverse flow over cylinders; and on free convection and vapor condensation of liquid metals. Also, problems connected with liquid metal boiling and the effects of quenching on hydraulic resistance and heat exchange are discussed. Formulas for calculations of heat exchange are included. (NSA-12-13095)

2473. Leitgebel, W.

THE BOILING OF CERTAIN METALS AND ALLOYS AT ATMOSPHERIC PRESSURE: Z. Anorg. allgem. Chem. 202, p. 305-24 (1931).

The app. used was a pair of C crucibles, one inverted as a cover while the lower one served as a container for the metal. The whole was surrounded by a high-frequency coil. Openings were provided in the upper crucible for the Pt/Pt-Rh thermoelement, vents and a tube for gas admission. Procedure is outlined for the standardization of the thermoelement. At 760 mm the flowing b.ps. were observed: Cd 767 ± 2°; Zn, 907 ± 2°; Mg, 1097 ± 3°; Tl, 1457 ± 10°; Bi, 1560 ± 5°; Sb, 1635 ± 8°; Pb, 1740 ± 10°. A diagram of log p vs 1/T constructed from the several b.ps. of the literature gives a series of straight lines which when extrapolated to 1/T = 0 give a mean limiting value of 4.6 atm, in accord with the Clausius-Clapeyron equation with the assumption of Trouton's const. as 21. The exptl. results range from 4.12 to 5.12; the variation is explained by variation of Trouton's const. with temp. B.p. curves are given for the following alloys: Al-Mg, Al-Zn, Bi-Fb, Bi-Sb, Cd-Pb, Cd-Mg, Cd-Zn, Cu-Zn, Mg-Sb, Mg-Zn, Pb-Sb, Pb-Tl, Pb-Zn, Sb-Zn. A max. is found in Bi-Sb and in Pb-Sb. The b. p. rise in the systems studied seems to be greater the smaller the at. wt. of the metal added. A ternary diagram is given for the system Cd-Pb-Zn. The rise in b.p. of Cd on addn. of Pb. and Zn is very slight; the curve follows that for the Pb-Zn system until about 70% Pb has been added, when a sharp rise occurs.

2474. Lin, Chi-Fang, et al.

BOILING HEAT TRANSFER COEFFICIENTS OF LIQUID METALS. Hua Kung Hsueh Pao No. 2, 102-12 (1958).

A single-tube evaporator was designed for investigating heat-transfer coeffs. of liquid metals in either a horizontal or a vertical position. The heating element, the evaporating vessel, and the condenser were made of stainless steel. The liquid metals employed were Hg and amalgams contg. various amts. of Mg and Na. The boiling heat-transfer coeffs. were detd. under pressures of 1-11 atm. (abs.), heat flux (q) of 5000-47,000 kcal/sq m/hr/°C, and boiling temps. of 356-524°. For Hg the following relation was obtained: 1 atm. (abs.), $\alpha = 4850q^{-0.26}$; 4-11 atm.: $\alpha = Aq^{0.46}$, where A is a const. Similar results were obtained for amalgams. Expts. were carried out under N atm.

2475. Lin, C., et al.

BOILING HEAT TRANSFER OF LIQUID METALS, JPRS-3512 (1959), 4 p.

Experiments were conducted on boiling mercury and magnesium under various pressures. Pure mercury under standard pressure gives the film type of boiling. The experimental value is greater than Bromley's theoretical heat-transfer value of the film type. Pure mercury boiling under pressure gives nuclear-boiling characteristics, but the effect of pressure on thermal coefficient is opposite to that of ordinary liquids. The addition of a small quantity of magnesium improves the permeability and also the heat transfer efficiency. The change of pressure does not affect greatly the heat transfer of the Mg-Hg system.

2476. Lin' Tszi-Fan, Yan Yu-tsi, Kun Fan'go

THE HEAT EMISSION COEFFICIENTS AT THE BOILING OF LIQUID METALS, Chem. Ind. and Engng., No. 2, pp. 147-152 (Chinese, English summary)(1959).

The heat emission was investigated at the boiling of mercury and magnesium- and sodium amalgams in separate vertical and horizontal pipes of stainless steel in a nitrogen atmosphere. The experiments were conducted at p = 1-11 atm abs. pressure, boiling point 356-524°C, Pr 0.0098 - 0.0077 and thermal loads q 5,000 - 47,000 kcal/m^2 hr. The equations for

rating the heat emission coefficient α in kcal/m^2 hr°C were obtained: $\alpha = 4{,}850\ q^{-0.26}$ for p = 1 atm abs; $\alpha = 8.0\ q^{0.46}p^{-0.29}$ for p = 4-11 atm abs.

2477. Lin'Tszi-Fan, Yan Yu-tsi, Sin Guy-Chen', Van Tszya-syan, Kun'Fan'go

THE HEAT EMISSION AT THE BOILING OF LIQUID METALS, Tr. Dal'ninskogo politekhn. in-ta, No. 8, pp. 67-77 (1959).

Results are presented from experiments on the investigation of heat emission at the boiling of mercury and mercuric amalgams in horizontal and vertical pipes. The thermal load and the pressure varied within the following limits: q = (5-47) 10^3kcal/m^{2}hr, P = 1-11 atm abs. The results of experiments with mercury are represented by the equation: $\alpha = Aq^{0.463}$, where α is the heat emission coefficient, A is a constant; the numerical values of A are presented for the pressure range studied. A considerable increase in heat emission was stated after addition of Mg to Hg. The experimental data for mercury amalgams are represented by the equation: $\alpha = Aq^n$, where A = 13.7, n = 0.425 at P = 1 atm abs. and A = 0.564, n = 0.750 at P = 3-11 atm abs. for the case of addition of 0.02% Mg. For 0.05% Mg A = 2.43 and n = 0.634 at P = 1 atm abs.

2478. Ling Chi-fang, Yang Yu-ch'i, Kun Fan'-go, Sin Guy-chen', Van Tszya-syan

HEAT EMISSION OF LIQUID METALS DURING BOILING, Scientia, pp. 832-833 (1959).

Experiments were made to investigate heat emission during boiling of pure Hg and Hg containing Mg at different pressures. The experiments were carried out under the following conditions: heat load q = 5,000 - 47,000 kcal/m^2 hour; pressure p = 1-11 abs. atm; boiling point t_k = 355.9 - 524°C; Pr number = 0.0098 - 0.0077. The experiments yielded the following results: 1) pure Hg at conventional pressure shows an envelope shape of boiling. The value of the heat emission coefficient α obtained by experimental means, is much higher than the value obtained by the theoretical formula of heat emission, in particular by the Bromley formula, which is not applicable to calculations at low values of the Pr number. 2) At a higher pressure, Hg boiling shows a globular shape; however, the effect of pressure on the coefficient of heat emission is opposite to that in conventional melts; α decreases at a pressure increased within the 4-11 atm range. 3) Addition of a small amount of Mg to Hg increases the effect of the heat emission; as a result α increases. It increases also at a higher amount of Mg added. At a Mg content of 0.05% the nature of Hg boiling approaches that of melts with conventional properties.

2479. Loshkin, A. N. and Krol', P. I.

CHARACTERISTICS OF MERCURY BOILING IN THE TUBES OF A MERCURY VAPOR GENERATOR, Translated from Zhur. Tekh. Fiz. 8, 1872-81, NDA-28 (1938), 26 p.

2480. Loshkin, A. N. and Izraelit, I. G.

INCREASING HEAT EXCHANGE BETWEEN A WALL AND BOILING MERCURY, ZhTF Journal of Technical Physics, 9, No. 24 (1939).

2481. Lyon, R. E.

EXPERIMENTAL BOILING RATES FOR LIQUID METALS, Ph.D. Thesis, U. of Mich., 95 pp (1953).

2482. Lyon, R. E., Foust, A. S. and Katz, D. L.

BOILING HEAT TRANSFER WITH LIQUID METALS, Chem. Eng. Prog., Sym. Series, No. 17, 51, 41-47 (1955).

Boiling heat transfer coefficients were measured for mercury, mercury plus 0.1% sodium, and mercury 0.02% magnesium and trace of titanium, sodium, sodium-potassium alloy, and cadmium at temperatures from 670 to 1,600°F and atmospheric pressure. The temperature differences were measured by thermocouples in the tube wall and in the bulk of the boiling liquid. The highest coefficients were for sodium and sodium-potassium alloys - up to 15,000 Btu/(hr)(°F)(sq ft). The combination of low coefficients with pure mercury and high coefficients with addition agents are interpreted as film and nucleate boiling, respectively. It follows that film boiling may be more the result of nonwetting characteristics of the surface than of heat flux or quantity of vapor evolved.

2483. Madsen, N. and Bonilla, C. F.

HEAT TRANSFER TO SODIUM-POTASSIUM ALLOY IN POOL BOILING, Chem. Eng. Prog. Sym. Ser. 56, No. 30, 251-9 (1960).

Film coefficients are presented for sodium-potassium-alloy (44 wt.% K) boiling on a horizontal surface.

The heat transfer at the boiling surface was calculated by subtracting the heat loss to the surroundings from the electrical input to the heater. Temperatures in the boiling liquid and the vapor space above it were also determined. The best temperature differential for computing the heat transfer coefficients was found to be the difference between the boiling surface temperature and the equilibrium boiling point of the sodium-potassium at the pressure of the vapor space. A correlating equation was derived statistically for heat velocity as a function of pressure and temperature differential.

2484. Mausteller, J. W.

LIQUID METAL BOILING SYSTEMS, Paper given at NASA-AEC Liquid-Metals Corrosion Meeting, NASA-TN-D-769(p. 83-6), Dec. 7-8, 1960, Washington, D. C.

Potassium was manufactured by reacting KCl with sodium in a stainless steel column packed with Raschig rings. Columns were not replaced because of corrosion but because of thermal fatigue. Sodium was evaporated under reduced pressures using a NaK heating loop. Operation totaled 650 hour with sodium vapor velocities up to 3000 ft/sec through the nozzle. No corrosion or erosion was visually evident in the nozzle. Oxygen effects were considered in an

oscillating-flow, isothermal sodium system at 925°F, holding oxygen to 0.003, 0.005, and 0.010 wt %. Nitriding was investigated in a number of sodium systems at temperatures to 1300°F. Stainless steels were used to hold liquid lithium and lithium-salt mixtures at 2000°F for days and sodium-salt mixtures for months at 1600 to 1800°F with no drastic failures.

2485. Mehringer, F. J.

DESIGN, FABRICATION, AND PERFORMANCE OF THE DUPLEX HEAT TRANSFER TUBE, KAPL 1797 (1956), 60 p.

The heat transfer characteristics and stress levels in duplex tubes for heat exchangers are interdependent. This summary assembles into a single report the various studies of the heat transfer characteristics and stress analyses that have been made. The heat transfer characteristics discussed are those for boiling water, liquid metal, and metal to metal contact. Analyses have also been made of the fabricating and operating stresses. As a result, recommendations have been made regarding material properties, tolerances, and surface conditions of the tubular components, fabricating procedures, and operating precautions. Where areas of uncertainty still exist, tests have been recommended. This information is significant to the Submarine Intermediate Reactor Test Steam Generator Program, since this steam generator is to have duplex heat exchanger tubes. 24 references.

2486. Nicholson, R. B.

SODIUM BOILING CALCULATIONS, AECU-3698 (1957), 7 p.

The equations are derived for making rough calculations of the pressure drop required to produce a given mass flow through a subassembly for a given heat generation for cases where the vapor volume fraction is 0.9 or less. The ratio of vapor velocity to liquid velocity is left as a parameter that is varied from unreasonably low to unreasonably high values. (NSA-12-10532)

2487. Nowinski, Tadeusz

THE PHYSICAL INTERACTION BETWEEN LIQUID PHASES OF METAL AND WATER, Referativnyy zhurnal, Elektrotekhnika i energetika, No. 5, 1962, 39, abstract 5 G317. (Ochrona pracy, v. 16, No. 7, 1961, 8-14. (Polish with summaries in Russian and English)).

There is a risk of explosion when liquid metal comes into contact with water or wet materials, or even when the liquid metal is separated from the water by a heat conducting wall which is insufficiently strong or does not make a good enough seal. Because of its high thermal conductivity and because it can be heated to a high temperature without the rise of pressure, liquid metal is used as a heat transfer medium when large quantities of heat must be removed rapidly as in some kinds of nuclear reactors and for cooling gas turbine blades The explosive effect is due to the heat stored in the liquid metal and to a number of physical factors which were studied on a special experimental rig. The following tests were made: liquid metal dropping from a crucible; a jet of liquid metal striking water; liquid metal immersed in water; liquid metal solidifying on the bottom of a water tank; explosions of differing intensities. A total of 880 tests was made with aluminum alloy and a few with magnesium alloy. Explosions occur when liquid metal at a temperature of 700-900°C penetrates to the bottom of a tank with the depth of water less than 25 cm and temperature below 50°C. Of importance is the relationship between the rate of flow of the liquid metal particles and the size of the hole through which the metal pours, as also is the height of the hole above the water surface. The special concept of 'kinematic defect of mass concentration' is introduced. A protective layer of oil or of bituminous base paint on the bottom and walls of the tank protects against the formation of a steam cushion which promotes explosion. 7 figures, 5 literature references.

2488. Noyes, R. C.

AN EXPERIMENTAL STUDY OF SODIUM POOL BOILING HEAT TRANSFER, NAA-Sr-6769 (1962), 37 p.

A saturated Na pool boiling experiment is described in which the test section was a horizontal, $\frac{3}{8}$-in.-diameter, electrically heated cylinder. Measurements of surface temperature and heat flux during nucleate boiling were made at pool temperature between 1200 and 1500°F and at heat fluxes up to 800,000 Btu/hr-ft^2. Burnout heat flux measurements were made at pool pressures between 0.5 and 1.5 psia. Empirical correlation of the nucleate boiling data showed heat transfer coefficients somewhat higher than previous predictions. A new nondimensional burnout correlation is derived which brings the Na measurements into agreement with published burnout values for water and various organics. This correlation predicts a burnout heat flux for Na pool boiling of 1.9×10^6 Btu/hr-ft^2 at one atmosphere, and it is recommended for burnout predictions for Na and other wetting liquid metals at pressures which are low relative to their critical pressure.

2489. Pierce, R. D., et al.

HEAT TRANSFER AND FLUID DYNAMICS IN MERCURY WATER SPRAY COLUMNS, BNL-2433 (1955).

Heat transfer and fluid dynamics were studied in columns spraying hot mercury into rising streams of water. Volumetric and area heat transfer coefficients are presented. These coefficients are lower than those reported for heat transfer from fixed spheres. The major flow of water bypassed the drops while water surrounding the drops flowed downward. The principal heat transfer resistance appears to lie between these rising and falling water streams. Outlet mercury temperature did not approach inlet water temperature as a limit because the flow patterns caused a discontinuous rise in the water temperature at the bottom of the column.

2490. Romie, F. E., et al.

HEAT TRANSFER TO BOILING MERCURY, J. Heat. Trans. 82, 387-88 (November 1960).

An experiment on heat transfer to boiling mercury flowing by natural circulation through a tube was carried out in conjunction with evaluation studies of a nuclear reactor cooled by boiling mercury. The objective of the experiment was limited to demonstrating that very high heat fluxes could be sustained by boiling mercury. Despite this limited objective, sufficient measurements were made to permit estimation of quality and density of the two-phase mixture leaving the test section. The maximum heat flux attained in the experiments was 600,000 Btu/hr-ft^2; higher fluxes were prevented by equipment limitations rather than by transition from the nucleate boiling regime. The maximum flux previously reported (1)[2] is 200,000 Btu/hr-ft^2.

2491. Styrikovich, M. A. and Semenovker, L. E.

SOME RELATIONSHIPS IN HEAT TRANSFER TO BOILING MERCURY IN FORCED CONVECTION, Translated for Atomics International from Zhur Tekh Fiz. 10, 1331-9, AEC-tr-3868 (1940).

The heat transfer to boiling Hg was studied in forced convection flow.

2492. Teitel, R. J.

BOILING POTASSIUM IN A COLUMBIUM-1% ZIRCONIUM CONTAINER AT 2000-2200°F, Trans. Am. Nuclear Soc., 4, No. 1, 91-2 (1961).

2493. Tidball, R. A., Mangold, F. L. and Tower, S. N.

REPORT NO. 1 ON 1000 KW SYSTEM, Memorandum Report No. 49, NP-5872 (1953), 14 p.

The 1000-Kw heat transfer system was designed to test pilot plant size liquid metal system components at temperatures to 1400°F. The test program was divided into phases: transferring heat to air and transferring heat to boiling water. Two liquid metal systems to prevent exposing the tubes of the liquid metal heater to full steam pressure in event of a failure of the stream generating equipment were used. The air cooled system is shown schematically. The NaK was circulated by a rotary magnet pump, through a flow meter into the NaK heater. The discharge from the heater was piped to the tube side of the intermediate heat exchanger, and returned to the pump. Sodium was circulated by a DC conduction pump, through the flow meter, the shell side of the intermediate heat exchanger, a swing check valve to the sodium cooler. Discharge of the sodium cooler passed through a stop valve, an a-c conduction pump to the suction of the d-c pump. The sodium was cooled by an air blast over finned tubes. Both NaK and sodium systems were fitted with diffusion type cold traps, expansion tanks, and emergency dump tanks. The sodium piping was fitted with tubular heaters (strapped to the outer surface) to preheat the piping before charging. Tests of the major components of this unit at various loads and temperatures are reported.

2494. Timchuck, B. J.

STUDY OF HEAT EXCHANGE IN LIQUID METALS DURING PHASE TRANSFORMATION, Inzh. Fiz. Zh. No. 11 (1959).

2495. Whitman, M. J. and Stockton, D. L.

BOILING RUBIDIUM AS A REACTOR COOLANT. PREPARATION OF RUBIDIUM METAL, PHYSICAL AND THERMODYNAMIC PROPERTIES, AND COMPATIBILITY WITH INCONEL, CF-55-6-49 (Pt. 1) (1954), 144 p.

Rubidium metal was investigated as a possible heat-transfer medium for an aircraft reactor. The separation of rubidium from other alkali metals by ion exchange was demonstrated. Data are presented on the physical and thermodynamic properties of rubidium and corrosive effects on Inconel at elevated temperatures. It was concluded on the basis of empirical formulas that more heat can be transferred in a boiling rubidium system than in a comparable boiling water system.

2496. Atomic Energy Commission

HEAT TRANSFER, Reports from Session XII, General Information Meeting, October 24, 25, 26, 1949, Oak Ridge, Tennessee, TID-278 (DEL.)(1957), 53 p.

Papers are presented on heat transfer with boiling, heat transfer to liquid metals, transient heat transfer effects resulting from supercriticality heat transfer coefficients for Bi alloys, and heat transfer and pressure drop through graphite ball columns.

NOZZLES, ORIFICES, APERTURES, ETC.

2497. Bailey, J. F.

METASTABLE FLOW OF SATURATED WATER, Trans. Am. Soc. Mech. Engrs. 73, 1109 (1951).

Nature of flow of saturated and nearly saturated water into regions where pressure is less than saturation pressure; method of computing mass rate of flow through orifices and nozzles based on rate of evaporation from metastable liquid core into surrounding ring of vapor; flow rates for orifices are predicted accurately, and rates for nozzles within 10%.

2498. Bauer, L. and Strasberg, M.

THE SOUND OF AIR BUBBLES RELEASED FROM NOZZLES, AD 17861 (1953).

2499. Benjamin, M. W. and Miller, J. G.

THE FLOW OF SATURATED WATER THROUGH THROTTLING ORIFICES, Trans. Am. Soc. Mech. Engrs., 63, 419-429 (1941).

Results of tests to determine flow characteristics for saturated water and for various mixtures of saturated water and steam through sharp edged thin plate orifices; investigation intended to determine feasibility of using throttling orifices alone or in combination with float operated drainers for regulating draining of condensate from feedwater heaters; design of orifice to be used in series with trap.

2500. Bottomley, H. T.

FLOW OF BOILING WATER THROUGH ORIFICES AND PIPES, Transactions of the North East Coast Institution of Engineers and Shipbuilders, 53, 65-100 (1936-1937).

Theory is developed and test data are reported. Tests on orifices show that the coefficient of discharge can be several times greater than unity because of surface tension lowering of vaporization pressure. Practical applications of pipe-flow data are suggested.

2501. Burneli, J. G.

FLOW OF BOILING WATER THROUGH NOZZLES, ORIFICES AND PIPES, Journal of the Institution of Engineers, Australia, 18, 41-9, E.I. 1946, 428 (March 1946); 172-3 (July-August, 1946).

Review of mathematical and experimental work published on subject including presentation of new data; development of formula for discharge through nozzles; for flow in pipes, experiments give greater discharge than thermodynamic theory; due to different velocities of water and steam in flashing mixture; charts and tables included.

2502. Chisholm, D.

THE FLOW OF STEAM-WATER MIXTURES THROUGH SHARP-EDGE ORIFICES, Eng. and Boiler House Rev., 73, 252-256 (Aug. 1958).

From theoretical consideration, parameters are developed which correlate data for flow of steam/water mixtures; equations are obtained which readily permit, by calculation, prediction of flow under such conditions within plus or minus 10% of measured values.

2503. Fiedler, R. A.

SHOCK LOCATION DURING TWO-PHASE FLOW IN AN OVEREXPANDED NOZZLE, M.S. Thesis, Mech. Eng., UCRL-6676 (1961).

An investigation was made of the location of compression zones occurring during the overexpansion of low quality steam-water flow through a converging-diverging nozzle. The compression zone locations were found to be dependent upon the rate of mixture expansion, which was determined by the chamber pressure and mixture quality. For a fixed quality, the compression zone moved downstream with increasing chamber pressure. For a fixed chamber pressure, the compression zone moved downstream with decreasing quality. The phase change during the expansion was calculated from an isentropic homogeneous equilibrium flow model, and the area occupied by the vapor phase was calculated from a two-phase momentum exchange model. It was concluded that the compression zones were formed by a pressure shock initiated by the overexpanded vapor phase being smeared out by the accompanying liquid drops that were not immediately affected by the vapor shock.

2504. Gavalas, G.

THEORETICAL INVESTIGATION OF FLOW THROUGH AN APERTURE SOLUTION OF THE TWO PHASE COMPRESSIBLE FLOW BY THE "HODOGRAPH TRANSFORMATION," Nuclear Reactor Containment Bimonthly Report No. 8, TID-14189 (October 1961), 15 p.

It was found that treatment of a two-phase mixture of liquid water and steam as a compressible fluid is possible provided the following assumptions are made: the mixture is homogeneous; the flow is isentropic; and the flow is two-dimensional, steady, and irrotational. A description of the problem in the Hodograph plane is presented along with a discussion of its applicability. Calculations of mass and momentum flow rates are presented. Treatment of metastable flows is discussed.

2505. Gavalas, George

TWO-PHASE FLOW THROUGH AN APERTURE, M. S. Thesis Dept. of Chem. Eng., Univ. of Minn., TID-15975 (1962).

In the outflow of saturated water through a two-dimensional opening (an aperture), the amount of vapor formed within the flashing fluid as the pressure drops is unknown. Use may be made of the analyses for the incompressible ideal flow in the case of no vaporization. For the other extreme of equilibrium between the liquid and vapor phases, a method was developed to treat the two-phase mixture as a compressible fluid, and with the help of the Hodograph Transformation specific results are presented. Finally, a growing bubble model was developed to approximate mixtures which exhibit an incomplete approach to equilibirum.

2506. Green, L., Jr.

EXPERIMENTAL STUDIES ON HEAT TRANSFER AND FLUID-FLOW SYSTEMS, Part 2 of Quart. Prog. Rpt. No. 1, AGC-AF-25, June 22 through Sept. 30, 1956, 38 p.

High temperature strength properties of graphite are being investigated. Studies on heat transfer in porous graphite and nozzle flow behavior are reported.

2507. Griffin, E. and Crong, E.

STEAM FLOW IN NOZZLES, Engineering, 160, No. 4159, 255, Sept. 28, 1945.

2508. Griffin, E. and Crang, T. F.

STEAM FLOW IN NOZZLES: VELOCITY COEFFICIENTS AT LOW SPEED, Proc. Inst. of Mech. Eng., 155, 83-89, 1946.

A considerable amount of controversy was raised by one aspect of the results reported by the Steam Nozzles Research Committee of the Institution over the years 1923-30. This was concerned with the variation of the velocity coefficient of a steam nozzle at low steam speeds, the Committee's results showing a tendency to higher values of coefficient at very low speeds. The work described in the present paper was undertaken to provide additional experimental

evidence on this point and, in order to be comparable with that of the Committee, was carried out on apparatus employing the same general principles, but embodying certain improvements in detail.

The impulse plate method was used in determining the steam velocity at the exit from the test nozzle. The apparatus was designed on a small scale for use with a small self-contained steam generating unit, and particular care was accordingly given to accuracy in all the necessary measurements. The design eliminated frictional effects in the determination of force on the impulse plate, and tests could be carried out with wet steam as well as superheated.

Two series of tests were made, one with steam superheated after expansion and the other with expansion into the supersaturated region. The exit velocity varied from about 500 to 1,200 ft per sec, the final pressure being nominally atmospheric in all cases. The results showed that the velocity coefficient decreased continuously from the maximum to the minimum steam velocity, and that the values of the coefficient were substantially the same for the two series at corresponding speeds. This result is not in agreement with the Steam Nozzles Research Committee's work, but confirms the conclusions of other investigators in this field.

2509. Hesson, J. C.

FLOW OF TWO-PHASE CARBON DIOXIDE THROUGH ORIFICES, Ph.D. Thesis, I.I.T., 159 pp. (1957).

2510. Hesson, J. C. and Peck, R. E.

FLOW OF TWO-PHASE CO_2 THROUGH ORIFICES, A.I.Ch.E. Journal, 4, 207-210 (1958).

Experimental flow rate data are presented for saturated liquid, saturated vapor, and two-phase liquid-vapor carbon dioxide through a convergent nozzle and a square-edged orifice. The data cover the range from the triple-point pressure to the critical pressure. Charts have been prepared for this complete range at critical flow. Results are also presented for subcritical flow.

The tests at various back pressures indicate that the saturated liquid behaved as a cold liquid without evaporation ahead of the throat.

Saturated vapor became supersaturated in the nozzle, and the vapor behaved as if no condensation occurred.

Equations are presented for the flow rates of saturated vapor, and two-phase mixtures in the critical flow region.

A Mollier (pressure-enthalpy) diagram is used to determine the flow rates of saturated vapor and two-phase mixtures where supersaturation takes place. In these cases, the lines of constant specific volume or density are extrapolated from the superheated region into the normal two-phase region to obtain values corrected for supersaturation.

2511. Hodkinson, B.

THE FLOW OF HOT WATER THROUGH A NOZZLE, Engineering 143, 629-630 (1937).

Attempt is made to extend A. Rateau's calculations over much wider range of steam conditions and of attaining greater accuracy, by making allowances for fact that at most usual steam temperatures density of water is appreciably less than unity; experiments conducted with water not boiling, but just ready to boil.

2512. Isbin, H. S. and Gavalas, G. R.

TWO PHASE FLOW THROUGH AN APERTURE, Proceedings of the 1962 Heat Transfer and Fluid Mechanics Institute, held at Univ. of Washington, Seattle, June 1962, Stanford Univ. Press, June 1962, Dept. Chem. Eng., Univ. of Minnesota, Minneapolis 14, Minn.

The design of nuclear reactor containment systems is based upon the energy release rates postulated for given classes of reactor accidents. One condition involves the outflow of water from a break in the reactor vessel containing saturated water. Analytical solutions are available for the flow of one-phase, incompressible and compressible ideal fluids through a two-dimensional aperture, and approximate solutions have been developed for the three-dimensional openings. Some related experimental investigations of the flow of two-phase mixtures and the flow of saturated water through openings are available, but the results are not sufficient to develop the necessary criteria and working models for the more general problem. The purpose of this paper is to present the results of calculations made for models approximating the flow of steam-water mixtures through apertures. Conditions for the evaluations range from the flow described as a single phase, steady, plane, irrotational and incompressible flow to a homogeneous non-equilibrium, plane, steady and irrotational mixture flow.

2513. Kliegel, J. R.

ONE DIMENSIONAL FLOW OF A GAS-PARTICLE SYSTEM, Space Technology Laboratories, Inc., Los Angeles, Calif., January 29, 1960.

The author examines the one-dimensional flow of a gas-particle system and presents a family of solutions to the equations governing these flows. If the particles do not undergo a phase change (solidification), then the solutions for the one-dimensional flow of a perfect gas are identical to the above family of solutions provided that a suitably modified Mach number and specific heat ratio are chosen. It is shown that these solutions correspond to flow in a nozzle in which the axial velocity gradient is constant. The design of a nozzle for use with a gas-particle exhaust is discussed and the nozzle throat region is shown to be the critical region in the design of such a nozzle. It is further shown that the nozzle throat conditions depend on the particle kinetic and thermal lags at the throat and hence on the nozzle inlet geometry. Relationships between the nozzle throat geometry and the particle lags in the throat region are given for both two-dimensional and axially symmetrical nozzles. It is shown that the one-dimensional

scaling laws for perfect gas nozzles and gas-particle nozzles are different. On a one-dimensional basis, two gas-particle nozzles are similar if they are the same length and have the same area ratio variation with length.

2514. Lord Rayleigh

ON THE INSTABILITY OF JETS, Proc. Lond. Math. Soc., 10 (1878) pp. 4-13.

2515. Maneely, D. J.

A STUDY OF THE EXPANSION PROCESS OF LOW-QUALITY STEAM THROUGH A deLAVEL NOZZLE (thesis), UCRL-6230 (Jan. 25, 1962) 66 p.

Three flow models are proposed in connection with a process of a very low quality steam-water mixture. These models are: an isentropic homogeneous equilibrium model, a slip flow model, and a frozen composition model. The models were compared to experimental data and it was found that isentropic homogeneous equilibrium model predicts the weight flow to within 15% for qualities above 10%. The proposed flow models were also used to predict other standard performance characteristics such as specific impulse and thrust coefficient. It was apparent from the studies that the phenomenon of slip flow and non-equilibrium may both be influencing the flow.

2516. Mellanby, A. L. and Kerr, W.

THE SUPERSATURATED CONDITION AS SHOWN BY NOZZLE FLOW, Proc. Inst. Mech. Engrs. 2, part 2, 855-883 (1922).

Gives flow curves for simple convergent-type nozzles in order to demonstrate clearly discharge effect, and to show degree of support afforded application of theoretical conception to nozzles, by actual experimental results.

2517. Neusen, K. F.

OPTIMIZING OF FLOW PARAMETERS FOR THE EXPANSION OF VERY LOW-QUALITY STEAM (thesis). (California, Univ. Livermore, Lawrence Radiation Lab.), UCRL-6152 (Jan. 25, 1962), 53 p.

An experimental investigation was made to determine design criteria for the expansion of very low quality steam through a convergent-divergent nozzle. To effect an optimum expansion where the nozzle pressure reaches ambient at the nozzle exit, an empirical relation was found between the initial steam quality and the nozzle geometry. The experimental data were compared to a simple homogeneous theory which assumes that the velocity of the liquid phase equals the velocity of the vapor phase throughout the nozzle. Calculated results from this theory are in surprisingly good agreement with the experimental results down to initial steam quality of 5%. A related problem, that of choosing a proper throat diameter for a nozzle expanding a 2-phase fluid is also discussed. The experimental mass flow data enable calculation of throat sizes for any nozzle using steam in this region of qualities.

2518. Rettaliatta, J. T.

UNDERCOOLING IN STEAM NOZZLES, Trans. Am. Soc. Mech. Eng. 58, 599-605 (1936).

Effect of wall roughness on flow of steam in nozzles; drop growth; occurrence of initial condensation.

2519. Richard, L. P.

THE EFFECT OF AN INITIALLY LARGE INTERNAL TEMPERATURE DIFFERENCE, AND OF CONDENSIBILITY OF THE GAS ON THE EXIT VELOCITY FOR TWO-PHASE FLOW OF A LIQUID AND A GAS THROUGH A NOZZLE, August 1959, M.S. Thesis in M.E., Purdue University, JPC.

2520. Saunders, O. A. and Calder, P. H.

HEAT TRANSFER IN NOZZLE AT SUPERSONIC SPEEDS, Engineering, 174, No. 4518, pp. 281-4 (1952).

In first series of experiments local heat transfer coefficient was measured along divergent section of convergent divergent nozzle in order to give well defined condition of flow at throat; hot combustion gases at some 865 C were used and nozzle was water cooled; analysis of results; illustrations.

2521. Siemes, W. and Kaufman, J. F.

PERIODIC GENERATION OF BUBBLES IN NOZZLES, Chemical Engineering Science, 5, 127-139 (1956)(in German).

The volumes of gas bubbles, generated at small gas velocities on vertical circular nozzles in liquids, were measured by using a stroboscope. Variables investigated were: gas velocity, liquid density, surface tension and viscosity, and diameter and wall thickness of the nozzles. It was found that the formation of gas bubbles in liquids of high and low viscosity occurs according to two different mechanisms. For the two ranges of viscosity two empirical equations were developed for calculating the volumes of the gas bubbles. Nozzle diameters varied between 0.35 to 1.95 mm, the liquid density between 0.7 to 1.8 g/cm^3, surface tension between 28 to 73 dyn/cm, and viscosity between 0.4 to 800 cP. The volume of the bubbles were determined from the measured rate of air flow and the stroboscopically determined number of bubbles. Experimental equipment for insuring reproductible and consistent conditions is described in detail. Periodic bubble formation occurred at a flow rate of a few cm^3/sec; at a flow rate of 10 to 100 cm^3/sec the continuous gas stream entered the liquid and then broke up into drops of various sizes (AMR, 1958, #2341).

2522. Silver, R. S. and Mitchell, J. A.

DISCHARGE OF SATURATED WATER THROUGH NOZZLES, Trans. Northeast Coast Institution of Engineers and Shipbuilders, 62, 51-72, D15-30, 1945-46.

Quantitative account of rate of vapor formation is required in order to give true estimate of flow conditions, and how they are affected by nozzle dimensions; theory proposed in which it is assumed that cylindrical stream of liquid emerges, remaining in

superheated metastable state, without formation of bubbles, evaporation occurring at its surface; concepts developed permit calculation of rate of evaporation.

2523. Silver, R. S.

TEMPERATURE AND PRESSURE PHENOMENON IN THE FLOW OF SATURATED LIQUID, Proc. Royal Soc., Series A, 194, 464 (1948).

Expts. on water and steam are reported. A theory for the amt. of vapor that will form is given. An analysis is given of the effect of the vapor on the flow of fluid through a nozzle. There is a corresponding crit. pressure analogous to that for a gas nozzle. The theory is confirmed in detail by the expts. Phenomena to be expected in pressure propagation through liquids near satn. temp. are discussed.

2524. Spialter, M. L.

CHARACTERISTICS OF TWO-PHASE FLOW THROUGH A VERTICAL VENTURI, New York University, Ph.D. Thesis (1952).

An experimental study was made to determine the flow characteristics of various fluids passing through a vertically mounted venturi. The fluids ranged in complexity from a single liquid (water) to a multi-component system made up of a mixture of liquids containing dissolved and entrained gases (water-isopropyl alcohol-nitrogen).

Most of the experimental work was done with water-nitrogen mixtures. Because of the relative insolubility of nitrogen in water this is the simplest of the two-phase fluids dealt with. The liquid phase is water alone, while the gas phase is composed of the entrained gases, nitrogen and water vapor. The flow characteristics in terms of measurable quantities of pressures and flow rates are established. Various dimensionless quantities and factors used by other investigators in related work are calculated from the experimental results.

The flow characteristics for the more complex fluid mixture of water, isopropyl alcohol, and nitrogen are found to be similar to those of the simpler fluids. Because the solubility of nitrogen has a measurable effect on the vapor pressure of an isopropyl alcohol solution, the liquid phase for such a mixture is composed of the alcohol solution and the dissolved nitrogen. The gas phase contains the entrained gases of nitrogen and vapors of the alcohol solution.

The phenomenon of cavitation was observed to occur in the venturi which was made of lucrite. The characteristics for flow under cavitating conditions differ from those of normal flow. The graphs of the calculated data depict these differences. Photographs of cavitating flow are included to help describe its physical appearance.

Application of the knowledge gained is made to the problem of predicting the performance of a centrifugal pump handling any liquid based on its performance with any other liquid. The NPSH technique is used, and the experimental results bear out the validity of using this criterion.

2525. Straub, L. G. and Silberman, E.

AIR-WATER MIXTURE FLOW THROUGH ORIFICES, BENDS, AND OTHER FITTINGS IN A HORIZONTAL PIPE, Project Report No. 63, St. Anthony Falls Hydraulic Laboratory, Univ. of Minnesota (1960).

2526. Tangren, R. F., Dodge, C. H. and Seifert, H. S.

COMPRESSIBILITY EFFECTS IN TWO-PHASE FLOW, J. Applied Physics, 20, 637-45 (1949).

A gas-water mixture, when expanded through a de Laval nozzle, acts as a compressible fluid. A general expression for the flow process in an idealized mixture is developed. The general thermohydrodynamic relations for flow through a de Laval nozzle are developed. The magnitude of the velocity of an energy pulse or signal through the mixture is determined and is compared with the velocity of flow. Experimental results are compared with those predicted using the equation developed.

2527. Weber, C.

DISINTEGRATION OF A LIQUID JET. Zeitschrift für Angewandte Mathematik und Mechanik. 11, 136-54 (1931) In German.

2528. Wegener, P. P.

WATER VAPOR CONDENSATION PROCESS IN SUPERSONIC NOZZLES, J. Appl. Phys. 25, 1485-91 (1954).

The history of experimental and theoretical investigations of water vapour condensation phenomena in supersonic nozzles is reviewed. It is then shown empirically for a given experiment that the shocklike disturbance visible in flow pictures delineates the collapse of the supercooled state of the water vapour present in the air. All flow properties are calculated through this extended condensation zone from pressure distribution measurements, and it is seen that no shock waves are involved in the process. Finally a conversion of these data to an equivalent constant-area flow reveals that the latter would be an example of a weak detonation observed in nature as predicted by Burgers and by Reed.

2529. Wegener, P. P. and Mack, L. M.

COMMENTS ON "CONDENSATION IN NOZZLES," J. Appl. Phys., 30, 1624 (1959)

Attention is drawn to an extensive literature on condensation in rocket and wind-tunnel nozzles, which should be used in any extension of the work of Wilde (Abstr. 6838 of 1959).

2530. Wilde, K. A.

CONDENSATION IN NOZZLES, J. App. Phys., 30, 577-580 (1959).

The extent of realization of vapour-liquid phase equilibrium in nozzles was investigated as a function of initial particle size, kinetic parameters, and nozzle dimensions. It was shown that condensation will occur on already present particles only for very small sizes and/or large nozzles 20-30 in. or more in diameter. The present rather rudimentary state

of knowledge of spontaneous nucleation does not enable any reliable evaluation of condensation by this mechanism.

ORGANIC FLUIDS

2531. Becraft, L. G.

BOILING HEAT TRANSFER CHARACTERISTICS OF SEVERAL ORGANIC LIQUIDS, Ph.D. Thesis Montana State College (1962), 72 p.

2532. Bochirol, L., et al.

USE OF ELECTRICAL FIELDS FOR IMPROVING HEAT EXCHANGE IN BOILING LIQUIDS, Comm. Energie At. (France), Rappt. No. 1857 (1961), 26 p.

The effect of application of elec. fields on the heat transfer coeffs. and on the crit. heat flux corresponding to the change from nucleate to film boiling of various liquids was studied. The liquids were hexane, C_6H_6, PhMe, trichlorethylene, acetone, EtCOMe, and demineralized H_2O. Mechanisms are given to explain the improvements found both for the natural convection zone in terms of the dielec. properties of the liquids and the zone of nucleate boiling in terms of forces acting on boiling nuclei. Some exptl. results are given concerning measurements made under pressure until local boiling occurred.

2533. Borishanskii, V. M.

HEAT TRANSFER DURING BOILING, Dostzheniya i Zadachi v Proizvodstve i Primenenii Kholoda v Narodnom Khozyaistve, pp. 39-46 (1960).

Investigations were made of heat transfer, and a theoretical generalization of the experimental results during film and bubble boiling is presented. The experimental studies of heat transfer during film boiling were carried out using ethyl alcohol, isooctane, octane, benzene, and ethyl ether on heatable graphite and steel surfaces at a rate of heat load $q = (250\text{-}900)\cdot 10^3$ kcal/m^2hr. Two zones were found to exist in the course of the heat-transfer coefficient α as a function of q: the transition zone and that of fixed film boiling. In the transition zone, α decreased with increasing q. In the zone of fixed film boiling, the heat transfer increased with increasing q. Here the pressure effect on α was identical at all values of q. The self-simulating nature of the kinematics of the vapor bubble motion relative to the linear dimension of the heated surface was determined by following the process photographically by means of high-speed motion pictures. A generalization of the experimental results based on the extended concept of the thermodynamic similarity of substances on the saturation line curve was given for the heat transfer during developed bubble boiling. Treatment of experimental data was done in a generalized thermodynamic coordinate system. It was shown that the experimental data lie along a curve with a maximum deviation of ±30%. The generalized dependence formulated allows calculation of the heat transfer on the basis of a single experimental α value together with the critical pressure of the substance in question. The complex character of the pressure effect on the intensity of heat transfer and the impossibility of its representation by a power function with a constant exponent is pointed out.

2534. Breen, B. P. and Westwater, J. W.

EFFECT OF DIAMETER OF HORIZONTAL TUBES ON FILM BOILING HEAT TRANSFER, Chem. Eng. Progr. 58, No. 7, 67-72 (1962).

Heat transfer from a horizontal, steam-heated, stainless steel tube (9 different outside diameters, 0.185-1.895 in.) to boiling Freon-113 (118°F) and iso-PrOH (180°F) was measured. From these data and other data in the literature for 8 other liquids (including O, H_2O, He, and pentane), a general relation $h(\lambda_c)^{1/4}/F = 0.59 + 0.069\ \lambda_c/D$ is found, where h is the heat transfer coeff., λ_c is a wave length corresponding to the smallest wave which can grow in amplitude on a flat horizontal interface and is related to surface tension and liquid and vapor ds., D is diam. of cylinder, and F is a factor of phys. consts. including heat of vaporization, thermal cond. of vapor, etc. This relation is applicable to a wider range of diams. (λ_c/D = 0.1-300) than the Bromley equation (CA 44, 5654a), $hD^{1/4}/F = 0.62$, (λ_c/D = 0.8-8). The new relation shows that h is independent of D for large D. It is suggested that for $\lambda_c/D < 0.8$, use $h(\lambda_c)^{1/4}/F = 0.60$, for λ_c/D between 0.8 and 8, use the Bromley equation, and for $\lambda_c/D > 8$, use $h(\lambda_c)^{1/4}/F = 0.16\ (\lambda_c/D)^{0.83}$. (CA-62-12280d)

2535. Cheng, P. T.

HEAT TRANSFER TO BOILING HYDROCARBONS BY NATURAL CIRCULATION IN VERTICAL TUBES, Ph.D. Thesis, University of Delaware (1951), 127 p.

2536. Chernobylskii, I. I. and Ratiani, G.

EXPERIMENTAL INVESTIGATION OF THE COEFFICIENT OF HEAT TRANSFER IN BOILING LARGE VOLUMES OF FREON-12, Khol. Tekh. 32, No. 3, 48-51 (1955).

Freon-12 (I) was compressed and evapd. in an exptl. unit which basically simulates the working mechanism of a refrigerator; the tube where the evapn. of I occurred could be exchanged. In the expts. were used Cu and steel tubes of either smooth or corrugated surfaces. The results of the expts. are presented in the form of graphs; it can be clearly seen that the coeff. of heat emission α is a function of the current of heat energy input q; the curves always consist of 2 parts, the function $\alpha = f(q)$ is different below and above q = 1800 kcal/(sq m x hr x °C).

2537. Colburn, A. P., et al.

EFFECT OF LOCAL BOILING AND AIR ENTRAINMENT ON TEMPERATURES OF LIQUID-COOLED CYLINDERS, NACA-TN-1498 (1948), 75 p.

A bench-rig app. is described which approximates engine-jacket conditions, except that the liquid flow was uniform around the cylinder so that results could be related to the literature on forced-convection heat transfer. Coolant-film coeffs. for H_2O and CH_3OH are correlated as dimensionless parameters (j-factors) as a function of Reynolds no. When the wall-coolant interface temp. is below the b.p. of the

coolant under existing pressures, data are in close agreement with the well-known equations for heat transfer in round pipes and in annular spaces. When the interface temp. is above the coolant b.p., local boiling effects are observed. At low liquid velocities, heat-transfer rates increase with increasing temp. excess of the wall over the coolant b.p. Entrained air also increases the heat-transfer coeffs. Effect of coolant pressure is to increase the b.p. and so decrease the temp. excess. (CA-42-4403g)

2538. Danilova, G. and Mazyukevich, I.

A STUDY OF THE BOILING PROCESS OF CERTAIN REFRIGERANTS, Kholodil'naya Tekh. 31, No. 2, 62-5 (1954).

The boiling process of NH_3 and Freon-12 was studied in a vertical steel tube boiler-condenser app., the diagram of which is given. It was shown that the sites of boiling are more numerous in case of the Freon than in the case of NH_3. Consequently the curve of heat transfer during boiling against heat loading lies higher for NH_3 than for Freon (curves are shown). For Freon-12 with heat loading from 2500 to 11,000 kcal/sq m hr the following relations hold: $\Delta t = 0.294 \times q^{0.3}$ and $\alpha = 3.4 \times q^{0.7}$; for NH_3 in the range of 4000-24,000 kcal/ sq m hr these are: $\Delta t = 4.54 \times 10^{-3} q^{0.7}$ and $\alpha = 220\ q^{0.3}$(cf. Robinson and Katz, C. A. 45,6436h).

2539. Danilova, G. N. and Bel'skii, V. K.

EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER IN BOILING FREON 22, Kholodil'n Tekhn. 39, No. 1, 7-13 (1962).

Boiling of Freon 22 on Ni and brass tubes was studied exptl. At low heat fluxes, corresponding to undeveloped nucleate boiling, $\alpha = 54.5\ q^{0.25}$ and $65\ q^{0.25}$ kcal/ sq m hr °C for the Ni and brass tubes, resp., where q is the heat flux (kcal/sq m hr). At high heat fluxes, $\alpha = 2.4\ q^{0.75}$ and $6.3\ q^{0.7}$, resp., hysteresis of the α vs. q curves is observed. Heat transfer is correlated by $Nu = 0.25 \times 10^{-2} Re^{0.75} Pr^{0.35} K_p^{0.65}$ for the Ni, and $Nu = 0.46 \times 10^{-2} Re^{0.7} Pr^{0.35} K_p^{0.65}$ for the brass tubes, where $K_p = p/\sqrt{\sigma(\gamma' - \gamma'')}$, p is pressure, σ surface tension, and γ d. The heat-transfer coeff. is 2.5-3.5 times as high as for water. This is due to the considerably smaller diam. of the Freon bubbles, hence the larger no. of bubble nuclei and higher d. of bubble detachment. Differences between heat transfer from Ni and brass tubes are attributed to the higher surface roughness of the latter. (CA-62-12279b)

2540. Dodd, C.

RADIO CARBON CONTENT OF DELAYED BOILING OF LIQUIDS, Proc. Phys. Soc., Vol. 68B, 686-9 (1955).

An investigation on the influence of radioactive sources on the time delay occurring before a superheated liquid boils. With the help of a 3 cm^3 bubble chamber filled alternatively with diethyl-ether and pentane (no mention whether normal or iso-pentane) it has been found that: (a) ionization from external sources reduces the delay time; (b) owing to the presence of C^{14}, normal diethyl-ether has a delay time shorter than diethyl-ether free from C^{14}. Numerical values of the dependence of delay time on ionization and temperature are given.

2541. Dunskus, T. and Westwater, J. W.

THE EFFECT OF TRACE ADDITIVES ON THE HEAT TRANSFER TO BOILING ISOPROPANOL, Chem. Eng. Prog. Symp. Series No. 32, 57, 173-81, Am. Inst. of Chem. Engrs. - Heat Transfer, Buffalo (1960), 210 p.

A study was made of the effect of eleven organic substances of high molecular weight on the heat transfer to boiling isopropanol in the nucleate, transition, and film-boiling regimes. The liquid was boiled at atmospheric pressure on a horizontal, steam-heated, $\frac{1}{4}$ in. copper tube. The temperature of the tube was determined by using the tube itself as a resistance thermometer. The maximum concentration of the additives was about 0.5 wt %. High-speed motion pictures of the boiling process were taken in all three regions of boiling. The peak heat flux of the solutions exceeded that exhibited by pure isopropanol by as much as 60%, and the critical temperature difference was raised also. The nucleate-boiling curve was moved towards higher values of the temperature difference at the wall, and the transition region was also extended in this direction at a given heat flux. The frequency of bubble release in the nucleate region at low heat fluxes for some of the solutions was up to three times greater than the corresponding value for the pure solvent. The various anomalies may be explained as being caused by a surface viscosity resulting from an increase in concentration of the solute at the interface due to evaporation of solvent.

2542. Fastovskii, V. G., Artym, R. I. and Rovinskii, A. E.

BOILING OF FREON-11, METHYLENE CHLORIDE AND BENZENE IN A HORIZONTAL TUBE, Teploenergetika 52, No. 2, 77-80 (1958).

CCl_3F, CH_2Cl_2, and C_6H_6 were boiled in a steel cylinder 170 mm diam. and 280 mm long. The liquid was heated electrically by a submerged, horizontal tube, 200 mm long, 8 mm in diam., 0.3 mm wall thickness, made of German silver. The heat fluxes used were detd. by measuring the power input to the heating element. The temps. were measured with copper-constantan thermocouples. At atm. pressure the crit. heat fluxes (values at which the heating tube burned out) in kcal/sq m hr for C_6H_6, CH_2Cl_2, and CCl_3F were, resp., 217,000,216,300, and 103,600; the crit. values of the coeffs. of heat transfer in kcal/sq m hr-degree were, resp., 7690, 9185, and 5790, and the crit. temp. differences, were, resp., 28.3, 23.6, and 17.80.

2543. Foltz, H. L. and Murray, R. G.

HEAT TRANSFER RATES TO BOILING FREON 114 IN VERTICAL COPPER TUBES, Preprint 23, Sec. Nat. Heat Trans. Conf. AIChE-ASME Chicago, Ill. Aug. 18-21, 1958, Symposium Ser. 29, 79-86 (1959).

The prediction of heat flux along the length of a tube boiler is a problem particularly in the design of high-efficiency gas coolers in which heat is transferred from the gas to a boiling liquid. Heat-transfer rates from condensing steam to boiling Freon 114 were measured in vertical copper tubes of 7/8-, 1/2-, and 1/4-in. diam. to determine where

the assumption of uniform heat flux could be safely used and how tube length, tube diameter, flow rates pressure, and temperature difference affected uniformity. Heat transfer rates were uniform along the length of the tube up to a temperature difference of 20°F; above this temperature difference 12.5% of the area transferred up to 75% of the total heat. The Freon pressure had no significant effect on the heat flux-temperature difference relationship. A 100% increase in the Freon flow rate resulted in a 20 to 30% increase in the maximum heat transferred. No relationship between heat flux and the ratio of tube length to tube diameter was found.

2544. Halfen, F.

FLOW STABILITY LOOP NUCLEATE BOILING HEAT TRANSFER WITH ORGANIC COOLANT, NAA-SR-Memo-6942 (1961) 8 p.

Nucleate boiling heat transfer experiments were conducted using the flow stability loop. The test section and instrumentation were the same as used in previous forced convection experiments with this loop. The organic coolant, isopropyl diphenyl, was used. Results were compared with the nucleate boiling heat transfer model used in FUGUE, Levy's generalized boiling heat transfer equation. An experimental correlation coefficient, B_L, was determined as a function of pressure. Excellent agreement was obtained between the experimental temperature differences and the values calculated with the Levy equation using the experimental correlation coefficient. The following ranges of variables were studied: heat flux, 40,000 to 100,000 Btu/hr ft^2; coolant velocity, 7 to 13 ft/sec; outlet pressure, 20 to 35 psia; wall superheat, 38 to 54°F; and coolant subcooling, 0 to 20°F. In all cases the experimental and calculated wall superheat temperatures agreed within 3°F.

2545. Huber, D. A. and Kortenhoeven, J.

SUMMARY OF EXTENDED BOILING TEST NO. 5 WITH IRRADIATED OMRE COOLANT, NAA-SR-Memo-4075 (1959) 7 p.

Studies were performed to demonstrate the feasibility of operating organic-cooled reactors for extended periods of time with irradiated organic coolant, under conditions of sub-cooled, nucleate boiling heat transfer at the fuel element surface.

2546. Insinger, T. H., Jr. and Bliss, H.

TRANSMISSION OF HEAT TO BOILING LIQUIDS, Trans. Amer. Inst. Chem. Engr., 36, 491-516 (1940).

Previous investigations; apparatus designed and operated with particular attention to accuracy of temperature and heat flow measurements; individual heat transfer coefficients from vertical chromium plated tube to boiling liquids determined for water, aqueous solutions of wetting agent and of sugar, carbon tetrachloride and isopropanol at atmospheric pressure and water at pressures below atmospheric.

2547. Jordan, D. P. and Leppert, G.

NUCLEATE BOILING CHARACTERISTICS OF ORGANIC REACTOR COOLANTS, Nuclear Science and Engineering 5, 349-59 (1959).

Experimental measurements are reported for nucleate boiling of various saturated liquid polyphenyls which are of interest as nuclear reactor coolants. Heat flux is presented as a function of the difference between the heater surface temperature and saturation temperature, and correlations by various semitheoretical methods are discussed. A peak heat flux is reported for all but one of the liquids tested, and good agreement is found with previous work with similar fluids. Methods are suggested which may be used to estimate the nucleate boiling characteristics of these liquids during forced convection at elevated pressures and liquid subcooling, even though the present tests include only pool boiling studies. These methods may be used in feasibility analyses of boiling-polyphenyl cooled and moderated reactors.

2548. Katz, D. L., et al.

BOILING AND CONDENSING FILM COEFFICIENTS FOR WATER AND NORMAL HEXANE, Petroleum Refiner 25, 419-22 (Sept. 1946).

Experimental atmospheric boiling and condensity film coefficients are presented for water and normal hexane; inside film coefficients for condensing steam are also given; temperature variations around and along boiling and condensing tubes are illustrated; heat transfer.

2549. Kurihara, H. M. and Myers, J. E.

THE EFFECTS OF SUPERHEAT AND SURFACE ROUGHNESS ON BOILING COEFFICIENTS, AIChE Journal 6, 83-91 (1960).

The effects of liquid superheat and surface roughness on boiling coeffs. were investigated in a series of expts. in which H_2O, acetone, n-hexane, CCl_4, and CS_2 were boiled on a flat plate. In addn. to the usual thermal measurements, the no. of active boiling centers was detd. whenever possible by visual means, and a quant. measure of surface roughness was made. The no. of active boiling centers on the plate increased with increasing surface roughness and the calcd. boiling coeffs. were proportional to the 1/3 power of the no. of bubble columns rising from the heated surface. An equation was derived relating boiling coeffs. to fluid properties and the active boiling centers on a surface. A 2nd equation, based on the theory of thermal fluctuations, was proposed to relate the no. of active boiling centers to the independent variables of surface-roughness and temp.-difference driving force. The limited data available follow this proposed relation. The results suggest a quant. method of relating the boiling coeff. to the character of the surface, which may explain the discrepancies observed in the slopes of the boiling curves reported in the literature and in the actual values reported for the boiling coeffs. measured on different surfaces. 29 references.

2550. Lavrova, V.

EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER TO BOILING FREON-12, Khol. Tekh 34, No. 3, 55-61 (1957).

A test loop for heat transfer studies is described. The test tubes were (a) 20.41 or (b) 23.92 mm. outer diam., working length about 240 mm.; heat was transferred to boiling Freon 12 on the outer surface by an elec. heater. At temps. between -5 and -25° and pressures between 1.3 and 2.7 atm. abs., the system had single phase natural convection conditions at the heating surface for transfer rates below 2000 kcal/sq m hr. Nucleate boiling began to be stable above this rate and always existed above 2500 kcal/sq m hr. The heat-transfer coeff. (α, kcal/sq m hr degree) is linear on a log-log plot with the heat transfer rate (q,kcal/sq m hr) as follows: α = 100 and 200 when q = 200 and 2500, respt., in the single phase natural convection region and α = 270 and 840 when q = 2000 and 10,000 resp., in the nucleate boiling region. q is also linear with Δt (Measured between tube wall and bulk liquid) on a log-log plot, as follows: q ranges from 200 to 2500 as Δt changes from 2 to 13° in the natural convection region and q varies from 2000 to 10,000 with Δt changing from 7.5 to 11° in the nucleate boiling region.

2551. Lukomskii, S. M.

HEAT TRANSFER IN BOILING, Bull. Acad. Sci. URSS Classe Sci. Tech, 1753-66 (1946).

The coeff. of heat transfer α and the heat flow $Q = \alpha\Delta t$, plotted against the temp. difference Δt between the heating surface and the boiling liquid, are max. at a crit. Δt_m corresponding to transition between bubble and film boiling, the fall of α and Q with further increasing Δt being due to a spheroidal condition of the boiling liquid. From available data, it is shown that in relative dimensionless coordinates Q/Q_m against $\Delta t/\Delta t_m$ (Q_m = max. Q at Δt_m), data for a series of various liquids (water, CO_2, $(CH_3)_2CHOH$, $n\text{-}C_4H_9OH$, $(CH_3)_2CH.\text{-}CH_2OH$) fit into one single curve with a spread of exptl. point not exceeding 10-20%. This permits rough detn. of Δt_m for any liquid from one measurement of Q at a given Δt preferably in the nonspheroidal region below Δt_m. Empirically, $Q_m = k.r^{0.8}d$, where Q_m is expressed in cal/sq m/hr, r = latent heat of vaporization in cal/kg, d = sp gr of the liquid at the satn. temp. in kg/cu m, k = a const. depending on the nature of the heating surface; for Cu, Cr-plated Cu, Fe, Al, and various liquids (water, MeOH, AcOEt, EtOH, CCl_4, n = C_7H_{16}, C_6H_6, etc) k = 4.2-8.2; approx. calcns. can be made with k = 5. (CA-41-3359b).

2552. Lukomskii, S. M. and Madorskaya, S. M.

HEAT TRANSFER TO BOILING ETHYL ALCOHOL INSIDE TUBES WITH NATURAL CIRCULATION, Izvest. Akad. Nauk SSSR, Otdel. Tekh. Nauk 1306-20 (1951).

Temp. difference, thermal flux, heat-transfer coeff., and pressure-temp. data are given for nucleate boiling inside tubes 22.5 and 30 mm in diam. at pressures from 1 atm. to crit. for 95% EtOH (tech. grade). Observations of Cichelli and Bonilla are qualitatively confirmed. The equation $h = (Ap)(q/A)^n$ is proposed where h is heat transfer coeff. in kcal/hr sq m, (Ap) is a constant dependent on pressure, (q/A) is thermal flux in kcal/hr sq m, p is pressure in atm., and n = 0.73-0.01 p. Paired values of Ap and p are: 2.2; 10, 10; 40, 20; 100, 27; 300, 33; 700, 40; 3000, 50; 50,000, 60. (CA-6195A).

2553. Morozov, V. G.

NEW EXPERIMENTAL DATA ON CRITICAL HEAT LOADS AT BOILING OF LIQUIDS ON A SUBMERGED HEATING SURFACE, Int. J. Heat Mass Transfer, 5 (661-666) (1962).

Results are presented of an experimental investigation of critical heat loads at boiling on a submerged heating surface, of ethanol, water and carbon tetrachloride. Values of the critical heat loads are determined, for ethanol, in the pressure range from 1 to 62·6 atm, and for water, from 1 to 36.5 atm. For carbon tetrachloride the value of q(cr-1) is defined at atmospheric pressure. Data of experiments are compared with those of other investigators and treated in the form of a critical dependence.

2554. Mostinskii, I. L. and Miropolskii, Z. L.

HEAT EXCHANGE DURING SURFACE BOILING OF WATER AND METHYL ALCOHOL IN A HORIZONTAL TUBE, Nauch. Doklady Vysshei Shkoly, Energet., No. 3, 157-64 (1958).

Results of studies of surface boiling heat transfer in the binary system H_2O-MeOH are expressed by the equation $\alpha_b = C\, q_b^{0.83}$, where α_b is the heat transfer coeff. in kg. cal/sq m hr degree at boiling and q_b is the heat flux in kg cal/sq m hr. A schematic drawing of the app. used is included.

2555. Nickelson, R. L. and Preckshot, G. W.

OBSERVATION ON BOILING CARBON TETRACHLORIDE FROM SURFACES, J Chem Eng Data 5, 310-15 (July 1960).

Experimental heat transfer measurements were made on the boiling of CCl_4 with the effects of absorbed or dissolved gases eliminated by fractionation of CCl_4. The surface roughness was held constant in an effort to study the effects of the chemical nature of the surface. The heat-transfer surfaces were 18-gage solid Cu, 20-gage solid Cu, Ag, and Au wires, and 18-gage Cu wires vapor-coated with Au, Ag, or Cu; and they were also used as resistance thermometers. The pressures for boiling CCl_4 were 0.5, 1, and 1.5 atm. Nonboiling natural convection heat transfer data were collected first, and then nucleate pool-boiling heat-transfer data were collected at ~50 % burnout. In the latter experiment, the boiling heat flux curves shifted with boiling time toward higher temperature excesses together with a slight tarnishing of the surfaces. For Au there was no shift and for Ag only a slight shift; but there was a very definite shift for Cu. The wire diameter appears to have no effect on nucleate boiling flux. Superheat data indicated that extraneous sources of

nuclei (gases and dust particles) were removed successfully. Nuclei count data are presented as a function of pressure excess.

2556. Pierre, B.

COEFFICIENT OF HEAT TRANSFER FOR BOILING FREON-12 IN HORIZONTAL TUBES, Heating and Air Treatment Engr. 19, 302-10 (Dec. 1956).

Report on tests conducted at Institution of Refrigeration Engineering, Stockholm, using ordinary compressor unit with oil separator fitted with bypass; derivation of formulas and their use in determining experimental values for heat transfer coefficient.

2557. Ratiani, G. V.

BOILING OF LARGE VOLUMES OF FREON-12 IN THE PRESENCE OF OIL IMPURITIES, Trudy. Inst. Energet. Akad. Nauk. Gruzin. SSR. 13, 155-62 (1960).

Expts. with Freon-12 contaminated with 3-58% machine oil SAG-1 (I) show that the coeff. of heat transfer (α) decreases with increased I concn., from 1175 at 3% to 315 kcal/sq m hr °C. at 58% I in the Freon. This decrease is attributed to preferential evapn. of the Freon from the boundary layers in contact with the heated surfaces, the enrichment of these layers in oil, and the resulting increase in the b.p. of these layers, with the creation of large temp. gradients between the wall and the boiling liquid. The formation of gas bubbles on the heated surface has a negligible effect on α; the main factor affecting the heat transfer is the free convection of the liquid. The exponent n in the equation $\alpha = cq^n$ where q is the heat flux to the system (in kcal/sq m hr), and c is a const., decreases sharply with increased I concn. in the Freon.

2558. Robinson, D. B. and Katz, D. L.

EFFECT OF VAPOR AGITATION ON BOILING COEFFICIENTS, Chem. Eng. Progr. 47, 317-24 (1951).

Boiling coeffs. were measured between the outside of 4 horizontal Cu tubes in a vertical row and boiling Freon 12. The effect of one tube on the heat transfer for another is reported for heat fluxes from 874 to 35,100 Btu/(hr)(sq ft). Vapor was injected below a single tube for a series of injection rates and boiling temp. differences. Boiling coeffs. for Freon 12 on Cu tubes ranged from 260 Btu/(hr)(sq ft)(F°) at a temp. difference of 7°F to 1600 at a temp. difference of 19.5°F. (CA-45-6436h).

2559. Seigel, L. G., Bryan, W. L. and Huppert, M. C.

HEAT TRANSFER RATES FOR REFRIGERANTS BOILING IN A HORIZONTAL TUBE EVAPORATOR, Heating, Piping and Air Conditioning, 21, 159-62 (Jan. 1949).

Variations in transfer rates for Freon-12; correlation between Freon and tube wall, weight flow of Freon, and surface area of evaporator; correlation enables accounting for effects of evaporator pressure, percentages of flash gas and L/D ratio; other results.

2560. Staley, C. F. and Baker, Merle

HEAT TRANSFER RATES BETWEEN HEATED TUBES AND BOILING REFRIGERANT, J. Am. Soc. Heating Refrigerating and Air-Conditioning Engrs. 1, 83-9 110, 112 (Apr. 1959).

Extensive data on Freon 22 are given.

2561. Sterman, L. S., et al.

INVESTIGATION OF HEAT TRANSFER DURING BOILING OF WATER AND ETHYL ALCOHOL IN PIPES, UCRL-TRANS 694, Translated from Fiz. Zhur., Akad Nauk Belorus SSR 2, No. 10, 40-5 (1959) 11 p.

An investigation is made of heat transfer to water boiling at a pressure of from 27 to ~90 atm. The process of steam formation takes place while the medium is being forced through a vertical pipe 16 mm. in diameter. In these same conditions experiments were conducted with boiling ethyl alcohol at a pressure of 2 atm. The investigation was carried out by boiling in a stainless steel pipe heated by an electric current. The thermal resistance of the wall of the pipe was determined by three different methods. The experimental data obtained are worked out in a generalized criterial relationship. Considerable data published in recent years by other investigators were also worked out in this relationship. It is shown that the generalized critical relationship obtained earlier satisfactorily describes heat exchange where there is directed movement of the medium.

2562. Styrikovich, M. A. and Polyakov, G. M.

THE CRITICAL THERMAL LOAD IN THE BOILING OF A LARGE VOLUME OF LIQUIDS, Translated from: Izvest. Akad. Nauk. SSSR, Otdel. Tekh. Nauk, 652-6, RAE-LIB-Trans-873 (1951)(AD-236634).

The crit. thermal load for different liquids was detd. in expts. under identical conditions of large liquid vols. and horizontal surfaces, which conditions give max. load. Values (in dcal/sq m -hr) at 1 atm. are: H_2O, 1,730,000; MeOH, 632,000; EtOH, 442,000; iso-PrOH, 403,000; C_6H_6, 412,000; EtOAc, 354,000; n-C_7H_{16}, 336,000.

2563. Van Stralen, S. J. D.

HEAT TRANSFER TO BOILING SKIM MILK, Neth. J. Sci. 4, 107-10 (1956).

The heat flux to boiling pasteurized skim milk was detd. by use of a Pt heating wire bolometer. Measurements showed the thermal cond. of the coagulated layer to be approx. 6×10^{-4} cal/sec/cm/degree at atm. pressure. At a pressure of 10 cm. Hg skim milk exhibited a higher heat-transfer coeff. and a higher max. of nucleate boiling than water.

2564. Wasserman, A. A., Erickson, A. J. and Mann, W. L.

A STUDY OF SURFACE BOILING HEAT TRANSFER TO FREON 113 (1952) 61 p.

Heat transfer in the range of nucleate and surface boiling for Freon 113 in a natural-circulation evaporator has been studied. The data have been

correlated in terms of rate of heat transfer, temperature difference (wall minus saturation), and fluid properties. The effect of surface conditions on boiling heat transfer is shown.

2565. Yoder, R. J. and Dodge, B. J.

HEAT TRANSFER COEFFICIENT OF BOILING FREON-12, Refrig. Eng. 60, 156-9, 192-6 (1952).

Calculated and exptl. data are given for average boiling film coefficient of Freon-12.

2566. Zieman, W. E. and Katz, D. L.

BOILING COEFFICIENTS FOR FINNED TUBES, Petroleum Refiner 26, No. 8, 78-82 (1947).

Overall coeffs. of heat transfer were measured for boiling iso-C_4H_{10} and n-C_6H_{14} outside horizontal tubes. The removal of steam condensate from the inside of the tube has a significant effect on heat transfer. A finned tube having 2-4 times the outside surface of a plain tube gave 1.4-2 times as much heat transfer per ft. length. (CA-44-4729i).

PHASE AND VELOCITY DISTRIBUTION

2567. Anderson, A. G.

THE DISTRIBUTION OF AIR IN SELF-AERATED FLOW IN A SMOOTH OPEN CHANNEL, AD-73408 (1955).

2568. Cowan, C., Jr.

TWO PHASE FLOW: ISOTHERMAL PRESSURE STUDIES AND A DEVICE FOR MAKING TEMPERATURE AND VELOCITY TRAVERSES, B. S. Thesis, Univ. of Delaware (1950).

2569. Donaldson, I. G.

THE TEMPERATURE, PRESSURE, AND VELOCITY DISTRIBUTION OF WATER, STEAM OR WATER, STEAM MIXTURE IN A HOMOGENEOUS PERMEABLE MEDIUM, Dept. of Science and Industrial Research, Lower Hutt, New Zealand, Report No. R-287.

2570. Dukler, A. E. and Wicks-III, M.

GAS-LIQUID FLOW IN CONDUITS, Being published in "Modern Chemical Engineering" - Editor, A. Acrivos, Reinhold Press, 1962.

This paper reviews past published data and correlations since 1950 on some macroscopic aspects of momentum transfer and phase distributions of two-phase flow. Observations are made of areas where additional research efforts are badly needed. A separate section discusses the heat and mass transfer processes of two-phase flow. Experimental data from over 100 references are tabulated (through IBM cards) and compared with published correlations.

2571. Novokhatskiy, Ye.M., Engineer

INFLUENCE OF THE TUBE DIAMETER ON THE STRUCTURE OF THE FLOW OF A BIPHASE LIQUID FLOWING IN VERTICAL TUBES, Izvestiya vysshikh uchebnykh zavedeniy. Energetika, no. 4, 93-97 (1961).

The article deals with results, obtained with the aid of an electrical method used for investigating the influence of the tube diameter on the structure of the flow of biphase liquid flowing in vertical tubes. It is stated to be the first time anyone has investigated the method to find quantitative relations and examine the influence of different factors on the structure of flow. Previous methods are mentioned such as: Visual observation photography and cinephotography, by which only the qualitative side of the complex structure of the flow of biphase liquids was investigated. The electrical method consists of comparing the capacity of a condenser filled with water to the capacity of the same condenser filled with biphase liquid. Using the density equation, the gas component of the biphase liquid was found. These condensers were embodied in the experimental part of the vertical tube. The consumption of biphase liquid was precisely measured. During the bullet-regime the relative distance between the bullets and also the diameter of the bubble-bullet was found by using a special method. Three experimental tubes with different diameters were used (69,52 and 24 mm). It is stressed that an equal amount of water was used during the different series of experiments, while the consumption of air was different and its distribution along the tube was taken down. Analyzing the experimental data the author concludes that: 1) The air-component of the biphase flow is greater in the center of the tube than in the layers next to the walls; this phenomenon is observed both in emulsive and bullet regime of the flow and confirms the theoretical results published by A. V. Kubratov (Ref. 5: Tr. MEI. no. 9, 1953). 2) The emulsive regime transfers into bullet-regime when $W_0''/W_0 = 1 \div 2$, where W_0'' is the relative velocity of air and that of water. This transition takes place gradually. In the beginning the flow pulsations start in the center of the tube and then propagate to the periphery. 3) In the tubes with large diameter the structure of the biphase flow is more homogeneous than in those with small diameter when the relative velocities of air and water are the same. 4) The bullet regime starts in the center of the tube, and with the increasing of the air component, when the consumption of water is constant, spreads along the entire cross section of the tube. The increasing of the diameter of the bubble bullets is more rapid in tubes with large diameters and considerably slower in tubes with small ones. 5) The ratio ϕ_{max}/ϕ_{av} (where ϕ_{max} is the value of the air-component in the center of the tube and ϕ_{av} the average value of the latter across the entire cross-section of the tube) is a characteristic for non-homogeneity of

the flow. 6) The influence of the diameter of the tube on the relative velocity of the air is shown. For tubes with diameters 69 and 52 mm the curves for the relative velocities are the same as the analogous curves obtained by V. I. Tolubinskiy (Ref. 6: Soobshteniya, KPI, 1949) after he had worked out A. P. Krylov's experimental data.

2572. Rose, W.

FLUID DISTRIBUTIONS CHARACTERIZING GAS-LIQUID FLOW, Journal of Petroleum Technology 3, 16-7 (Feb. 1951).

Attainment of uniform gas-liquid distributions in multiphase flow systems and especially in those of so-called Haasler type is complicated by gas compressibility and dependence of fluid distributions on interfacial curvatures phenomena; expression for maximum difference in capillary pressure which will obtain in given linear gas-liquid flow system is derived for use in conjunction with empirical data showing variation of saturation with capillary pressure.

2573. Saito, R. and Yamaki, H.

EXPERIMENTAL STUDIES OF THE BOILING PHENOMENA. I. DENSITY DISTRIBUTIONS OF STEAM WATER MIXTURE IN THE MULTIPLE RECTANGULAR CHANNELS UNDER ATMOSPHERIC PRESSURE, J. Atomic Energy Soc. Japan 1, 40-45 (June 1959).

To study the water boiling phenomena under atmospheric pressure, a natural circulation loop with multiple rectangular channels was constructed for observing the behavior of steam bubbles and for measuring the distribution of voids in the heated sections by the gamma-ray attenuation method. The relative velocities of steam water were evaluated from the results obtained. The precise effects of the channel width on the bubble size and the relative velocity of steam water could not be obtained, but the general characteristics of boiling were observed. Upon comparing the results of the experiments with calculations based on the Behringer's and Johnson's data, slight deviations were found, especially when compared with the Behringer's data. It is concluded that the effect of the inlet velocity on the relative velocity must be taken into account, and that special attention is necessary in applying the Behringer's data to practical design, at least under atmospheric pressure.

2574. Smith, M. G. and Hoe, Y. L.

WATER VELOCITIES IN THE TWO PHASE FLOW OF STEAM AND WATER IN 4.06 AND 6.06 INCH DIAMETER HORIZONTAL PIPELINES, Dominion Laboratory, Dept. of Scientific and Industrial Research, New Zealand, Sept. 1956. C.E. 174, Report No. DL 1186.

PRESSURE DROPS (SEE ALSO MOMENTUM LOSS)

2575. Bazilevich, A. I.

LAWS OF RESISTANCE DURING TURBULENT MOTION OF TWO PHASE LIQUIDS, Nauch. Zapiski L'vov. Politekh. Inst. No. 31, 114-26 (1955).

The problem of selection of similarity criteria for 2-phase liquids and of the dependence of the coeff. of hydraulic losses in pipelines on Re are discussed. The principal calcn. formulas for the detn. of hydraulic losses in pipelines are cited. From Referat. Zhur., Khim. 1956, Abstr. No. 70585.

2576. Begell, Wm. and Hoopes, J. W., Jr.

ACCELERATION PRESSURE DROPS IN TWO-PHASE FLOW, Columbia University, New York, Cu-18-54-At-dP-Ch.E (1954) 14 p.

A procedure for a step-wise trial-and-error method of obtaining pressure drops in a two-phase water-system is described using the Martinelli-Nelson equations for stratified flow. The procedure may be applied to the steam boilers, evaporators, and condensate return lines. A nomograph for steam qualities up to 25% and over the temperature range 170° to 350°F for rapid evaluation of two-phase acceleration pressure drop and a chart for rapid computation of the Lockhart and Martinelli empirical parameter X_{tt} are presented. This parameter for two-phase flow equals the square root of the ratio of liquid friction drop to vapor friction drop, assuming each phase flowing alone. The subscript "tt" presumes that both the liquid and the vapor in the flowing two-phase fluid are in turbulent flow.

2577. Brigham, W. E., Holstein, E. D., and Huntington, R. L.

HOW UPHILL AND DOWNHILL FLOW AFFECT PRESSURE DROP, The Oil and Gas Journal, p. 145 ff. (Nov. 11, 1957).

2578. Boelter, L. M. K. and Keppner, R. H.

PRESSURE DROP ACCOMPANYING TWO-COMPONENT FLOW THROUGH PIPES, Industrial Engineering Chemistry, 31, 426-34 (1939).

Data were obtained under conditions of service of a heater in a citrus orchard. Mixtures used were oil and water and oil and air. Data are given for 1/2 in. galvanized pipe and 1/2 in. and 3/4 in. black pipe. The authors have attempted to present experimental evidence which will allow the design of two-component flow systems of dimensions and properties not too far removed from the experimental range covered. Further experimental data are needed to extend the range of applicability of the results and to establish the basic variables.

2579. Burr, E. H. and LeTourneau, B. W.

BETTIS THERMAL AND HYDRAULICS SECTION PRESSURE DROP DATA REDUCTION CODE, (WAPD-R(TH)-587 (Del.)) (May 28, 1960).

A digital computer code which combines and supersedes the IBM-650 codes (SO108 and SO185) was written for calculation of total pressure drop as the sum of friction, acceleration, and elevation components. The code is designed to handle any size test section. The number of axial space increments at which calculations can be performed was increased from 24 to 30. The equations used are given.

2580. Chisholm, D. and Laird, A. D. K.

TWO PHASE FLOW IN ROUGH TUBES, Trans. Am. Soc. of Mech. Engineers 80, 276 (1958).

Data are presented for pressure drop and satn. during flow of air-water mixtures in smooth and rough tubes. Approximate empirical relations developed by using these improvements correlated by majority of the data within 15%.

2581. Cordle, H. J. and Haass, W. P.

PROPOSED METHOD OF TWO-PHASE PRESSURE DROP CALCULATION FOR THE DESIGN OF THE PAR EMERGENCY DRAIN PIPING, WCAP-667 (1957) 14 p.

During an emergency fuel dump from the Pennsylvania Advanced Reactor, the slurry will flash into a vapor-liquid mixture. Design calculations for the emergency drain system will thus require a calculational method for two-phase flow and pressure drop. A literature survey revealed two such methods, a homogeneous method and the Martinelli method. These two methods are described and discussed. The homogeneous method appears most promising for PAR conditions. 8 references.

2582. Dittus, F. W. and Hildebrand, A.

A METHOD OF DETERMINING THE PRESSURE DROP FOR OIL-VAPOR MIXTURES FLOWING THROUGH FURNACE COILS, Transactions of the American Society of Mechanical Engineers, 64, 185-192 (1942).

This paper outlines a procedure for calculating pressure drops which has been used by the authors in the design of furnaces over a period of several years. The resultant total pressure drops have in each case checked closely with the calculated values. The equations given in the paper are set up to determine the pressure gradient for the part of the furnace where a liquid-vapor composition exists, particularly in the case of a vaporizing petroleum oil. The method as outlined consists of a combination of mathematical equations and graphical solutions.

2583. Eddy, K. C.

PRESSURE DROPS IN TWO PHASE FLOW, M. S. Thesis, Univ. of Minnesota (1954) 71 p.

There are five conclusions to be drawn from the results of this investigation. They are:

1. The method proposed by Martinelli and Nelson and the homogeneous flow "friction factor" method for the calculation of two-phase pressure drops are not completely satisfactory. However, until better correlations are developed, these two methods are recommended.

2. The method of gamma-ray absorption has proven itself adaptable to the investigation of flow areas, phase distribution, and flow patterns in two-phase flow.

3. For the flow range investigated, a gravity distorted annular or "crescent" flow pattern has been postulated.

4. The flow of the two phases appears to be primarily continuous in each phase.

5. The slip ratio (ratio of the gas velocity to the liquid velocity), calculated on the basis of phase continuity, changes by only 70 per cent in increasing the quality tenfold (i.e. from 0.004 to 0.047).

2584. Evans, L. B. and Churchill, S. W.

THE EFFECT OF AXIAL PROMOTERS ON THE HEAT TRANSFER AND PRESSURE DROP INSIDE A TUBE, AIChE Preprint 26, New York (1962) 38 p.

The pressure drop and rate of heat transfer were measured for water flowing in a tube containing bluff-body promoters. Disks and streamline shapes of several sizes were mounted at various uniform spacings along a small, axially centered rod. Solid axial cores of various uniform diameters were also investigated. A uniform heat flux density was imposed along the wall and local heat transfer coefficients were determined from temperature measurements. The pressure drop and rate of heat transfer were both increased substantially by the streamline shapes and even more by the disks. Generalized empirical correlations are presented for the heat transfer coefficient and the effective drag coefficient or friction factor for disks, streamline shapes and annuli. The correlations provide the basis for selection and the economic evaluation of promoters.

2585. Frazier, A. W.

PRESSURE DROP IN TWO-PHASE FLUID FLOW, Carnegie Institute of Technology, B. S. Thesis (1942) 26 p.

The effect of viscosity and density on the pressure drop associated with the simultaneous flow of air and water or a sugar solution was studied. The investigator concludes that the type of flow cannot be used in calculating friction because one type of flow gradually runs into another. This continuity gives the pressure drop as a continuous function of the air rate at a constant water rate. The volume-velocity plot seems to be a satisfactory answer to the classification of the types of flow, but it cannot be used quantitatively.

2586. Hatch, M. R.

PREDICTION OF PRESSURE DROP IN TWO PHASE SINGLE-COMPONENT FLUID FLOW, Cryogenic Engineering Laboratory, National Bureau of Standards, Boulder, Colorado, Preprint (1961).

2587. Haywood, R. W., et. al.

EXPERIMENTAL STUDY OF THE FLOW CONDITIONS AND PRESSURE DROP OF STEAM-WATER MIXTURES AT HIGH PRESSURES IN HEATED AND UNHEATED TUBES, Chartered Mech Engr. 8, 170-1 (Mar. 1961) See also S. African Min and Eng. J. 72, 231 (1961).

Analysis of flow conditions in $1\frac{1}{2}$ in. bore vertical and horizontal pipes from -ray measurements; correlation with 1-in. bore results; comparisons of pressure drop with values predicted on assumption that 2-phase mixture flows as homogeneous fluid; effects of slip, acceleration and gravitational pressure drops.

2588. Houghten, F. C. and Guteberlet, C.

FLOW OF CONDENSATE AND AIR IN STEAM-HEATING RETURNS, Transactions of the American Society of Heating and Ventilating Engineers, 39, 179 (1933).

The pressure drop relation for a return main carrying only water, thus simulating a wet return main, is given for the system studied. Greater rates of water delivery were found for a given pressure drop than would be given by the usual hydraulic formula and accepted constants. Corrected constants giving flows equal to that observed are presented. A much-used formula for flow of air in pipe is shown to given flows which agree closely with those experimentally determined.

The pressure drop-flow relation is given for different ratios of air and water flowing in one-inch, 1.5 inch, 2-inch pipes, when operating as a dry return main. The capacities of these three sizes of pipe when plotted against pipe diameter give consistent curves, which are extrapolated with fair accuracy to larger pipe sizes.

2589. Inoya, Koichi

HOLD-UP AND PRESSURE DROP IN TWO PHASE FLOW OF AIR AND WATER, Kikai no Kenkyu 10, 1007-11 (1958).

Hold-up and pressure drops in 2- αphase flow were measured, and the results are compared with those in the literature. The air-water system was investigated in a $\frac{3}{4}$-in. pipe which was installed vertically or horizontally.

2590. Isbin, H. S., Moen, R. H. and Mosher, D. R.

TWO-PHASE PRESSURE DROPS, Atomic Energy Comm., AECU-2994 (1954) 98 p.

A survey of the literature on two-phase flow has been made with the purpose of critically examining design methods for evaluating pressure drops in steam-water mixture flows. Several simplified physical models have been used in developing equations and correlations for predicting pressure drops and flow rates. A discussion of the factors involved is presented along with several new comparisons between estimated pressure drops and experimental data.

2591. Isbin, H. S.

WORKING CONFERENCE NO. 1: TWO-PHASE FLOW PRESSURE DROP, Reactor Heat Transfer Conference, New York, TID-7529 (Pt.1) Nov. 1 and 2, 1956, p. 579-585.

The purpose of the Conference was to examine critically the present status of the knowledge and experience acquired in the evaluation of two-phase (gas-liquid) flow pressure drops.

2592. Jordan, D. P. and Leppert, G.

PRESSURE DROP AND VAPOR VOLUME WITH SUB-COOLED NUCLEATE BOILING, Internat. J. Heat Mass Transfer (BG) vol. 5, 751-61 (Aug. 1962).

Reynold's analogy between the transfer of heat and momentum is applied to forced-convection, subcooled boiling to predict the pressure drop. Experimental measurements of static pressure, vapour volume per unit area and heater wall temperature in an annular geometry permit the calculation of the local friction factor and the local Stanton number, from which it is demonstrated that the analogy gives a good approximation to the friction factor if a correction is made for the acceleration effects. However, this agreement is not found near the start of the heated length; local deviations of the measured quantities from those downstream are found in the entrance region.

2593. Knapp, W. C. and Metzger, J. W.

GRAPHICAL REPRESENTATION OF FRICTIONAL LOSSES IN COMMERCIAL PIPE OF AIR AND STEAM FLOWING TURBULENTLY, American Society of Mechanical Engineers, Preprint of Paper No. 54-Sa-17, 1954, p. 15. Am. Soc. of Mech. Engrs., Trans. 77, 675-81 (1955).

Data relating to problem of pressure losses in pipes at various conditions of temperature and pressure; graphical solution for determining frictional losses in pipes of various sizes carrying air and steam, together with mathematical analysis from which it is evolved.

2594. Knight, A. D. K.

PREDICTION OF PRESSURE DROP DURING THE CONDENSATION OF STEAM, University of Tulsa, M. S. Thesis (1954) 105 p.

The purpose of this research project was to accumulate sufficient experimental data to enable a correlation of the variables involved in predicting the pressure drop occurring during two-phase flow, the simultaneous flow of liquid and vapor, in a circular pipe. This study was further limited to a consideration of the pressure drop occurring in a two-phase system involving the condensation of steam. It was intended that the work of the author would constitute a supplement to and possible corroboration of the results obtained by Carlson.

2595. Kreith, F. and Summerfield, M.

PRESSURE DROP AND CONVECTIVE HEAT TRANSFER WITH SURFACE BOILING AT HIGH HEAT FLUX; DATA FOR ANILINE AND N-BUTYL ALCOHOL, Trans. ASME 72, 869-78 (1950).

Heat transfer coefficients to com.-grade aniline and BuOH were measured in the heat-flux range from 0.3 to 5 Btu per sq in. per sec and in the pressure range from 30 to 400 lb. per sq in. abs. at velocities from 20 to 40 ft per sec. The test section consisted of a 0.5-in. (internal diam.) stainless-steel tube which was heated electrically.

2596. Lamb, D. E. and White, J. L.

USE OF MOMENTUM AND ENERGY EQUATIONS IN TWO-PHASE FLOW, AIChE J. 8, 281-3, (1962).

Derivations are given for the momentum and mech. energy equations. Their relation is shown to the pressure-drop correlation in 2-phase flow. Reply. H. S. Isbin. Ibid. 284; cf. preceding abstr. (CA-62-16355h).

2597. Larkins, R. P., White, R. R. and Jeffrey, D. W.

TWO PHASE CONCURRENT FLOW IN PACKED BEDS, AIChE Journal 7, 231-9 (1961).

Pressure drop and liquid satn. accompanying 2-phase concurrent flow were studied in a variety of packings and with gas-liquid systems with a wide range of fluid properties. Two basic flow patterns were observed with nonfoaming systems. Correlations of pressure-drop and liquid-satn. data were obtained in terms of the single-phase friction losses for the liquid and the gas when each flows alone in the bed.

2598. Lockhart, R. W.

ISOTHERMAL PRESSURE DROP FOR TWO-PHASE TWO-COMPONENT VISCOUS-VISCOUS FLOW IN A TUBE AT VARIOUS ANGLES WITH THE HORIZONTAL, University of California, M. S. Thesis (1945), 58 p.

A total of 268 runs were recorded: 196 were for two-phase two-component flow, and 72 were for single component flow of air or of the liquids. The range of the variables of the runs are found in Table 1.

The results of this investigation indicate that the analysis presented by Martinelli, Putnam, and Lockhart for two-phase two-component flow with both phases in the viscous regime is applicable; that is, the two-phase pressure drop may be represented by:

$$\left(\frac{\Delta P}{\Delta L}\right)_{T-P} = \left(\frac{\Delta P}{\Delta L}\right)_{g} \Phi^2_{\nu\nu}$$

and that the dimensionless modulus χ_{vv} can be correlated as a function of:

$$\chi_{vv} = \frac{W_l \gamma_g \mu_l}{W_g \gamma_l \mu_g}$$

There were no effects observed in the two-phase two-component flow results when the test section was rotated to some angle with respect to the horizontal. The static head in the test section when it was in the vertical positions (maximum static head) was less than 0.1% of the pressure drop; so that correction to convert the data to equivalent horizontal position was neglected.

Experimentally the correlation between two-phase two-component flow data through a porous media (permeabilities of consolidated sands of 0.5 to 260 darcys) and through a glass tube with the fluids in the viscous regime was verified on the χ_{vv} vs. Φ_{vv} curve within a maximum error of 20%.

2599. Lockhart, R. W.

AN ANALYSIS OF ISOTHERMAL TWO-PHASE TWO-COMPONENT FLOW DATA, University of California, Mechanical Engineer Thesis (1947).

R. C. Martinelli and co-workers postulated that four types of two-phase component flow mechanisms exist. These are: (1) gas turbulent, liquid turbulent; (2) gas turbulent, liquid viscous; (3) gas viscous, liquid viscous. (4) gas viscous, liquid turbulent. In this thesis Lockhart reaches the following conclusions:

1. Two-phase two-component pressure drop, Φ, and the liquid saturation R_ℓ, can be correlated for flow mechanisms 1, 2, and 3 with the two-phase two-component flow modulus, χ. From these relations and the pipe diameter, the liquid flow modulus α, the gaseous phase modulus, β, and the hydraulic diameters D_ℓ and D_g can be calculated.

2. Absolute velocity of the gaseous phase is usually greater than the absolute velocity of the liquid phase.

3. For flow mechanism 3, there is no change in the pressure drop modulus, Φ, or the liquid saturation, R_ℓ, for a given value of χ when the test section is related from vertically up, to horizontal, to vertically down.

4. A practical use of the R_ℓ and Φ correlation curves for the three flow mechanisms is to predict the pressure drop in the riser column of a gas lift pump.

2600. Lockhart, R. W. and Martinelli, R. C.

PROPOSED CORRELATION OF DATA FOR ISOTHERMAL TWO PHASE, TWO-COMPONENT FLOW IN PIPES, Chem. Eng. Prog., 45, 39-48 (1949).

Data are presented for the simultaneous flow of air and liquids including benzene, kerosene, water, and various oils in pipes varying in diameter from 0.0586 in. to 1.017 in. Four types of isothermal two-phase, two-component flow are shown to exist depending upon whether each phase is flowing viscously or turbulently. The pressure drop resulting from these various flow mechanisms is correlated by means of parameter X equal to the square root of the ratio of the pressure drop in the pipe if the liquid flowed alone to the pressure drop if the gas flowed alone. Tentative criteria are proposed for the transition of the flow from one type to another. The percentage of pipe filled with liquid under any flow conditions is also shown to be correlated for all four flow types by means of the parameter X.

2601. Lunde, K. E.

HEAT TRANSFER AND PRESSURE DROP IN TWO PHASE FLOW, Paper Presented at the AIChE Fourth National Heat Transfer Conference, 1960, Chem. Eng. Prog. Symp. Series No. 32, 57, 24-31 (1961).

Ht. transfer to fluids in a condition involving more than one fluid phase is probably of greater industrial significance than any other heat transfer process. The most familiar of these is the boiling of water, but the vaporization of other compounds as well as condensation and the transfer of heat to and from mixtures of fixed gases and liquids is also an every-day encounter.

Although all these processes are basically analogous, they have been treated as rather separate entities, no doubt because of their complexity and because of the widely different conditions under which they are employed. Under highly specific circumstances (such as conventional boilers) experience has enabled accurate design of equipment. If however, new or divergent conditions are involved, the available correlations of experimental data are not sufficiently general to justify much confidence in their predictions.

Several investigators have carried out studies of two-phase heat transfer with two-component systems (one a fixed gas) so that the complicating factor of simultaneous mass transfer could largely be avoided. No satisfactory basis for correlating even these data has appeared in the literature and it has been generally conceded that a valid physical model is needed as a basis for correlation.

The present paper is largely concerned with a correlation of two-phase, two-component heat transfer on the basis of a physical model, but it includes an extension to vaporization processes and two-phase pressure drop.

2602. Maker, F. L.

PRESSURE DROP OF EVAPORATING FLUID IN TUBULAR HEATER, Am. Soc. Mech. Engrs. Paper 55-Pet-29, September 1955.

Pressure drop in refinery heater where fluid is evaporating has generally been computed by trial and error method that is time consuming; method by M. Ludwig is very simple and fast for pressures above atmospheric, and where velocity pressure effects are minor; simple graphical method for integrating pressure drop from known required conditions at outlet.

2603. Marchaterre, J. F.

TWO-PHASE FRICTIONAL PRESSURE DROP - PREDICTION FROM LEVY'S MOMENTUM MODEL, TECHNICAL BRIEF, Journal of Heat Transfer, 83, 503-505 (1961).

2604. Marcy, G. P.

PRESSURE DROP WITH CHANGE OF PHASE IN A CAPILLARY TUBE, Refrigerating Engrg., 57, 53 (1949).

Original method of computing length of capillary tube to be used for adiabatic expansion of refrigerant; rate of flow for given tube may be found also; solution obtained by graphical integration of Fanning equation and does not depend upon empirical factors; good correlation with test data found within limited range of conditions investigated.

2605. Martinelli, R. C., Putnam, J. A. and Lockhart, R. W.

TWO-PHASE, TWO COMPONENT FLOW IN THE VISCOUS REGION, Trans. ASME, 42, 681-705 (1946).

The analysis for two-phase, two-component flow in a tube when both phases are flowing viscously is presented. Experimental data for flow of air and oil in a capillary tube verify the analysis and allow the predictions of the two-phase, two-component viscous-viscous, pressure drop for other similar flow systems. It is noted that, apparently, the angle of the tube with the horizontal has no appreciable effect on the two-component frictional-pressure drop. A comparison is made between the data in this paper and the available data for two-phase, two-component flow in porous media. The two sets of data are shown to be comparable and the data for the capillary tube are postulated to be a special case of flow through a porous medium with very high permeability, and with no interstices into which fluid can be "side-tracked."

2606. Martinelli, R. C. and Nelson, D. B.

PREDICTION OF PRESSURE DROP DURING FORCED CIRCULATION BOILING OF WATER, Trans. ASME, 70, 695-702 (1948).

A tentative method for the rapid calculation of the pressure drop during forced-circulation boiling of water is presented. The method is based upon the application of pressure-drop data, obtained during the isothermal flow of air and various liquids, to the evaluation of local pressure gradients during forced-circulation boiling. Curves are developed by means of which the pressure drop during boiling can be estimated quickly once the exit quality, the boiling pressure, and the pressure drop for 100% liquid are known. The proposed method is definitely an extrapolation of existing data, and, as such, required further experimental verification.

2607. Martinelli, R. C. and Lockhart, R. W.

PROPOSED CORRELATION OF DATA FOR ISOTHERMAL TWO-PHASE, TWO-COMPONENT FLOW IN PIPES, Chem. Eng. Prog. 45, 39-50 (1949).

Data are for simultaneous flow of air and liquids including benzene, kerosene, water and various oils in pipes varying in diameter from .0586 to 1.017 in; four types of isothermal flow are shown to exist depending upon whether each phase is flowing viscously or turbulently; pressure drop from these various flow mechanisms is correlated; other results.

2608. May, C. J. and Laird, A.

THE EFFICIENCY OF FLOWING WELLS, J. of the Inst. of Petroleum Technology, 20, 214-241 (1934).

Factors affecting the pressure drop in a flowing well are discussed and experiments described the object of which was to determine the laws of flow and

suitable numerical constants for Masjid-i-Sulaiman oil. Apparatus is described for measuring pressures in a flowing well. It is concluded that over the range of velocities in which friction is appreciable the Fanning equation is satisfactory with a constant friction factor. An equation is developed for slippage loss when the ratio of gas to oil is less than 1:1; the velocity of slip is estimated at about 0.5 ft/sec.

2609. Miller, M. S.

PRESSURE DROP IN FORCED CIRCULATION FLOW OF SUB COOLED WATER WITH AND WITHOUT SURFACE BOILING, M. S. Thesis, M. I. T. (1954).

2610. Moen, R. H.

PRESSURE DROP IN TWO PHASE FLOW: AN INVESTIGATION OF THE STEAM-WATER SYSTEM AT HIGH PRESSURES AND HIGH TEMPERATURES, Ph.D. Thesis, Univ. of Minnesota (1956).

2611. Moore, T. V. and Schilthuis, R. J.

CALCULATION OF PRESSURE DROPS IN FLOWING WELLS, Trans. of the American Institute of Mechanical Engineers, 103, 170-190 (1933).

Recent work has led to the development of a new hypothesis which presupposes certain conditions affecting the flow of oil and gas in wells. When the proposed equations are corrected to allow for these conditions, an agreement between the observed and calculated performance of actual wells is obtained. In this paper, the method of calculating the pressure drop in actual wells is considered and the application of the method to the design of tubing is discussed.

2612. Morgan, Charles

PRESSURE LOSS CHARACTERISTICS OF AIRCRAFT FUEL SYSTEM COMPONENTS, Consolidated Vultee Aircraft Corp., Report No. ZK-006 (June 15, 1952).

This report relates the results of an intensive literature survey which compiled, compared, and analyzed all the information which could be found pertaining to pressure loss characteristics and phenomena of conduit and conduit fittings utilized to aircraft fuel systems. In addition, the compiled results are presented in a manner which is most easily understood by the designer and may be expeditiously applied by him in the design of an aircraft fuel system.

2613. Morgan, Charles

PREDICTING PRESSURE LOSSES OF SYSTEMS CONDUCTION 2-PHASE FLUIDS, Consolidated Vultee Aircraft Corp., Report No. ZK-007 (July 15, 1952).

This report concerns itself with the prediction of pressure losses in aircraft fuel system components conducting fuel (and dissolved air) in 2 phases, liquid and gaseous. It reports the results of an extensive literature search on the subject, the conduct of which was described in the first report of this series (ZK-006). The results have been analyzed, compared and presented so that: (a) what information that is available may be expeditiously utilized by non-specialized design personnel, and (b) conclusions may be drawn as to the state of knowledge of pressure losses in 2-phase flow.

The analytical background procedures and data concerning single phase flow are not herein included. Rather, this report may be considered a specialized continuance of Ref. 1, to which the reader is referred for the above material.

2614. Mosher, D. R.

TWO PHASE STEAM-WATER PRESSURE DROPS, M. S. Thesis, Univ. of Minnesota (1954).

An investigation was made of the friction pressure drop existing when steam-water mixtures flow adiabatically through 1 in. ID pipe. The range of experimental variables are as follows: quality - 0.02-1; total flow - 900-2500 lbs/hr; pressure - 25-100 psia. A statistical method of obtaining empirical equations for the 2-phase pressure drop was then examined.

2615. Neely, C. F.

A METHOD OF COMPUTING PIPESTILL PRESSURE DROPS, University of Tulsa, M. S. Thesis, (1949) 61 p.

A tubestill, or pipestill, is an apparatus in which oil is continuously heated during passage through pipes exposed to a heat source. In addition to simple heating, vaporization or cracking may take place. This thesis will be concerned with the former process. Its purpose will be to advance a method by which pressure drops occurring in a pipestill, as heating and vaporization take place, may be computed quickly and accurately.

2616. Nesbit, J. R.

CHARACTERISTICS OF TWO-PHASE FLUID FLOW, Carnegie Institute of Technology, B. S. Thesis, (1940) 21 p.

The object of this research is to study types of flow and attempts to gain data and to correlate factors pertaining to the pressure drop of the flow of air and water in a pipe.

2617. Neusen, K. F., Kangas, G. J. and Sher, N. C.

HEAT TRANSFER TO SUPERHEATED STEAM IN A THIN ANNULUS, AIChE Preprint 23, New York (1962) 34 p.

Heat transfer and pressure drop studies have been completed for superheated steam flowing in thin annular passages at 600 psia. The annuli were formed by an 0.878 in. OD tube inside of a 0.997 in. ID tube giving a gap of 0.0595 in. The 6 ft long tubes were held concentric by 3, 0.058 in. longitudinal wire spacers, 120° apart. Test conditions included Reynolds numbers from 35,000 to 140,000, heat fluxes as high as 125,000 Btu/hr-ft^2, and steam temperatures from saturation (489°F) to 1200°F. Local friction factors were measured for both heated and isothermal steam over the complete temperature range. Local heat transfer coefficients were measured on both the inner and outer heat transfer surfaces. Film coefficients and friction factors are compared with available correlations, and the effects

of variable fluid properties and length to diameter ratio (heat transfer data were obtained for L/D_e up to 430) are discussed.

2618. Owens, W. L., Jr.

TWO-PHASE PRESSURE GRADIENT, International Developments in Heat Transfer, Part II, ASME, 1961, p. 363-8.

Presents a solution, theoretical in nature for the calculation of two-phase pressure drop for isothermal and non-isothermal flow, which will not be limited to any specific flow problem or substance. The derivation of an expression representing two-phase pressure gradient is made with the assumption of homogeneous flow, and two phase friction factor being the same as for single phase liquid flow.

2619. Owens, W. L., Jr. and Schrock, V. E.

LOCAL PRESSURE GRADIENTS FOR SUBCOOLED BOILING OF WATER IN VERTICAL TUBES, ASME Paper 60-WA-249.

2620. Rogers, M. C. and Thiele, E. W.

PRESSURE DROPS IN BUBBLE CAP COLUMN, Ind. Eng. Chem. 26, 524-528 (1934).

Exptl. data are given on the pressure drop in a bubble cap with a single triangular or rectangular slot. Air, H_2 and CO_2 were bubbled through water and naphtha at rates and depths, respectively, to give a range of slot opening of 0 to 100%.

2621. Rohsenow, W. M. and Clark, J. A.

HEAT TRANSFER AND PRESSURE DROP DATA FOR HIGH HEAT FLUX DENSITIES TO WATER AT HIGH SUBCRITICAL PRESSURES, NP 3385 (1951).

2622. Schrader, H.

PRESSURE DROP AND HEAT AND MASS TRANSFER FOR COUNTER CURRENT LIQUID GAS FLOW IN PACKED COLUMNS, Kaltetechnik 10, 290 (1958).

Two-phase flow was investigated in a column having a diam. of 22.65 cm. and a length of 55 cm., packed with 16 mm. Raschig rings. Air and water were used in the expts. Measurements revealed 3 different flow ranges which broke sharply at well-defined points, and coincided for pressure drop as well as heat and mass transfer. The higher the pressure drop, the more intensive was the transfer.

2623. Sher, N. C.

REVIEW OF MARTINELLI-NELSON PRESSURE DROP CORRELATION, WAPD-TH-219 (1956) 16 p.

The Martinelli-Nelson predictions of two-phase pressure drop due to head and momentum changes have been reviewed, and the underlying assumptions, postulates, and data are discussed. Modifications to the predicted void fraction values are proposed in order to eliminate the possibility of predicting slip ratios less than unity. The effect of the adjustment at 2000 psia on the boiling pressure drop data reported in WAPD-TH-204 is to bring the results from the data reductions according to the Martinelli and homogeneous models into even closer agreement.

2624. Shug'ev, V. and Sorokin, S.

THE HYDRAULIC RESISTANCE OF A TWO-PHASE MIXTURE, Zhurnal Tekhnicheskoi Fiziki, 9, 1854 (1939).

2625. Shuster, W. W.

EFFECT OF VOID FRACTION ON THE PRESSURE DROP THROUGH BEDS OF REGULARLY PACKED SPHERES, Ph.D. Thesis, Rensselaer Polytechnic Institute (1952) 73 p.

2626. Soo, S. L.

STATISTICAL PROPERTIES OF MOMENTUM TRANSFER IN TWO PHASE FLOW, Chem. Eng. Sci. 5, 57 (1956).

The momentum transfer was studied in a 2-phase stream consisting of particles carried by a fluid. Application of the statistical theory of turbulence shows that the characteristics of turbulence of one phase can be detd. from the other phase. The parameters affecting the momentum transfer are described.

2627. Taylor, R. N.

A CORRELATION FOR PRESSURE DROP WITH CONCURRENT TWO-PHASE FLOW IN PACKED COLUMNS, Carnegie Institute of Technology, M. S. Thesis (1954).

An investigation was undertaken to provide a correlation for predicting the pressure drop of two-phase cocurrent flow in packed towers. Unpublished experimental data taken by two groups of investigators measuring the pressure drop for a gas-liquid system in a 2.24 ID packed column were used in the development of the correlation. A method has been developed based on air-water data wherein the pressure drop can be predicted within an accuracy of about 25 per cent. The equations can be applied to towers containing packings of spheres, Raschig rings or Berl saddles.

The experimental data were used to check the Brownell-Katz correlation for two-phase cocurrent flow. It was found that the correlation would predict the pressure drop to an accuracy of about 70-90 per cent.

2628. Teletov, S. G.

SUR LES COEFFICIENTS DE RESISTANCE DU MOUVEMENT DES MELANGE A DEUX PHASES, Doklady Akademii Nauk Soyuza Sovetskikh Sotsialisticheskikh Respublik 51, 579-82 (1946).

This article describes a theoretical and experimental investigation of the coefficient of resistance of a two-phase fluid flowing in a pipe.

2629. Thomas, W. J. and Portalski, S.

HYDRODYNAMICS OF COUNTERCURRENT FLOW IN WETTED WALL COLUMNS, Ind. Eng. Chem. 50, 1081-8 (1958).

Exptl. results of pressure-drop detn. across a wetted-wall column with an air-water countercurrent system are given. Different curves obtained by

plotting pressure drop against flow conditions show definite characteristics which can be quantitatively interpreted. These curves show that a viscous-flow condition may be assocd. with large waves, and that these waves begin to break up into smaller waves at a Reynolds no. of liquid film Re_L = 900 to 1000. This breakup occurs at lower Re_L values than previously stated for the beginning of the transition region. Further, the lower pressure drop assocd. with smaller waves continues to decrease throughout the transition range. When full turbulence is reached, the pressure drop increases. The transition region extends up to Re_L = 1500 in some cases; this value is higher than previously stated. Correction. Ibid. 1266.

2630. Thomsen, Eric Gottfried

PRESSURE DROP ACCOMPANYING TWO-COMPONENT FLOW IN A CLOSED CONDUIT WITH VARIOUS LIQUIDS AND AIR, University of California, M. S. Thesis, 1940, p. 32.

The investigation was performed for the approximate gas rate range of 0.005 to 0.03 pounds per second and a liquid range of 0.01 to 0.1 pounds per second, for mixture of air and the following liquids: water, benzene, kerosene, glycerine and water, and water and Kemenol.

The following pertinent results were obtained: glycerine and water, and water and Kemenol, are unsuitable for the study of two-component flow because of the tendency to foam thus complicating the problem through the introduction of additional variables. Conclusive evidence was found that water, studied in the experimental range, must flow in turbulent motion; a consideration of the behavior of benzene and kerosene justified the assumption that turbulent motion also exists for these fluids. Further it was found that the data of friction factor based on the air rate and pipe diameter plotted as a function of Re_g.

$$\frac{\nu_g}{\nu_\ell} \cdot \frac{W_g}{W_\ell}$$

on log-log paper for water, benzene, and kerosene could be cross-plotted by a series of parallel lines representing constant parameters of volume of pipe filled with liquid to total volume of pipe. It was also found that for the experimental range studied, the pressure gradients for all fluids tested, except for glycerine and water, can be approximated by the following equation:

$$\frac{\Delta p}{\Delta_\ell} = 1.72 \times 10^6 \left(\frac{W_g}{W_\ell}\right)^{1.82} \times W_\ell^{2.38} \times \frac{T_m}{P_m} \quad .$$

2631. Trethowen, H. A.

FLOW OF GAS LIQUID MIXTURES IN PIPES, New Zealand Eng. 15, 151-5 (May 15, 1960).

Characteristics and patterns of two-phase fluid flow; discussion of common Martinelli and "homogeneous" methods; variation is suggested for Martinelli method to give quick and easy method of estimating frictional pressure drop for flashing mixtures of steam and water in geothermal heating; method does not eliminate additional work involved in calculating further pressure drop due to momentum change and static head.

2632. Ulugol, V. L.

PRESSURE GRADIENTS ASSOCIATED WITH NON-ADIABATIC TWO-PHASE FLOW, Heat Transfer and Thermodynamics Lab, U. of Mich.(1961).

2633. Vohr, J.

ENERGY EQUATION FOR TWO-PHASE FLOW, AIChE, J. 8, 280-1 (1962).

2634. Welsh, P. J.

PRESSURE DROP DUE TO FRICTION IN TWO-PHASE FLUID FLOW, Carnegie Institute of Technology, B. S. Thesis (1938) 17 p.

Pressure drops for air-liquid two-phase fluid flow in glass tubes are given. The design and utilization of experimental equipment is elucidated.

2635. Westmoreland, J. C.

PREDICTION OF THE PRESSURE LOSS AND DENSITY FACTORS FOR TWO PHASE ANNULAR FLOW WITH OR WITHOUT HEAT GENERATION, KAPL-1792 (1957) 35 p.

A simple analysis is presented for predicting pressure loss and density factors for two-phase, one-component annular flow with and without heat generation. All four combinations of laminar and turbulent flow in both the annulus and core are considered. The analysis is based on assumed velocity profiles and matching velocity and shear stress at the liquid-vapor interface. The theory is found to compare favorably with experimental results on both vertical and horizontal sections. The application of the theory to natural circulation steam generators is also presented.

2636. Wickey, R. O.

HIGH PRESSURE TWO PHASE STEAM-WATER PRESSURE DROPS, M. S. Thesis, Univ. of Minnesota (1956).

2637. Woods, W. K.

QUALITATIVE ANALYSIS OF PRESSURE DROP DURING IN-PILE BOILING, HW-31157 (1954) 8 p.

The analysis described in this memorandum develops the concepts that the existence of unstable conditions during in-pile boiling is relatively independent of the actual heat load on the tube, and that such unstable conditions are influenced as greatly by the amount of sub-cooling of the inlet water as they are by the pressure at which the steam is discharged from the pile. Unstable conditions may be suppressed by high flow resistance upstream from the tube, but the required resistance would be excessive in present piles. The required amount of upstream resistance may be minimized or even reduced to zero by using judicious combinations of high discharge pressure and high inlet water

temperatures. Moreover, under these conditions, a change in the resistance downstream from the tube has a comparatively small effect on the amount of upstream throttling required. The analysis developed mathematically is concerned with some of the conditions which should prevail in order to operate a pile satisfactorily with boiling occurring inside the process tubes.

2638. Yano, G. E.

PRESSURE DROP DURING EVAPORATION OF WATER IN TUBES, McGill University, Canada, M. S. Thesis, (1953).

A theoretical and experimental discussion of two-phase flow considering mass transfer phenomenon is included in this thesis.

2639. Socony Mobil Oil Company

PRESSURE DROP IN 4 INCH PIPE FOR AIR-WATER, Unpublished report.

Annuli

2640. Adorni, N., et al.

RESULTS OF WET STEAM COOLING EXPERIMENTS: PRESSURE DROP, HEAT TRANSFER AND BURNOUT MEASUREMENTS IN ANNULAR TUBES WITH EXTERNAL HEATING, Special Report No. 4, EURAEC-44 (CISE-R-30)(Dec. 1960) 88 p.

Data obtained at the Piacenza heat transfer facility are presented tabularly concerning pressure drops with power and with zero power, heat transfer coefficients, and burnout heat fluxes. Graphic data are included on pressure drops with zero power vs. mean steam quality and for burnout heat fluxes vs. steam quality at burnout.

2641. Adorni, N., et al.

RESULTS OF WET STEAM COOLING EXPERIMENTS: PRESSURE DROP, HEAT TRANSFER AND BURNOUT MEASUREMENTS IN ANNULAR TUBES WITH INTERNAL AND BILATERAL HEATING, Centro Informazioni Studi Esperienze Report R 31, EURAEC-45, January 1961, Milan, Italy, Special Report No. 5, 64 p.

Heat transfer data are presented on internally and bilaterally heated annular test elements. Data obtained using wet steam are given for pressure drop with zero power, pressure drop with power, heat transfer coefficients, and burnout heat flux.

2642. Hoopes, J. W., Jr.

FLOW OF STEAM-WATER MIXTURES IN A HEATED ANNULUS AND THROUGH ORIFICES, AIChE Journal 3, 268-275 (1957).

Values of total pressure drop are presented for the flow of vaporizing water in an internally heated 1-in. ID by $1\frac{1}{4}$ in. OD annulus at mass velocities of 270 to 1440 lb/sec ft^2, pressures of 9 to 180 lb/in^2, and up to 0.34 fraction by weight vaporized. There is no evidence of "sonic" pressure jumps at the outlet. Various methods of correlating the results are discussed. Pressure drops through approximately 0.3-inch orifice holes, with the mixture discharging into cool water, are given for mass velocities of 308 to 1650 lb/sec ft^2 at the "vena contracta," and up to 0.34 fraction vaporization of the entering mixture. It was found that the ratio of the two-phase pressure drop to the drop with no vaporization was approximately a linear function of the quality in the vena contracta but was only $\frac{1}{10}$ to $\frac{1}{3}$ as great as would be predicted if the mixture were to expand as a homogeneous fluid. Prediction of orifice pressure drops is improved if slip between vapor and liquid is considered. 10 references.

2643. McNutt, C. R. and Carbon, M. W.

EXPERIMENTAL STUDIES ON STEAM WATER PRESSURE DROPS IN AN ANNULUS WITH HEAT TRANSFER, HW-38242 (Rev. 1) (1955) 27 p.

Pressure drops are reported for forced circulation flow of steam-water mixtures in a 23.5 ft long, 1.43 inch ID, 0.1 inch thick, horizontal annulus. The inner surface of the annulus was uniformly heated over a range from 97,000 to 233,000 Btu/hr-ft^2, exit pressures extended from 100 to 500 psig, and exit steam qualities varied from 0 to 60% by weight. Liquid water entered the annulus and boiling lengths up to 15 feet were investigated. Moreover, the Woods and the Martinelli and Nelson methods of calculating two-phase pressure drop were applied to the experimental conditions, and the deviations between the analytical and the test results are presented.

2644. Stein, R. P. et al.

PRESSURE DROP AND HEAT TRANSFER TO NON-BOILING AND BOILING WATER IN TURBULENT FLOW IN AN INTERNALLY HEATED ANNULUS, Chemical Engineering Progress, Symposium Series 50, No. 11, 115-26 (1954).

Water was pumped through annuli $\frac{1}{8}$ in. wide, 1.08 in. internal diameter, and 14 ft long, electrically heated at their inner surfaces. Uniform and cosine heat-flux distributions were employed, as well as concentric and 30% eccentric annuli. Nonboiling overall friction factors for concentric annuli agreed with pipe values and for the eccentric case were about 30% less. Circumferential average local heat-transfer coefficients agreed with the Colburn j-factor correlation for turbulent flow inside tubes and were substantially independent of eccentricity. The usual definition of film temperature correlated the results best. Efflux velocities with boiling were well above the calculated maximum values for homegeneous fluids. Inlet pressures during coolant boiling were checked by two incremental calculation methods. Homogeneous, or "fog," flow gave inlet pressures that were somewhat too high and Martinelli and Nelson's "slip" flow gave pressures too low by a larger amount. A modified plot by Lockhart and Martinelli of "ℓ" was obtained which gives good agreement in calculating two-phase frictional pressure drop for the runs reported. It is recommended for downward flow in concentric annuli of similar dimensions. DA 48,9120e (1954).

Fittings, Bends, Etc.

2645. Cohen, M. I.

AN INVESTIGATION OF PRESSURE DROP IN A TWO PHASE TWO COMPONENT FLOW IN BENDS M.I.T. S. B. Thesis (1957).

2646. Deobald, T. L.

AN EXPERIMENTAL INVESTIGATION OF TWO-PHASE FLOW PRESSURE LOSSES IN PIPE ELBOWS, HW-SA-2564 (1962) 108 p., Thesis submitted to Univ. of Idaho.

Results of a study concerning two-phase steam-water flow through pipe elbows are presented. The applicability of the approach used in the analysis of this type flow, relating the pressure drop occurring during two-phase flow to the pressure drop occurring if only a single phase were flowing in the system, is examined. The work is limited to standard 1 in. welding ells with steam pressures at 25 to 50 psia and steam qualities of 0 to 100%.

2647. Sharp, R. K.

TWO PHASE PRESSURE LOSSES IN VALVES AND FITTINGS, M. S. Thesis, Georgia Inst. of Tech. (1956).

Horizontal Flow

2648. Abou-Sabe, Abdel-Hamid Aly

HEAT TRANSFER AND PRESSURE DROP DURING TWO-PHASE TWO-COMPONENT FLOW IN A HORIZONTAL TUBE, University of California, Ph. D. Thesis, 1951, p. 120.

The case of the two-phase two-component isothermal and non-isothermal air water flow in a 0.870 inch I.D., steam jacketed, horizontal tube was investigated experimentally.

Correlation of the two-phase isothermal and non-isothermal pressure drop data obtained by using Martinelli's modulus, equal to the square root of the ratio of the pressure drop if the liquid flowed alone, to the pressure drop if the gas flowed alone, indicated that the two-phase flow pressure drop is not a function of this modulus alone. Modification of the analysis presented by Martinelli to take into account the effect of the flow patterns and the roughness at the gas-liquid interface, results in an improved correlation of the two-phase flow pressure drop; within ± 10 per cent. The modified analysis, however, restricts the generality offered by Martinelli's method of correlation and, furthermore, depends on an experimental factor for which additional data are needed to establish its values.

The observed flow patterns were correlated as a function of the rates of flow of the two phases and the correlation is in fair agreement with data reported in the literature.

Data taken for the percentage volume of the pipe occupied by the liquid (liquid saturation) were shown to be correlated by using Martinelli's modulus.

An effective two-phase flow heat transfer coefficient was defined and an analysis of this coefficient for turbulent flow, based on analogy with single phase flow systems, was developed.

Data on the two-phase flow heat transfer were correlated within ±15 per cent on the basis of the expression developed for the defined two-phase flow heat transfer coefficient.

An alternative method of correlation of the heat transfer data within ±20 per cent, based on its relation to the two-phase flow pressure drop is also presented.

2649. Armand, A. A.

THE RESISTANCE DURING THE MOVEMENT OF A TWO PHASE SYSTEM IN HORIZONTAL PIPES, AERE-TRANS-828 (Mar. 1959), Translated from Vsesoyuznogo Teploteknicheskoga Instituta imena Feliksa Dzerzhinskogo, 15, 16-23 (1946).

Experiments were conducted in smooth brass pipes. The air content was varied from 0 to 95 percent by weight, and the throughput of water was varied from 4200 to 10 kg/hr. Visual observations and cinematographic evidence indicate the existence of a diversified stream structure. A scheme of all flow types observed is given, and formulas to express these types are deduced.

2650. Armand, A. A. and Treshchev, G. G.

STUDY OF THE RESISTANCE TO MOTION OF STEAM-WATER MIXTURE IN A HEATED BOILER TUBE UNDER HIGH PRESSURE, Translated from Izv. VTI, Nr 4, 1-5, AERE-LIB/TRANS-816 (1947).

The results of an experimental investigation of resistance to motion in a horizontal pipe of a two phase air-water mixture are given. On the basis of the investigation, formulas for calculating the resistance, covering pressures from 10 to 180 atmospheres, were derived.

2651. Bergelin, O. P. and Gazley, C.

CO-CURRENT GAS-LIQUID FLOW. I. FLOW IN HORIZONTAL TUBES, American Society of Mechanical Engineers, Preprint of Paper, May 1949, p. 5-18.

The major portion of the paper is devoted to the characteristics of stratified flow. Laminar and turbulent flow in each phase are discussed and the conditions of interfacial wave formation are given. Careful measurements are reported on the gas-pressure drop, the position of the interface and the interfacial gradients for air-water flow through tubes one and two inches in diameter. The gas-phase pressure drop along a smooth interface is shown to be similar to the pressure drop during a single phase flow in a smooth pipe, while the pressure drop along a wavy interface exhibits the characteristics of flow in a rough pipe.

2652. Brigham, W. E.

CONCURRENT TWO-PHASE FLOW OF LIQUIDS AND GASES IN HORIZONTAL PIPING, Ph.D. Thesis, Univ. of Okla. (1962) 140 p.

2653. Chenoweth, J. M. and Martin, M. W.

A PRESSURE DROP CORRELATION FOR TURBULENT TWO PHASE FLOW OF GAS-LIQUID MIXTURES IN HORIZONTAL PIPES, Pet. Ref. 34, 151 (1955).

Study of pressure drops for flow of two-phase mixtures of air and water in $1\frac{1}{2}$ in. and 3-in. pipes; total of 264 runs presented for tests covering pressures to 100 psia, liquid rates to 200 gpm, and air rates to 700 scfm; comparison with previous results; new correlation for turbulent two-phase flow.

2654. Chenoweth, J. M. and Martin, M. W.

PRESSURE DROP OF GAS-LIQUID MIXTURES IN HORIZONTAL PIPES, Pet. Eng. 28, 642-645 (1956).

Study of pressure drops for flow of two-phase mixtures of air and water in $1\frac{1}{2}$ in. and 3 in. pipes; total of 264 runs presented for tests covering pressures to 100 psia, liquid rates to 200 gpm, and air rates to 700 scfm; comparison with previous results; new correlation for turbulent two-phase flow.

2655. Davis, E. J.

HEAT TRANSFER AND PRESSURE DROP FOR HIGH QUALITY STEAM-WATER MIXTURES FLOWING IN A HORIZONTAL, RECTANGULAR DUCT, HEATED ON ONE SIDE, Ph. D. Thesis, U. of Wash., 210 p. (1961).

2656. Diehl, J. E. and Unruh, C. H.

TWO-PHASE PRESSURE DROP FOR HORIZONTAL CROSSFLOW THROUGH TUBE BANK, ASME Paper 58-HT-20 (1958).

Study of pressure drop for horizontal crossflow of two-phase gas liquid mixtures through four tube banks, with horizontal tubes; two tube banks have staggered-tube layouts, 60 to 45°; two have in-line or 90° tube-field layouts, 60 and 45°; two have in-line or 90° tubefield layouts; test systems studied were air-water and pentane vapor-pentane liquid; pressure drop correlation is developed for horizontal two-phase crossflow through tube banks; relevance to condensers and reboilers, in refineries, etc.

2657. Evans, L. B. and Churchill, S. W.

THE ECONOMICS OF USING PROMOTERS TO IMPROVE HEAT TRANSFER INSIDE TUBES, AIChE Preprint 3, New York (1962) 28 p.

A method is presented for determining the economic feasibility of using promoters in a heat transfer tube. The procedure requires that the rate of heat transfer and the pressure drop be known as a function of flow rate and fluid properties for the promoters under consideration. Recent empirical correlations for the heat transfer and pressure drop in tubes containing promoters are reviewed and converted to a common form. The promoters include roughening elements on the tube wall, twisted metal strips, packing material, solid axial cores, and bluff bodies centered in the tube. The method of economic analysis is illustrated for a representative application. It is shown that in certain situations a distinct monetary savings can be realized by the use of the proper promoter. In many cases the use of the promoter can provide flexibility in design and operation. On the other hand, misdesign or misoperation of an exchanger containing a promoter can be very expensive. The advantages and disadvantages of various types of promoters are discussed.

2658. Fried, Lawrence

HEAT TRANSFER AND PRESSURE DROP FOR AIR-WATER MIXTURES FLOWING IN A HORIZONTAL TUBE, University of California, M. S. Thesis (1953).

Pressure drop and heat transfer for an air-water mixture flowing in a horizontal 0.737 inch I.D. copper pipe were investigated at selected water rates. The isothermal and non-isothermal pressure drop can be correlated by Martinelli's method within +14 percent and -10 percent. The data showed a trend for each liquid rate that was different from the overall correlation, as has been noted by others.

2659. Fried, Lawrence

PRESSURE DROP AND HEAT TRANSFER FOR TWO-PHASE, TWO-COMPONENT FLOW, Chemical Engineering Progress, Symposium Series 50, No. 9, 47-51 (1954).

Pressure drop and heat transfer for an air-water mixture flowing in a horizontal 0.737-inch I.D. pipe were investigated at water rates of 2 to 26 gal/min and air rates of 2 to 45 standard cu ft/min where the flow of both phases was always turbulent. When kinetic-energy changes are compensated for, Martinelli's correlation for isothermal pressure drops is applicable to nonisothermal flow. Heat-transfer coefficients can be predicted from plots of ψ^2, equal to the ratio of the two-phase to the liquid-phase heat-transfer coefficient, against ϕ^2, equal to the ratio of the two-phase to the liquid-phase pressure drop. Heat-transfer coefficients were computed by use of logarithmic and integrated mean-temperature differences; the latter gave the better correlation.

2660. Gollobin, L. P.

A STUDY OF THE PRESSURE DROP ACCOMPANYING FLOW OF A FLASHING FLUID IN A CIRCULAR PIPE, Kansas State College of Agriculture and Applied Science, M. S. Thesis (1952) 75 p.

Use of the ring flow picture and the associated mathematical analysis yielded satisfactory results for the prediction of frictional pressure drops due to the adiabatic flow of a flashing water-steam mixture in a horizontal three-eighths inch I.P.S.-schedule 40 galvanized iron pipe, within the range of experimental data. The range of data observed were: mass velocity, G, from 73.5 to 133 lbs/sec (sq ft); inlet pressure, 27.7 to 42 psia; and inlet quality, y, 0.026 to 1.95%. More detailed conclusions resulting from acceptance of the presented analysis are as follows:

(1). A flashing fluid exhibits an annular ring type flow.

(2). Linear velocities of the vapor and liquid streams increase together and are the same at any cross section downstream in the pipe.

(3). The diameter of flow for both phases approaches closely the inside diameter of the pipe, even at low values of quality.

(4). The overall head loss measured during flow of the flashing fluid consists of velocity and friction head terms. There is little difficulty associated with approximating velocity heads which are based on k.e. changes only, for both one and two-phase flow problems. Combined friction heads are the sum of vapor and liquid flow contributions.

(5). Except for conditions of very low inlet quality the gas phase flow frictional contribution is most important in determining the overall friction head.

2661. Govier, G. W. and Omer, M. M.

HORIZONTAL PIPELINE FLOW OF AIR-WATER MIXTURES, Can. J. Chem. Eng., 40, 93-104 (1962).

New data on the flow patterns, pressure drop, and holdup encountered in the horizontal flow of air-water mixts. for a 1.026-in. pipe cover the air-water ratios of 0.1-200 for 10 superficial water velocities of 0.01-5.03 ft/sec. The pressure drop data are correlated in terms of a 2-phase friction factor, the air-water vol. ratio, and a Reynolds no. based on the superficial velocity. (CA-62-13582g).

2662. Isbin, H. S., et. al.

TWO PHASE STEAM-WATER PRESSURE DROPS, CEP Symp. Ser. No. 23, 55, 75-84 (1959).

Frictional pressure drops for steam-water mixtures have been determined for the following ranges of conditions; pressure, 25 to 1415 psia; total flow rate, 454 to 4350 lb/hr; and quality from about 0.03 to 0.98. The steam-water mixtures were synthesized by mixing steam and water, and pressure drops were measured for adiabatic flow in horizontal pipes, 0.484 and 1.062-in.i.d. Considerable care was taken to insure that the method of mixing did not influence the pressure drop results, and that the pressure measurements were made sufficiently far from both entrance and exit. The data are compared to standard correlations, and a new restricted correlation is suggested which takes into account the pressure and flow rate dependencies.

2663. Jakob, M., Leppert, G. and Reynolds, J. B.

PRESSURE DROP DURING FORCED-CIRCULATION BOILING, Chem. Eng. Prog. Sym. Ser. 52, No. 18, 29 (1956).

Experimental results are reported for pressure drop during forced-circulation boiling of distilled water in an electrically heated horizontal tube. Empirical correlations are presented for the variation of the static pressure gradient with weight fraction evaporated and with absolute system pressure, together with correlations for the total static pressure drop from the inception of boiling to the end of the heated length as a function of the total fraction evaporated and of absolute pressure.

2664. Jenkins, R.

TWO PHASE TWO-COMPONENT FLOW OF AIR AND WATER, M. S. Thesis, Univ. of Delaware, (Sept. 1947) 52 p.

The many developments of recent years involving two-phase flow in pipes have created a need for methods to predict flow characteristics and pressure drops for this complicated type of fluid flow.

Pressure drop data were takenduring the simultaneous flow of air and water in a horizontal 1-inch copper tube. The air flow rate was varied from 5 to 250 lbs/hr while the water flow rate was varied from 170 to 2900 lbs/hr. The method of correlation used by Martinelli brought the data to within ±40% of the mean. This degree of correlation is similar to that reported by Martinelli. The data of this investigation, which were taken in the liquid phase, do not agree with those of Gazley and Bergelin, taken in the gas phase, probably because of the effect of hydraulic gradient.

A classification of the flow phenomena into several categories was made on both basis of visual observations and on the basis of the plot of a fictitious friction factor vs. a fictitious Reynolds number. These categories of flow are defined and descriptions of their characteristics are given. A preliminary theoretical study is presented, based upon the more important variables. The resulting expressions, however, do not represent the experimental data with sufficient accuracy to be of practical value, and it appears that additional factors must be considered in future analyses.

2665. King, C. D. G.

HEAT TRANSFER AND PRESSURE DROP FOR AN AIR-WATER MIXTURE FLOWING IN A 0.737 INCH ID HORIZONTAL PIPE, Univ. of California, MS Thesis (1952).

The heat transfer and pressure drop characteristics of two-phase, two-component, nonisothermal flow of an air-water mixture in a 0.737 inch ID copper pipe were investigated experimentally.

After correction to allow for the change of momentum of the fluids, the two-phase non-isothermal pressure drop was correlated by means of Martinelli's modulus X equal to the square root of the ratio of the pressure drop for the liquid considered as flowing alone and filling the entire pipe to the pressure drop for the gas considered in the same manner. The results indicate, as has previously been found, that the liquid rate also appears to be a significant parameter.

The liquid volume ratio, R, was also correlated using the modulus X. Abou-Sabe's investigation indicated that the flow pattern might be of significance, but no indication of this was found in this investigation.

The flow patterns for various flow rates were investigated. For a given combination of flow rates of the liquid and gas, widely divergent flow patterns were noted at the entrance to and exit from the test section, a condition which did not occur during Abou-Sabe's investigation. This leaves open to question the method of prediction of the flow pattern, developed by Abou-Sabe, which is dependent only on the weight rates of flow of the two phases.

2666. Leppert, G.

PRESSURE DROP DURING FORCED CIRCULATION BOILING, Ph.D. Thesis; Illinois Institute of Technology (1954) 110 p.

The experimental work reported herein is limited in its scope to forced circulation of water through a horizontal round tube with the following approximate ranges of variables:

a. Mass velocity: 110 to 360 lb/sec ft^2. This corresponds to inlet liquid velocities of 1.8 to 6 ft/sec.

b. Absolute pressures: 30 to 300 psia.

c. Heat flux: 350,000 B/hr ft^2 maximum. This corresponds to a maximum power input of 60 Kw to the test section.

d. Fraction of flow evaporated: 44% maximum.

e. Ratio of net boiling length to inside diameter of tube: 64 to 128.

2667. Lester, G. W.

CORRELATION OF TWO-PHASE PRESSURE DROP MEASUREMENTS FOR STEAM-WATER MIXTURES IN A 4.06 IN. DIAMETER AND A 6.06 IN. DIAMETER HORIZONTAL PIPELINE, AERE CE/M 217 (1958).

2668. Lilleleht, L. U.

INTERFACIAL STRUCTURE FOR A HORIZONTAL COCURRENT AIR-WATER FLOW, Ph.D. Thesis, U. of Ill. (1962) 141 p.

2669. Martinelli, R. C., et al.

ISOTHERMAL PRESSURE DROP FOR TWO-PHASE TWO-COMPONENT FLOW IN A HORIZONTAL PIPE, Am. Soc. Mech. Engrs. Trans. 66, 139-51 (1944).

Static pressure drop accompanying isothermal two-phase two-component flow of air and eight various liquids, including benzene, water, and SAE 40 oil, was measured for flow conditions varying from all air to all liquid in 1-in. glass pipe and $\frac{1}{2}$-in. galvanized iron pipe; macroscopic analysis of flow phenomenon is presented.

2670. Melvin, B. W., Jr.

A STUDY OF ISOTHERMAL PRESSURE DROP FOR TWO PHASE FLOW OF OIL AND AIR THROUGH A HORIZONTAL PIPE, B. S. Thesis, Univ. of Delaware (1950).

2671. Pike, R. W., Jr.

THE ADIABATIC, EVAPORATION, TWO-PHASE FLOW OF STEAM AND WATER IN HORIZONTAL PIPE, Ph.D. Thesis, Georgia Inst. of Tech. (1962) 251 p.

2672. Ravens, C.

PRESSURE DROP AND HEAT TRANSFER ACCOMPANYING TWO COMPONENT TWO PHASE FLOW IN HORIZONTAL PIPES, M. S. Thesis, Univ. of Calif. (1941).

2673. Ravenscroft, R. W.

PRESSURE DROP AND HEAT TRANSFER ACCOMPANYING TWO-COMPONENT, TWO-PHASE FLOW IN HORIZONTAL PIPES, University of California, M. S. Thesis (1943) 63 p.

This thesis is an attempt to coordinate the writer's research and several other poly-component, poly-phase flow researches. The complexity of the problem is increased by the consideration of: I. Properties of Components; II. Intercomponent Properties; III. Physical Properties of the Flow System; IV. Ambient Conditions Affecting Flow System; V. Degrees of Control of Variables.

There were observed the following types of flow: (a) slug flow, (b) liquid in bottom, (c) eccentric annular ring flow, (d) concentric annular ring flow, (e) froth, mist, emulsion flow, (f) dog tooth flow. The conditions for each type of flow were given. A heat exchanger for two-component flow is described. A theoretical prediction of pressure drop during evaporation using isothermal data and a sample problem are given.

2674. Reid, R. C., et al.

TWO PHASE PRESSURE DROPS IN LARGE DIAMETER PIPES, AIChE Jour. 3, 321 (1957).

Four and six-inch steel pipes were installed in parallel on straight horizontal run of 76 ft to investigate two-phase flow in large pipes; flow sheet of system is shown; single-phase pressure drops were experimentally determined and were compared with values calculated by use of roughness factors of 0.00015 and 0.0015 ft; results compared with other experiments.

2675. Reynolds, J. B.

LOCAL BOILING PRESSURE DROP, ANL-5178 (1954) 44 p.

Local boiling pressure drop data for forced circulation of distilled water in a uniformly heated, horizontal, Type 347 stainless steel tube ($\frac{3}{8}$ in. ID x $\frac{1}{2}$ in. OD x 6 ft long) is correlated within ±20% over the following range of variables: heat fluxes from 130,000 to 304,000 Btu/(hr)(sq ft); mass velocities from 343 to 652 lb/(sec)(sq ft) (corresponding to inlet water velocities of 7 to 10.6 fps); and pressures from 45 to 100 psia.

Graphical comparison of local boiling pressure drop to isothermal pressure drop shows a maximum ratio of approximately 2.6.

2676. Rogers, J. D.

TWO-PHASE FLOW OF HYDROGEN IN HORIZONTAL TUBES, University of California, AECU-2203 (nd) 85 p.

Estimation of the pressure drop and vapor composition resulting from liquid hydrogen transfers over a range of conditions, developed with respect to present-day knowledge of two-phase flow, has been undertaken. Rigorous equations are used, and calculations as functions of the parameters diameter, $\frac{1}{8}$ inch to 4 inch; mass rate, 4.4×10^{-3} to .42 lbs/sec pressure, 14 to 30 psia, gas composition, 0.005 to 0.775 weight fraction; and heat leak, equivalent to 0 to 4.4×10^{-3} Btu/ft-sec for a $\frac{3}{4}$ in. line have been made.

2677. Taylor, T. H. M.

PRESSURE DROP ACCOMPANYING ISOTHERMAL TWO-COMPONENT TWO-PHASE FLOW IN A HORIZONTAL GLASS PIPE, University of California, M. S. Thesis, 1943.

The surface tension effect appears minor over the range studied, since no particular change in pressure drop was noted upon adding Nekal BX to water for a surface tension reduction of 36 per cent. However, a tremendous change in flow type was noted, the wetting agent causing the two phases to coalesce, forming an emulsion. This result would indicate that for substantial flow rates, the flow has only a minor effect upon the pressure drop.

The "apparent kinematic viscosity" had been calculated and plotted against the weight-rate ratio, which is the pounds of air per second divided by the pounds of liquid per second through the pipe. The apparent kinematic viscosity was computed by using the single-phase Weisbach equation and composite Reynolds number vs. friction factor curves. In substituting into the single-phase equations, the weight rate used was the sum of the weight rates of air and liquid; density was the sum of weight rates of air and liquid divided by product of weight rate of the air and the specific volume of air plus the product of the weight rate of liquid and the specific volume of the liquid.

2678. Van Wingen, N.

PRESSURE DROP FOR OIL-GAS MIXTURES IN HORIZONTAL FLOW LINES, World Oil 129, 156-8 (October 1949).

A comparison between analytically derived and empirical pressure drop data for mixtures in 3-inch flow lines indicates a generally satisfactory agreement.

2679. Wicks, M.

ENTRAINMENT AND PRESSURE DROP FOR HORIZONTAL TWO-PHASE FLOW OF AIR AND WATER, Ph.D. Thesis, U. of Houston, 175 p (1958).

2680. Widell, T.

PRESSURE LOSSES IN FLOW OF GAS AND LIQUID MIXTURES IN HORIZONTAL PIPES, Tidskrift for Teknisk-Vetenskaplig Forskning 20, 60-74 (1949).

The pressure loss with simultaneous flow of air and water and of steam and water in horizontal pipes has been determined. The test results differ from those obtained in the United States.

2681. Yagi, S. and Kato, Y.

FUNDAMENTAL STUDIES OF HORIZONTAL-PIPE REACTOR. Chemical Engineering (Japan) 18, 2-15, 1954, Flow Mechanism and Pressure Drop of Two Phase Flow in a Horizontal Pipe.

Pressure drops in the horizontal-pipe reactor are presented. During the parallel flow of high-velocity gas and atomized liquid in the pipe, such operations as absorption and desorption and chemical reaction processes are effectively carried out owing to the increase of the contact area and the chance of collision. For flow patterns and pressure drops of gas-liquid mixture through horizontal pipes flow patterns are classified into five stages according to the flow rates, and an experimental formula is derived for the pressure drops of the flow.

In absorption of CO_2 by Na_2CO_3 and K_2CO_3 solns. over-all absorption coeffs., KGa were measured under various conditions; they are expressed as functions of gas velocity, liquid flow rate, pipe diam., temp., and degree of conversion to bicarbonate over the couen. ranges (Na = 0.25-1.5V and K = 0.22-2.6N).

Inclined Tubes

2682. Bogdanov, F. F.

INVESTIGATION ON THE EFFECT OF VELOCITY OF FLOW OF WATER ON THE HEAT TRANSFER COEFFICIENT DURING BOILING IN INCLINED TUBES, Izvest. Akad. Nauk. SSSR Otdel. Tekh. Nauk. No. 4, 136-40 (1955).

The results of an investigation on the effect of the rate of motion of the liquid on the heat exchange coefficient, when it boils in an inclined tube, are described. Figures are given to show the heat exchange coefficient as a function of the circulation rate, for various values of the pressure and specific thermal load. It is shown that this coefficient is a linear function of the circulation rate, in the range of this parameter investigated. Some considerations are given regarding the mechanism of the heat exchange process when the circulating liquid boils in tubes, and a criterial form of generalization is proposed for this form of heat exchange.

2683. Brigham, W. B. and Holstein, E. D.

TWO PHASE CONCURRENT FLOW OF LIQUIDS AND AIR THROUGH INCLINED PIPES, ASME Paper No. 57-Pet-14 (1958).

Study of effect of up and down hill flow on pressure drops; recent field results show that excessive pressure drops have been encountered in two-phase pipe lines through hilly country; tests made with oil, water and air.

2684. Kosterin, S. I.

STUDY OF INFLUENCE OF TUBE DIAMETER AND POSITION UPON HYDRAULIC RESISTANCE AND FLOW STRUCTURE OF GAS-LIQUID MIXTURES, Izvestiya Akademii Nauk Soyuza Sovetskikh Sotsialisticheskikh Respublik, Otdelenie Tekhnicheskikh Nauk 1949, No. 12 1824-1831.

This article discusses some results of investigations of hydraulic resistances and flow structures of gas-liquid mixtures in horizontal still tubes 15 meters in length and of four different diameters, as well as in a vertical and an inclined tube 25 mm. in diameter.

2685. Levy, S. and Swan, C. L.

PERFORMANCE-TWO-PHASE PRESSURE DROP, BURNOUT, AND HYDRAULIC OSCILLATION OF AN INCLINED TEST SECTION WITH NET STEAM GENERATION AT 1000 PSIA, GEAP-3228 (Rev. 1) (1959) 26 p.

Burnout, pressure-drop, and hydraulic-oscillation tests were performed in an annular geometry inclined 45° from the vertical. Data are presented for a uniformly heated rod, 0.540 in. in diameter and 9 ft 2 in. long, located within a circular pipe of 0.875 in. ID. All measurements were made with net steam generation at 1000 psia, and the test variables covered ranges previously studied in the vertical direction. The test results reveal that the performance of the inclined section can be readily determined from that of a vertical channel.

2686. Sevigny, R.

AN INVESTIGATION OF ISOTHERMAL, CO-CURRENT, TWO-FLUID, TWO-PHASE FLOW IN AN INCLINED TUBE, Ph.D. Thesis, Univ. of Rochester (1962) 181 p.

2687. Styrikovitch, M. A. and Miropolskii, Z. L.

ON THE EFFECT OF ANGLE OF SLOPE ON THE TEMPERATURE STATE OF THE WALL OF STEAM GENERATING TUBES AT HIGH PRESSURES, Translated from: Doklady Akad Nauk SSSR 80, 57-60 IGRL-T/R-4 (1951).

Vertical Flow

2688. Anderson, G. H. and Mantzouranis, B. G.

TWO PHASE (GAS-LIQUID) FLOW PHENOMENA, PART 1, PRESSURE DROP AND HOLD UP FOR TWO PHASE FLOW IN VERTICAL TUBES, Chem. Eng. Sci. 12, 109-26, (May 1960) 233-42 (July 1960).

A theory for 2-phase flow in a vertical tube when the liquid flow is annular is developed. Published data on hold-up and pressure drop, together with original data on air-H_2O mixts. in a $\frac{1}{2}$-in.-diam. glass tube, are examd. in the light of this theory. The theory is found to fit the data satisfactorily and also to predict conditions under which annular flow changes to slug flow.

2689. Armand, A. A.

INVESTIGATION OF THE MECHANISM OF TWO-PHASE FLOW IN VERTICAL PIPES, ARTICLE IN THE BOOK ENTITLED, HYDRODYNAMICS AND HEAT TRANSFER WITH BOILING, Edited by M. A. Styrikovich, Acad. Nauk. SSSR Moscow, AEC-TR-4490 (1954).

2690. Becker, K. M., Hernborg, G. and Bode, M.

AN EXPERIMENTAL STUDY OF PRESSURE GRADIENTS FOR FLOW OF BOILING WATER IN A VERTICAL ROUND DUCT, Part I, AE 69 (March 1962) 46 p.

Frictional pressure gradients for flow of boiling water in a vertical channel have been measured in a wide range of variables. The test section consisted of an electrically heated 10 mm inner diameter stainless steel tube of 3120 mm length.

Data were obtained for pressures between 6 and 42 ata, steam qualities between 0 and 80%, flow rates between 0.03 and 0.40 kg/sec and surface heat flux between 24 and 80 W/cm^2.

Preliminary measurements of heat transfer and pressure drop for one phase flow of water showed an excellent agreement with one phase flow theory. Extrapolating our data to 100% quality, an excellent agreement with one-phase flow theory is also found for this case.

The two phase flow results are generally 0-40% higher than the results of Martinelli and Nelson. Extrapolating our data to 137 ata fine agreement is found with the results of Sher and Green.

On the basis of the measured pressure gradients, a very simple empirical equation has been established for engineering use. This equation correlates our data (more than 1000 points) with a maximum discrepancy of ±20% and with an average discrepancy of ±5%.

AKTIEBOLAGET ATOMENERGI, Stockholm, Sweden.

2691. Becker, K. M., Hernborg, G. and Bode, M.

AN EXPERIMENTAL STUDY OF PRESSURE GRADIENTS FOR FLOW OF BOILING WATER IN VERTICAL ROUND DUCTS, AE 70 (1962) 32 p.

The present report contains the results of the second phase of an experimental investigation concerning frictional pressure gradients for the flow of boiling water in vertical channels. The test section for this phase consisted of an electric heated stainless steel tube of 3120 mm length and 7.76 mm inner diameter.

Data were obtained for pressures between 6 and 41 ata, steam qualities between 0 and 70 per cent, flow rates between 0.025 and 0.210 Kg/sec and surface heat flux between 30 and 91 W/cm^2.

The results are in excellent agreement with our earlier data for flow in a 9.93 mm inner diameter duct, which were presented in report AE-69.

From the measurements we conclude that in the range investigated the non-dimensional pressure gradient ratio, ϕ^2, is dependent of mass flow rate, inlet sub-cooling and surface heat flux.

On the basis of the measured pressure gradients, the following empirical equation has been established for engineering use.

$$\phi^2 = 1 + 2400\left(\frac{x}{p}\right)^{0.96}$$

This equation correlates our data (more than 1000 points) with a discrepancy of less than ±15 per cent.

AKTIEBOLAGET ATOMENERGI, Stockholm, Sweden.

2692. Bergelin, O. P. and Kegel, P. K.

CO-CURRENT GAS-LIQUID FLOW II. FLOW IN VERTICAL TUBES, American Society of Mechanical Engineers, Preprint of Paper, May 1949, p. 19-28.

An experimental study is reported on the pressure drop for the downward turbulent flow of air and water through a vertical one inch tube. The liquid was introduced at the two walls so that the gas essentially flowed through the center of an annulus of liquid. The present results lie within the spread of previous data when correlated by the method of Martinelli and co-workers. The results are compared on ϵ friction factor Reynolds number basis with data for annular flow in a horizontal tube and the two cases are shown to approach each other at high gas velocities. In both cases the presence of the liquid phase causes "rough-pipe" pressure drop characteristics for the gas phase. The experimental results are extended to cover the pressure drop during the condensation of water and several organic vapors in a vertical tube condenser. An empirical relation is proposed as a correlating factor for the physical properties of the materials and a tentative correlation is presented. Measured and calculated pressure drops are compared for the condensation for 5 materials.

2693. Collier, J. G.

PRESSURE DROP DATA FOR THE FORCED CONVECTIVE FLOW OF STEAM-WATER MIXTURES IN VERTICAL HEATED AND UNHEATED ANNULI, AERE-R 3808 (Mar 1962) 95 p.

Data are presented for pressure drop in steam-water mixtures flowing in vertical annuli at pressures up to 80 psia, with and without heat addition. Preliminary analyses are based on the homogeneous and Lockhart-Martinelli models.

2694. Cook, W. H.

BOILING DENSITY STUDIES IN MULTIPLE RECTANGULAR CHANNELS, p. 110, Reactor Heat Transfer Information Meeting Held at Brookhaven National Lab. Oct. 18-19, 1954, BNL-2446 (Dec. 1955) 195 p.

The density of a steam-water mixture boiling at 600 psia is being studied in a natural circulation loop constructed at Argonne National Laboratory. The apparatus measures the density of the steam-water mixture along a 60 inch channel length. The channel presently consists of three $\frac{1}{4}$ inch channels 4 inches in depth but may be modified for other geometry. Density measurement is accomplished by attenuation of gamma rays from a thulium source.

It is planned to study power density, inlet subcooling, geometry and pressure effects upon steam void formation. Preliminary results are discussed.

2695. Cook, W. H.

BOILING DENSITY IN VERTICAL RECTANGULAR MULTICHANNEL SECTIONS WITH NATURAL CIRCULATION, ANL-5621 (1956) 125 p.

Boiling density experiments were conducted on $\frac{7}{16}$ x $3\frac{11}{16}$-inch channels, two and four feet long, at pressures from 164.7 to 614.7 psia, inlet subcoolings up to 20F and exit steam weight fractions up to 0.15. Power input was varied from 10 to 50 kw/liter for a 5.04-liter coolant volume by resistance heating of $\frac{1}{16}$-inch stainless steel plates. High-resistivity, demineralized water was used throughout the tests.

The steam void fraction was studied rather than density because it is conveniently related to the ratio of steam to liquid velocities (v_g/v_f) and the steam weight fraction (x), which are fundamentally involved in continuity of the two phases.

Steam void fraction curves normalized with respect to average void fraction demonstrated that thermal equilibrium did not exist over portions of the channel when inlet liquid temperature was below saturation, although thermal equilibrium was again reestablished at the exit of 48-inch long channels. Data of runs with inlet liquid at saturation temperature, where thermal equilibrium was assured, were studied with analytical models for variation of (v_g/v_f) with length using the normalized void fraction plots.

A definite change of v_g/v_f with position in the channel was shown to exist, the variation being approximately linear with channel length for runs where inlet liquid was at saturation temperature.

Assuming v_g/v_f to be a function of the volume rate of vapor flow and the volume rate of liquid flow, it may be shown that the rate of change of v_g/v_f with length is proportional to the rate of vaporization. Experimental data verified this and showed the change of v_g/v_f with length approaches zero when the rate of vaporization approaches zero. Experiments with unheated riser sections also show this to be true. The conclusion was drawn that the change of v_g/v_f reflects the acceleration required to remove steam formed in the channel.

Satisfactory correlations of v_g/v_f for saturated inlet conditions were found from plots of v_g/v_f versus volume rate of liquid flow and plots of v_g/v_f versus the ratio of liquid to vapor fractions. These correlations appeared unsatisfactory, however, for data obtained with inlet liquid below saturation temperature. A general correlation was found for all data by use of an analytical model. Plots derived from the analytical model showed v_g/v_f to be a function of the rate of vaporization for liquid inlet temperatures

below, and at, saturation, with a small spread due to effects of per cent of the channel length in boiling L_b/L.

Values of v_g/v_f at the exit of a two-foot channel were shown to be the values at the corresponding point of a longer channel, indicating that length of channel is not a prime factor in determining phase velocity relationships.

Flow and two-phase pressure drop data were obtained for predicting flow in channels. A correlation of the Martinelli ratio of two-phase friction gradient to single-phase friction gradient with mean steam void fraction was satisfactory for all pressures.

2696. Dinos, Nicholas

PRESSURE DROP FOR FLOW OF BOILING WATER AT HIGH PRESSURE, DP-698 (May 1962) 22 p.

Pressure drops were measured for the upward flow of boiling water inside a heated tube that mocked up a coolant channel of a power reactor fuel assembly. The tube was 18 feet long and $\frac{1}{2}$ inch in diameter; the test conditions included system pressures between 400 and 1000 psia, mass velocities from 0.8×10^6 to 7.9×10^6 lb/(hr)(ft^2), inlet subcoolings from 29 to 96°C, and exit vapor qualities up to 50%. For certain conditions, the flow was a multiple-valued function of the pressure drop. The measured pressure drops were an average of 7% higher than values calculated on the assumption that the two-phase mixture was a single phase with averaged properties.

2697. Dukler, A. E.

AN INVESTIGATION OF PRESSURE DROP FOR ISOTHERMAL TWO-PHASE FILM FLOW IN A VERTICAL TUBE, University of Delaware, M. S. Thesis (1949) 88 p.

This investigation was concerned with the pressure drop occurring during the two-phase, concurrent downward flow of water and air in a one-inch vertical tube where the water flowed as an annulus on the tube wall with the air as a moving core. Pressure drop data were obtained for water rates from 172 lbs/hr to 730 lbs/hr and over a range of air rates from 22 lbs/hr to 227 lbs/hr.

2698. Dunn, J. S. C.

GAS-LIQUID FLOW IN VERTICAL PIPES, M. S. Thesis, Univ. of Edmonton, 148 p. (1952).

The problem undertaken is an investigation of the significance of certain variables on the pressure drop and the liquid hold-up in flowing two-phase mixtures of air and water in vertical tubes. The objective is to present the pressure drop data in the form of a friction factor-Reynolds number relationship with the necessary other parameters similar to that for single-phase flow.

2699. Epperson, T. R.

TWO-PHASE FRICTIONAL PRESSURE DROP DURING NATURAL CIRCULATION BOILING IN A VERTICAL RECTANGULAR HEATED CHANNEL, M. Sc. Thesis, Michigan College of Mining and Technology (1957).

2700. Foltz, H. L. and Murray, R. G.

TWO-PHASE FLOW RATES AND PRESSURE DROPS IN PARALLEL TUBES, Chem. Eng. Prog., 56, 83 (1960).

Two phase Freon-114 flow rates and pressure drops were measured in an electrically heated natural-circulation loop containing two 4- and two 8-ft lengths of vertical brass pipes. The flow rates through the 8-ft pipes increased with an increase in heat flux, reached a maximum at 3,200 Btu/(hr)(sq ft), and then decreased as the heat flux was increased. The maximum obtainable heat flux, for both long and short pipes, was limited to 14,000 Btu/(hr)(sq ft) because of the limitations on the electrical heaters. The flow rates through the 4-ft pipes continued to increase with increases in heat flux up to the maximum. An equation which assumed fog flow, or no slip was developed from a mechanical energy balance to calculate two-phase pressure drops. This equation, containing only the independent variables of heat input, flow rate, and pipe length, was programmed for an analogue computer, and a series of pressure-drop curves, representing different flow rates, as a function of heat input was drawn for each pipe length. The calculated pressure drops were approximately 25% lower than the measured values, owing primarily to the effect of slip and subcooling at the inlet end of each tube.

2701. Geib, F. R.

PRESSURE DROP DUE TO THE VERTICAL FLOW OF AIR-WATER MIXTURE, University of Illinois, B. S. Thesis (1939).

An effort has been made to determine the pressure drop occurring with the vertical flow of two phases, i.e., water and air. The variables studied were the water and air rates and the bubble size.

The pressure drop resulting from 88.5 lbs/min of water flowing through a 1.055 inch diameter glass tube 5.17 ft long, was 0.16 lbs/sq in. Using the same tube but with an air-water mixture flowing, volumetric ratio of air to water equal to 0.167 and a water rate of 88.5 lb/min, the pressure drop was 0.272 lbs/sq in. thus illustrating the importance of gases on the pressure drop of flowing fluids. As the bubble size is one of the determining factors in this type of flow an attempt to calibrate a grid type bubble was also carried out with no success.

2702. Green, S. J., et. al.

PRESSURE DROP IN RECTANGULAR CHANNELS AT 2000 PSIA, 1956, In Reactor Heat Transfer Conference of 1956, J. E. Viscardi, Comp. p. 172-191, TID-7529 (pt 1).

The desirability of improving the thermal design criteria for pressurized water reactors has stimulated an experimental program to study the pressure drops associated with high-pressure water systems. These studies included isothermal, heating, local boiling, and bulk boiling conditions during vertical upflow in a geometrically simulated reactor channel at 2000 psia. Experiments were performed in test sections with nominal dimensions of 27 in. by 1 in. by 0.097 in. and 27 in. by 1 in. by 0.050 in.; however,

only 11 runs have been completed with the smaller channels. Pressure drop data have been obtained for mass velocities from 0.7 x 10^6 lb/hr-ft^2 to 5.0 x 10^6 lb/hr-ft^2, inlet temperatures from 400°F to 625°F, heat fluxes (axial heat flux distribution is uniform) as high as 1.0 x 10^6 Btu/hr-ft^2, and exit qualities as high as 40%. Preliminary design recommendations, based upon available data, are presented.

2703. Green, S. J. and Sher, N. C.

BOILING PRESSURE DROP IN THIN RECTANGULAR CHANNELS, Preprint No. 146, Session 24, Presented at Nuclear Engineering and Science Conference, Chicago, Mar. 17-21, 1958. American Institute of Chemical Engineers (1958) 41 p.

Tests conducted at Bettis Plant have yielded steady-state boiling and non-boiling pressure drop data for water flowing vertically upward in rectangular channels at 2000 and 1100 psia. Available void data, obtained at conditions corresponding to some of the pressure drop tests, have been reviewed, and a technique for incorporating these data in an analysis of pressure drop data has been developed. Preliminary results show that local boiling pressure drop can be treated on exactly the same basis as bulk boiling pressure drop if the necessary void information is available. A procedure has been developed for estimating boiling and non-boiling pressure drops in rectangular channels at 2000 psia independently of the experimental void data.

2704. Hoglund, B. M., et al.

TWO-PHASE PRESSURE DROP IN A NATURAL CIRCULATION BOILING CHANNEL, ANL-5760 (1961) 41 p.

Experimental two-phase pressure drop data were obtained from a $\frac{1}{2}$ x 2 x 60-in. vertical, uniformly heated, test section. The local volume fraction of steam was measured simultaneously with the pressure drop, thus allowing separation of the terms for hydrostatic and acceleration pressure drops from the over-all static pressure drop. The results are expressed in terms of an average two-phase friction factor multiplier, $\overline{R} = \Delta P_{TPF}/\Delta P_{LO}$, and are compared with the Martinelli-Nelson correlation, the Lottes-Flinn correlation, and a correlation combining that of Martinelli-Nelson and a flowrate parameter. The ranges of variables include: pressure from 150 to 600 psig; power density from 17.2 to 94.5 kw/liter of coolant; sub-cooling from 4.8 to 25.7°F; exit qualities from 0.009 to 0.065; exit steam volume fraction from 0.19 to 0.77; and velocities from 2.56 to 3.43 fps.

2705. Holloway, C. A., Jr.

FLOW OF GAS-LIQUID MIXTURE IN A VERTICAL TUBE, University of Illinois, M. S. Thesis (1938).

It is frequently necessary for a chemical engineer to calculate the friction drop of a gas-liquid mixture which is flowing in pipes. As far as can be learned, up to the present time no work has been done to indicate whether or not the ordinary methods of calculation apply in this instance. Our present research indicates that these methods are satisfactory, provided that in using a certain property of the fluid flowing, the weighed average of the property of the gas and of the property of the liquid is the one used.

2706. Hughmark, G. A. and Pressburg, B. S.

HOLDUP AND PRESSURE DROP WITH GAS-LIQUID FLOW IN A VERTICAL PIPE, AIChE Jour. 7, 677-82 (1961).

Vertical upward concurrent air-liquid flow was investigated under isothermal conditions in a test section of 1-in. schedule 40 pipe. Pressure drop was measured with a mercury manometer connected to two pressure taps 20 ft. apart in the section. Liquid was trapped between two quick shutoff valves activated by two solenoid valves. The liquid was drained from the section to provide the holdup data. Six liquids were used to determine the effect of density, viscosity, and surface tension. The experimental holdup, and two-phase pressure drop data were not in agreement with the Lockhart-Martinelli type of correlation for horizontal flow. A statistical correlation for holdup was developed to include fluid physical properties, total mass velocity, and the air-liquid ratio entering the pipe. Similarly a pressure drop correlation was developed which expressed the two-phase pressure drop as a function of the slip velocity, liquid physical properties, and total mass velocity. This correlation showed an average percentage error of less than 15% between the observed and the calculated total pressure drop.

2707. Huth, L. H.

THE VERTICAL FLOW OF A GAS-LIQUID MIXTURE, University of Illinois, B. S. Thesis (1938).

This investigation was conducted to determine if the Fanning equation holds for an air-water mixture. The equation presented by Moore and Wilde was also tested with the data obtained. It was discovered that the frictional drop could not be calculated by either equation.

2708. Jacket, H. S., Roarty, J. R. and Sher, N. C.

BOILING PRESSURE DROP IN RECTANGULAR CHANNELS, WAPD-TH-204 (1956) 22 p.

A considerable amount of bulk boiling pressure drop data has been obtained from vertical, rectangular, Zircaloy-2 channels at 2000 psia along with additional heating and local boiling results. The over-all ranges of test conditions have been extended to include mass velocities from 0.7 x 10^6 to 5.0 x 10^6 lb/hr-ft^2, inlet temperatures from 400 to 625°F, heat fluxes as high as 1.0 x 10^6 Btu/hr-ft^2 and exit qualities as high as 40%. Nine 27 in. x 1 in. x 0.097 in. and two 27 in. x 1 in. x 0.050 in. test sections have been used; however, only 11 runs were performed in the smaller channels. Test conditions existing during each run are presented.

2709. Jaroshek, K. and Brandt, F.

INVESTIGATIONS OF FRICTIONAL PRESSURE LOSSES IN STEAM AND WATER MIXTURES AND LEAD VELOCITY OF STEAM IN VERTICAL BOILER TUBES, Transl. from Brennstoff-Wärme Kraft 11, 407-13, AEC-TR-3977 (1959).

The values known at present on lead velocities of steam and friction coefficients were supplemented by means of measurements in a vertically flowing steam-and-water mixture in a water circulation model of a natural size up to the pressure of 200 atm abs for a tube of 57.5 mm in inside diameter. Theoretical interpretation of the data allowed one to analyze the lead velocity as a true constituent determined by the square profile density. The increase in the friction coefficients could be explained by an increased degree of turbulence of the mixture flow. The measurements on a 42.0 mm tube light diameter lead one to conclude that there is a substantial effect of the diameter, but it has to be tested in the future.

2710. Jens, W. H. and Lottes, P. A.

TWO-PHASE PRESSURE DROP AND BURNOUT USING WATER FLOWING IN ROUND AND RECTANGULAR CHANNELS, ANL-4915 (1952) 44 p.

Two-phase pressure drop data and burnout data are reported for a vertical rectangular channel with upflow of water within the channel. Burnout data are also reported for upflow of water through a vertical pipe.

A comparison is made between experimental and calculated pressure drops. The Martinelli-Nelson method of calculating two-phase pressure drop is used with a suitable correction for hydrostatic head.

Burnout data indicate that vertical channels or tubes with upflow of water within the tubes will not overheat or burn out until the value of exit quality ranges from 70 to 100 per cent for the range of variables: inside diameter, 0.1 to 1 inch; length-diameter ratio, over 40; heat flux, up to 300,000 Btu/(hr)(sq ft); inlet subcooling, up to 150°F; and exit pressure, 14.7 psia lb/sq in. absolute. Extrapolation to other ranges is not recommended.

The effect of length-diameter ratio on the value of exit quality at burnout is also given.

2711. Katsuhara, T.

PRESSURE DROP DUE TO A FRICTION FOR PARALLEL FLOW OF MIXTURES OF VAPOR AND WATER IN A DOWNCOMER, JSME Bulletin(Japan Society of Mechanical Engineers), 1, 145-149 (1958).

Author experimentally investigated the pressure drop due to friction for the flow of water containing bubbles in a non-heated downcomer.

First, the pressure drop due to friction and dryness fraction for the parallel downward flow of the mixtures of air and water were measured in a vertical 1500 mm long and 19-mm ID glass pipe. Next, the ratios of the coefficient of friction in high-pressure regions were extensively computed from the results of the above experiment. Finally, when non-heated downcomer was used it was proposed that 0.03 be adopted as an approximate value of the coefficient of friction.

2712. Kegel, P. K.

TWO-PHASE FLOW IN A VERTICAL COLUMN, University of Delaware, B. S. Thesis (1948) 47 p.

This paper presents data for two-phase flow in a vertical, one-inch inside diameter, eleven foot long copper tube. The fluids used in this investigation were air and water, flowing co-currently through the tube. The water rate was varied from 300 to 1400 lbs/hr., while the air rate was varied from 61 to 190 lbs/hr. The flow was in the region of turbulence in all cases.

The pressure drop measurements show that the rate of pressure drop rises sharply as the water rate is increased. Superficial friction factors for the air stream indicate the presence of increasing roughness as the flow of water increased.

The correlation using parameters Φ and X indicates that the methods of Martinelli and Gazley are suitable for the prediction of pressure drop for annular flow in both horizontal and vertical tubes.

The pressure drop for two-phase, annular flow in a vertical tube is apparently greatly influenced by the degree of interfacial roughness. This degree of roughness is a function of the liquid rate for a given air rate.

The assumption of a smooth interface apparently will not hold for annular flow, since the superficial friction factor vs. Reynolds number curve does not follow the curve for smooth pipes.

2713. Lee, G.

TWO-PHASE PRESSURE DROP OF LIQUIDS BOILING IN VERTICAL TUBES, Cambridge, Mass. Institute of Technology, M. S. Thesis (1952).

2714. Le Tourneau, B. W. and Troy, M.

HEATING, LOCAL BOILING, AND TWO-PHASE DROP FOR VERTICAL UPFLOW OF WATER AT PRESSURES BELOW 1850 PSIA, TEST DATA AND CORRELATIONS, WAPD-TH-410 (1959).

Because of the immediate interest in operating reactors at pressures below 200 psia, tests were run with vertical upflow of water to obtain overall pressure drop information at different conditions of flow, pressure and channel geometry in order to evaluate and improve, if necessary, existing design procedures. Since there was an immediate need for improved pressure drop information, the tests described in the report were run because of their comparative simplicity and because the information obtained would represent a considerable improvement over the very inadequate information that is currently available.

2715. Lieberson, N. G.

TWO-PHASE FLOW IN VERTICAL PIPES, Cambridge, Mass. Institute of Technology, M. S. Thesis (1952).

2716. Powers, J. T.

PRESSURE DROP DUE TO THE FLOW OF A GAS LIQUID MIXTURE IN A VERTICAL TUBE, University of Illinois, B. S. Thesis (1940).

The pressure drop in a vertical glass tube with an air-water mixture flowing was determined for water rates from 20 to 132 lbs/min and air rates from 0.01 to 0.12 lb/min. The section of the tube used was 5.17 ft long and trapped between two stopcocks and the relative volume of air to liquid determined. By the method of Hershey, friction factors were calculated and plotted against the velocity of the mixture. A plot of ϕ, the relative volume of air to liquid, vs. $N\, v/\sqrt{d^5 g}$, a dimensionless function of the relative velocity of air, was also made.

2717. Quinn, J. A.

THE MECHANICS OF TWO-PHASE FLOW-COCURRENT COGRAVITY FLOW OF IDEAL VERTICAL FLUIDIZED SYSTEMS, Ph.D. Thesis, Princeton Univ. 89 p. (1960).

2718. Radford, B. A.

GAS-LIQUID FLOW IN VERTICAL PIPES - A PRELIMINARY INVESTIGATION, Univ. of Alberta, Canada, M. S. Thesis (1949).

Pressure drop versus rate of flow data have been determined for air-water mixtures flowing through a vertical, 22.88-foot section of smooth butyrate tubing having an inside diameter of 1.049 inches. For seven constant water rates varying from .000400 ft^3/sec to .00500 $ft^3/sec.$, the air rates were varied from zero to approximately one $ft^3/sec.$ The pressure sections were measured. Visual observations of the flow pattern were made.

This preliminary analysis showed that as the air rate increased from zero, the measured pressure drop passed through a first minimum point, a maximum point, a second minimum point and then increased smoothly for each constant water rate. Closely related to the change in pressure was a transition in the flow pattern from "slug" flow, to "froth" flow, to "film" flow and, finally, to "mist" flow.

The first minimum, the result of a rapid decrease in hydrostatic head, was characterized by "slug" flow. The pressure increase from the first minimum point to the maximum point was accompanied by a transition to pulsating, frothy flow. The rapid increase in the relative velocity of the air to the water indicated that "slippage" due to water holdup was mainly responsible for the increase in the pressure gradient. As the air rate was further increased, the pulsating "froth" flow gradually gave way to "film" flow and the measured pressure drop decreased to a second minimum point. During this decrease in pressure drop there was a decrease in the relative velocity of the air to the water. At higher rates the film disappeared and the vertical section was filled with rapidly flowing mist. The measured pressure drop for the "mist" flow increased smoothly with increased air rates and appeared to be due mainly to wall friction.

Results indicated that the "film" minimum point and the "froth" maximum point disappear at some higher water rate. The maximum and minimum pressure drop conditions for the various constant water rates occurred at similar air rates. This indicated that the flow pattern depends mainly on the air rate, and suggested that a modified Reynolds number based on the air rate might be used for further interpretative work.

2719. Schoeffel, D. E.

PRESSURE DROP AND HEAT TRANSFER IN TWO-PHASE FLOW IN A VERTICAL TUBE, Cambridge, Mass. Institute of Technology, M. S. Thesis (1952).

2720. Sher, N. C.

PRELIMINARY INVESTIGATION OF PRESSURE DROP AND HEAT TRANSFER IN RECTANGULAR CHANNELS AT 1100 PSIA, WAPD-TH-265, (1956) 46 p.

Preliminary design recommendations have been presented for estimating heating, local boiling, and bulk boiling pressure drop during upflow in vertical rectangular channels at 1100 psia. These recommendations are of the same form as previously presented for 2000 psia. The preliminary heat transfer data may be interpreted as showing fair agreement with Dittus-Boelter and Jens and Lottes correlations for predicting nonboiling and boiling forced convection heat transfer coefficients, respectively. However, uncertainties in the experimental technique prevent revising the existing design equation for calculating forced convection heat transfer coefficients.

2721. Sher, N. C.

ESTIMATION OF BOILING AND NON-BOILING PRESSURE DROP IN RECTANGULAR CHANNELS AT 2000 PSIA, WAPD-TH-300 (1957) 68 p.

2722. Sher, N. C. and Green, S. J.

BOILING PRESSURE DROP IN THIN RECTANGULAR CHANNELS, New England Engineering and Science Conf., Preprint No. 146 (1958).

2723. Short, W. L.

THE UPWARDS VERTICAL FLOW OF AIR WATER AND OIL-WATER MIXTURES: EFFECT OF SECOND PHASE DENSITY ON PRESSURE DROP, FLOW PATTERN AND HOLDUP, M. S. Thesis, Univ. of Edmonton (1957).

2724. Styrikovich, M. A.

HEAD LOSSES FROM ACCELERATION BY MOVEMENT OF STEAM-WATER MIXTURES IN VERTICAL PIPES, Kotloturbostroenie, No. 4, 8-12 (1946).

2725. Sullivan, G. A.

THE UPWARDS VERTICAL FLOW OF AIR-WATER AND OIL-WATER MIXTURES: EFFECT OF SECOND PHASE DENSITY ON PRESSURE DROP AND HOLDUP, M. S. Thesis, Univ. of Edmonton (1958).

2726. Sutor, W. L.

STUDIES ON HEAT TRANSFER AND PRESSURE DROP FOR BOILING WATER FLOWING IN A VERTICAL TUBE, University of Minnesota, Ph.D. Thesis, (1951) 82 p.

This study has led to several definite conclusions on phenomena associated with the operation of natural-circulation evaporators.

1. Results were graphically presented which show the effect of addition of heat to the liquid container on the heat transfer and flow characteristics in a natural-circulation evaporator. An appreciable increase in heat transfer coefficient with increasing amount of heat added was found. Whether this would prove to be an economical method for increasing the heat transfer capacity of a given sized evaporator was not determined.

2. Quantitative investigations were made of two different correlations recommended in the literature for determining the pressure drop in liquid-vapor flow processes.

The method of Benjamin and Miller appeared to be theoretically unsound and generally useless as a means of finding quantitatively the pressure drop in short pipes. Criticism was mainly directed at the omission of slip velocity in their analysis.

The method of Lockhart and Martinelli offered a more logical basis for evaluating the various factors contributing to the pressure drop. Calculated values of pressure drop checked within about one-half pound per square inch of the experimental values. General trends that occurred were qualitatively predicted.

2727. Uren, L. C.

FLOW RESISTANCE OF GAS-OIL MIXTURES THROUGH VERTICAL PIPES, Transactions of the American Institute of Mining and Metallurgical Engineers, 86, 209-219 (1930).

The conclusions reached in this paper are: (1) the density and viscosity of gas-oil mixtures vary as logarithmic functions of the gas-oil ratio; (2) within the range of gas-oil mixtures commonly produced from flowing and gas-lift wells, increase in the volume ratio of gas to that of oil, at a given pressure, results in increased pressure loss per linear unit of flow through the eduction tube; (3) increase in pressure for a given gas-oil ratio or a given flow velocity is productive of decreased unit pressure loss; (4) critical gas-oil ratio probably exists for any set of conditions, at which the pressure loss in flow through tubing is a minimum (5) in applying the Fanning equation to the flow of gas-oil mixtures through the vertical pipes, the friction factor (f) is found to be a logarithmic function of the Reynolds number.

2728. Weiss, D. H.

PRESSURE DROP IN TWO-PHASE FLOW, Illinois Institute of Technology, (Thesis), AECU-2180 (1952) 77 p.

The purpose of this study was to investigate experimentally two-phase flow in a single vertical channel, which was uniformly heated. The channel was a 0.174-in. I.D., 24-in. long electrically heated stainless steel tube through which distilled water was passed. The variation of pressure drop with system pressure, inlet temperature and velocity, and heat flux was determined. The conditions under which the tube fails due to local overheat was determined. An investigation was made of the characteristics of the single vertical heated channel when operating in parallel with a large number of vertical unheated channels. These data may be applied in developing methods of calculating two-phase pressure drop for use in the design of equipment for heat transfer in forced circulation at high heat flux. Use of the Martinelli and Nelson method of calculating the pressure drop is illustrated.

2729. Yagi, S. and Sasaki, T.

VERTICAL PIPE REACTOR II. PRESSURE DROP IN GAS-LIQUID TWO-PHASE FLOW, Chemical Engineering (Japan) 17, 216-23 (1953).

Experiments were carried out in vertical glass pipes of 8, 10.25, 12.5, and 17.5 mm inner diameter, employing air and various liquids under substantially isothermal conditions. Pressure drop, Δp in kg/sq m, is found to be expressed by different equations for two ranges of flow patterns. For the mist flow range,

$$\Delta p/p_{gl} = 5000\ (u_l^{-2}/2gd)^{0.75}(dL/u_l)^{-0.6}$$

and for the unsteady flow range,

$$\Delta p/p_{gl} = 0.9 \times 10^{-4}(u_l^{-2})/=gd)(\phi_l)^2 d^{0.44} \quad ,$$

where p_g and p_l are density in kg/cu m of gas and liquid, respectively; u_g and u_l, are velocity in m/sec of gas and liquid respectively, l and d are length and diameter (in m), respectively, of the pipe; L and u are mass velocity in kg/sq m sec and viscosity in kg/m sec, of liquid, respectively, and ϕ is liquid holdup in cu m/cu m. It is also shown that liquid holdup is correlated with other variables by the same experimental equation as presented in the previous paper. (CA-46-7376d).

SEPARATION OF MIXTURES

2730. Billet, Reinhard

SEPARATION OF LIQUID MIXTURES BY PARTIAL DISTILLATION (IN-FALLING-FILM STILLS) Tech. Hochschule, Karlsruhe, Ger., Chem.-Ing.-Tech. 29, 733 (1957).

A theoretical interpretation of the phys. processes and the factors affecting distn. in a falling-film still, with rotating wipers for liquid redistribution, is presented. Math. relations are developed under the following headings; basic equations for partial sepn. of liquid in thin-film distn., heat-transfer coeffs. for stills with rotating elements, ratio of liquid to vapor mixt. at any column cross section, variation of liquid and vapor concn. along the column wall, pressure distribution and vapor formation in the liquid-film layer, residence time of materials in the app., and comparison between falling-film and conventional recirculating stills. A comprehensive numerical example is given for a benzene-toluene mixt. (CA-52-2464b).

2731. Bock, E.

STEAM SEPARATION, A Literature Search, BDIT-31 (Feb. 1961) 10 p.

An annotated bibliography is given, consisting of 32 references as a general introduction and survey on steam separation. Design problems in reactor technology were decisive in the selection of the abstracts.

2732. Gleim, V. G.

RATIONAL PROCESS OF BOILING OF SOLUTIONS AND FACTORS OF ITS DETERMINATION, J. Appl. Chem. USSR 26, 1099-1106 (1953).

The appearance of liquid phase in vapor space occurs through fountaining of liquid on bursting of bubbles and subsequent breaking away of droplets. The curve relating droplet carry-over to rate of vaporization shows 3 critical points: max. quantity of carry-over, max. development of foam cover, and beginning of ejection of boiler water. Droplet carry-over can be prevented by creation of the min. necessary layer of shielding foam on the vaporizing surface. ' The development of this foam layer should not reach the limits at which the foam itself or the products of its breakdown are carried over. This can be achieved by regular blow-down of the boiler. Introduction of foam inhibitors eliminating carry-over of foam and ejection of boiler water by no means reduces the amt. of humidity in steam under "normal" boiling conditions. (CA 48-7959a).

2733. Gleim, V. G.

THE GENERAL THEORY OF MOISTURE CARRY OVER FROM BOILING SOLUTIONS, Zhur. Priklad Khim 28, 12-20 (1955).

Aq. solns. of NaOH with a foam inhibitor (4 mg/l distearoylhexamethylenediamine) were boiled at a const. rate at atm. pressure. The humidity of the steam increased at first slowly (0.5%) as the NaOH concn. increased to 700-800 mg/l, then it rose rapidly to 3.5% at 1000 mg/l NaOH. The height and the stability of the foam as functions of NaOH concn. are practically parallel curves falling gradually. The laboratory expts. were extended to locomotives and the results led to the conclusion (by elimination of all other sources) that the humidity of the steam was caused by the carry-over of films from burst steam bubbles. Expts. with distd. H_2O showed that the rise of a drop of liquid formed by a broken air bubble was directly proportional to the diam. of the bubble and that there was a crit. diam. (~7 mm. for distd. H_2O) at which the rise of the liquid was negligible. For larger bubbles the broken film forms a spray. This was demonstrated photographically.

2734. Guhman, A. A.

ON THE FORMULA OF KRUZHILIN CONCERNED WITH THE DEPENDENCE OF STEAM MOISTURE UPON THE VAPOR LOAD, Izv. Akad. Nauk., SSSR, O.T.N., no. 2, 280 (1952).

2735. Judin, J.

SEPARATION OF LIQUID GAS MIXTURES, (Swiss Patent 343,367) February 15, 1960.

The sepn. at least partly occurs in a curved blast pipe provided with a diffuser. This blast pipe and diffuser prevent secondary mist formation as a result of orifice impact. The radius of curvature of the blast pipe orifice must be made to coincide with the radius of the vessel wall. This prevents secondary mist as a result of mech. impact. The gas which seps. from the liquid passes with moderate velocity but considerable turbulence over a liquid film in the screw-like lining of the blast pipe so that finely divided drops of liquid still present in the gas sep. out on the surface of the film.

2736. Kruzhilin, G. N.

SOME REMARKS ON THE ARTICLE BY M. D. STYRIKOVICH, L. S. STERMAN, AND T. H. MARGULOVA, Izv. Akad. Nauk, SSSR, O.T.N. No. 10, p. 1560, 1951.

2737. Kruzhilin, G. N.

THE DEPENDENCE OF THE PERMISSIBLE VAPOR LOAD OF A BOILER ON THE PRESSURE, Izv. Akad. Nauk. SSSR, Otd. Tekh. Nauk, No. 7, 1106 (1951) (In Russian).

2738. Kurbatov, A. V.

BUBBLING AND THE PROBLEM OF CRITICAL LOADS IN STEAM SEPARATION, Trudy Moskovskogo energeticheskogo Instutiua, (Trans. of the Moscow Power Engineering Institute), Nr XI, Gosenergoizdat, (1953).

2739. Moyer, W. H.

DEVELOPMENT AND TESTING OF A STEAM-WATER SEPARATOR FOR A HOMOGENEOUS BOILING WATER REACTOR UTILIZING NATURAL CIRCULATION, Final Report, AECU-3396 (1955) 57 p.

Progress is reported in the development and testing of a steam-water separator for a homogeneous boiling water reactor utilizing natural circulation. Results are presented from a study of pressure drop in conventional separators, a study of capacity in a conventional separator, and tests of numerous separator designs. Recommendations are made for a separator design.

2740. Mravca, A. E. and Simpson, D. E.

STEAM CARRYUNDER, Nuclear Superheat Meeting No. 4, Idaho Falls, Idaho, TID-7617, April 13-14, 1961 (71 p) (COO-263).

Minutes are presented on the fourth Nuclear Superheat Meeting. The status of BORAX-V, BONUS, Pathfinder, and VESR is discussed. Other developments of superheaters are outlined.

2741. Mravca, A. E. and Simpson, D. E.

STEAM-WATER SEPARATION TEST, Nuclear Superheat Meeting No. 5, San Jose, California, TID-7630 September 13-15, 1961, 103 p. (COO-264).

Minutes of the fifth AEC-sponsored nuclear superheat meetings are presented. Topics covered include: SADE loop experiment, out-of-pile corrosion experiments, SADE activity levels, heat transfer experiments, steam separator development, fuel technology, E-SADE program, NUSU critical experiments, BONUS critical experiments, engineering physics calculations, superheat fuel development, superheat critical experiments, BORAX-V superheat fuel elements, water chemistry program, in-core instrumentation development, UO_2 vibratory compaction development, status of nuclear superheat plants under design and construction, and nuclear superheat design studies.

2742. Ongman, H. D.

CHICAGO OPERATIONS OFFICE STEAM SEPARATION PROGRAM, February-March, 1960 Final Report, 31 p., GEAP-3389.

A program is described for free-surface steam-water separation at 600 psig. The investigation was conducted in support of the design for incorporation in the Experimental Boiling Water Reactor at 100 Mw thermal. Equipment is described and the test procedures are outlined along with operation. Resulting data are presented tabularly.

2743. Petrick, M.

A STUDY OF CARRYUNDER PHENOMENA DURING VAPOR LIQUID SEPARATION, Am. Inst. of Chem. Eng. Journal 9, 253-60 (1963).

A simple model for the carryunder phenomena is presented and an analytical expression for the quality ratio X_D/X_R is derived. The dominating factor in this analysis is the definition of a specific area in the riser from which carryunder emanates. Data taken from an atmospheric air-water loop are compared with the predicted values for weight percent carryunder for the parameter range studied ($0.2 \times 10^{-3} < x < 2.0 \times 10^{-3}$, 1 ft/sec $< V_D <$ 2.5 ft/sec.). The proposed model proved to be quite successful and good agreement between measured and calculated values were obtained.

A dimensional analysis of the pertinent parameters affecting carryunder was also made and a series of dimensionless groupings were derived. These groupings were then used to develop empirical correlations for predicting carryunder. The empirical correlation adequately represents a series of high-pressure data over the following parameter range: $0.1 < \alpha_R < 0.5$, $0.5 < V_D < 2.5$ ft/sec., P=600,000, 1500 psi but the air-water data taken at atmospheric pressure deviated substantially. A non-dimensionless empirical correlation, however, was developed for the X_D/S_R ratio, and its predicted values compared well with the data from both the atmospheric air-water and high-pressure loop. Fair agreement was obtained also with preliminary data taken on a large reactor system (EBWR).

2744. Riesland, J. I.

RESULTS OF AIR-WATER AND STEAM-WATER TESTS ON RADIAL VANE STEAM SEPARATOR MODELS, GEAP-3787 (1961) 47 p.

Activities in a program are described to develop a compact radial vane-type separator for saturated steam-water mixtures. Design of the tests and models is described and results are given. Data indicate that the separators meet the requirements for boiling water superheat reactor application. Results also indicate that separator steam-water capacity can be predicted from air-water test results. Further development is recommended.

2745. Roesler, F. C.

ON THE ELIMINATION OF GASES FROM LIQUIDS IN LAMINAR FLOW, Z. Angew. Phys. 3, 376-9 (1951). (AMR-5-1457).

Author shows that the rate of elimination of gases dissolved in a viscous liquid is considerably increased if the liquid is in laminar motion. This is because convection effects increase the order of magnitude of the "gas-concentration-layer" thickness, and therefore the action of any given gas bubble is felt over a greater volume of liquid; and because viscous shear forces acting on gas-bubble walls tend to break up the larger bubbles, thus giving a larger number of nuclei for the elimination process. These ideas are illustrated by rough estimates for a Couette flow.

2746. Ryley, D. J.

BEHAVIOR OF WATER GLOBULES IN STEAM, Engineer 198, 74-78 (July 16, 1954).

Theoretical study of dynamic aspects of globule behavior; treatment deals with size, trajectory, drift velocity ratio and movements of globules; fracture of globules; new kind of chart described for finding wind velocity necessary to break undeformed spherical globule under specified conditions; work gives useful hints concerning design of moisture separators and concerning problem of erosion of low pressure turbine blading.

2747. Shikinami, I.

WATER-STEAM SEPARATORS FOR BOILERS, Netsu-Kanri 9, 32-9 (1957).

A survey of the mechanism of sepn. of H_2O in various boiler systems is presented.

2748. Steamer, A. G. and Ongman, H. D.

FREE-SURFACE SEPARATION OF STEAM AND WATER FOR APPLICATION IN A MARINE REACTOR AT 1000 PSIG, GEAP-3489 (1960) 67 p.

A series of free-surface steam separation tests were carried out at 1000 psig to obtain data to aid in checking out analytical methods for the effect of ship's motion on steam separation. Data are presented on the shape and height of the steam-water interface with respect to the indicated water level for two vessel sizes. Further data are presented on the effects of water level and downcomer water velocity on steam carryunder.

2749. Sterman, L. S.

ON THE THEORY OF STEAM SEPARATION, Zhur. Tekh. Fiz., 28, 1562-1574 (1958) (In Russian).

The paper presents a system of differential equations describing the processes involved in the carrying out of moisture by steam in the form of drops. It also gives a system of similarity criteria. The characterizing relations obtained are used for the generalization of the experimental data.

2750. Styrikovich, M. A., Sterman, L. S. and Margulova, T. Kh.

CONCERNING THE ESTABLISHED LAWS OF CARRYOVER OF MOISTURE BY STEAM IN BOILERS, Izv. Akad. Nauk., SSSR, Otd. Tekh. Nauk., No. 8, 1250 (1951) (In Russian).

2751. Vella, S. and Zavattarelli, R.

FINAL RESULTS OF STEAM-WATER MIXING AND SEPARATION EXPERIMENTS: PHASES DISTRIBUTION AND SEPARATION EFFICIENCY, Final Report, July 15-Sept. 15, 1961, Work performed under U.S.-Euratom Joint Research and Development Program, (LAB/STU-1469) 109 p., EURAEC-209.

Results of steam-water experiments are presented along with a description of experimental conditions. It was found that the ratio of the local mass velocities in the mixture and the average mass velocity of the mixture depends on the average steam quality. Data on phase distribution under average inlet conditions are presented graphically. Results of the separation investigations confirm results obtained in air-water experiments.

2752. Weber, H. E. and Glicksman, L. R.

A STUDY OF THE EFFECTS OF SHIP'S MOTION IN FREE-SURFACE STEAM-WATER SEPARATION, GEAP-3492 (1960) 38 p.

A study of the liquid-vapor separation problem was undertaken. Particular attention was paid to the carryover problem and carryunder problem. Expressions or methods for evaluating the liquid carryover were obtained. The same was done for the vapor carryunder problem; i.e., the vapor carried along with the liquid in the return line from the separator. A flow model was established and the analysis for the carryover problem imposed the condition that the shear and liquid gravitational forces balanced at the liquid-vapor interface with zero liquid velocity. Also, the flow over the bubbles at the liquid-vapor interface was laminar so that the shear stress was inversely proportional to the liquid film thickness. For the carryunder problem, the vapor bubble buoyancy and drag forces were equated to determine permissible liquid velocities in the downcomer.

2753. Ansaldo, S.p. A., Genoa

CAN-1 - QUARTERLY PROGRESS REPORT, October 16, 1960 to March 15, 1961, Part A., Technical Report, EURAEC-99 (1951) 50 p.

Final results of the air-water separation experiments are presented. A detailed description of the high-pressure loop and its instrumentation is given. The efficiency of the separators giving the best results ranged from 96 to 100%. Diagrams and tables are included.

2754. Societe Nationale d'Etude et de Construction de Moteurs d'Aviation.

A STUDY OF THE SEPARATION OF WATER/STEAM MIXTURES, Special Report No. 7, Div. Atomiques, Suresnes, France, EURAEC-148 (Sept. 1961) 61 p.

Results are presented from a study of centrifugal separation of water and steam in boiling water reactors. It is noted that the poor results obtained show that small-scale whirls are not adequate for separation. It is recommended that a design in which a natural primary separation takes place through the free surface on top of the reactor tank be used. The water which still contains steam should be introduced into separators mounted on the core periphery and low-steam-content water should be introduced into the separators tangentially and in the upper half. Separated water is then exhausted at the base of the separators.

2755. Combustion Engineering, Inc.

DEVELOPMENT OF STEAM SEPARATION DEVICES, Final Report, Combustion Eng. Inc. Nuclear Div., CEND 136 (Sept. 1961) 105 p.

A program for the development of steam separation devices for large integral boiler-superheater reactors is being conducted. The experimental program conducted to establish the most reasonable steam separation arrangement for the NUSU 200-MWe reference design of an integral boiler-superheater reactor is summarized.

TRANSIENTS AND INSTABILITY

2756. Alstad, C. D., et al.

THE TRANSIENT BEHAVIOR OF SINGLE-PHASE NATURAL CIRCULATION WATER LOOP SYSTEMS, ANL-5409 (1956) 55 p.

Studies were directed toward the development and experimental verification of a practical method for predicting the transient behavior of single-phase, natural circulation water loop systems.

Two experimental loops, along with a complete system of equations used in connection with an illustrative problem, are described in detail. Comparison of experimental results with numerical solutions indicates that the transient behavior of the systems could be satisfactorily predicted for engineering purposes. The reliability of the method is related directly to the accuracy with which the physical parameters of the loop system are known. (NSA-10-3800).

2757. Anderson, R. P. and Lottes, P. A.

BOILING STABILITY, Reactor Technology, J. of Nucl. Energy, Part B, 2, 3, (Feb. 1962).

There are several types of stability conditions connected with boiling. The first type is the stability associated with a liquid-vapor interface, when the liquid is located above the vapor. Two other types are associated with boiling water reactors and

reactor simulating test loops which have both demonstrated unstable behavior under certain operating conditions. The first type of boiling stability is important in studying the nature of burnout or critical boiling heat flux. The second and third type, however, are considered to be of more importance for natural circulation boiling systems since flow instability usually appears at lower heat fluxes than the critical flux. Therefore the discussions in this paper are limited to boiling flow stability problems as applied to natural circulation boiling systems and reactors. Reactor technology, in its present state, cannot predict either the dependence of the oscillation inception point or the frequency and amplitude of oscillation on operating conditions or design parameters. However, an experimental test program using both reactors and hydrodynamic test loops has shown certain trends in the dependence of oscillation on various parameters and conditions.

Analytical work using experimental data has been published. There is enough uncertainty of stability cause and dependence that models used as a basis for the published analytical work are useful only in predicting trends which can be compared with experimental data and in approximate extrapolation of the performance of an existing reactor to more stringent operating conditions. They do not give a consistent theoretical understanding of stability nor do they allow prediction of stability conditions in a reactor proposal during its design stages.

2758. Akcazu, A. Z.

THEORETICAL FEEDBACK ANALYSIS IN BOILING WATER REACTORS, ANL-6221 (Oct. 1960) 66 p.

The dynamic behavior of boiling water reactors for small perturbations was investigated in a systematic way. General expressions for the transfer functions associated with the individual feedback mechanisms were obtained for an arbitrary flux distribution, weighting function, and steam velocity distribution. Specific forms were derived in the case of a first power flux weighting, a uniform steam velocity distribution, and a sinusoidal flux distribution with an adjustable wave length. These forms were simplified and single time-constant transfer functions were obtained. The error involved in the lumped time-constant approximation was shown to be as large as 4 db in amplitude in certain feedback mechanisms. Theoretical results were applied to the experimental power void transfer function obtained at Ramo-Wooldridge Research Laboratory, and to the EBWR transfer function. In the former case, the agreement was found to be reasonably good, but yet more systematic experimental data were needed to reach a definite conclusion as to the validity of the proposed model, which assumes a time lag associated with steam formation and a steam perturbation speed greater than the steady state steam velocity. In the second application, the agreement between the experimental and calculated reactor responses was proved to be better than 5 db in amplitude and 10° in phase, in the entire frequency range from 0.01 to 100 rad/sec. (NSA-15-6989)

2759. Beckjord, E. S.

DYNAMIC ANALYSIS OF NATURAL CIRCULATION BOILING WATER POWER REACTORS, ANL-5799 (1958) 30 p.

Linear Feedback Control Theory is used to analyze the small-signal dynamic behavior of direct cycle, natural circulation boiling water reactor systems.

Transfer functions for thermodynamic and hydraulic effects are derived in terms of reactor core and vessel dimensions. They are used to construct a theoretical system block diagram for the EBWR. (NSA-12-8712).

2760. Argonne Staff

EXPERIMENTAL INVESTIGATION OF THE SELF-LIMITATION OF POWER DURING REACTIVITY TRANSIENTS IN A SUBCOOLED WATER-MODERATED REACTOR, ANL-5323 (1954).

2761. Beckjord, E. S.

THE STABILITY OF TWO-PHASE FLOW LOOPS AND RESPONSE TO SHIP'S MOTION, GEAP-3493 (Rev. 1) (1960) 50 p.

Investigations were made to determine the dynamics of stationary two-phase flow loops and of those accelerated by ship's motion, and the controlling parameters. The results apply to boiling water reactors, and enable prediction and design of stable two-phase flow in reactors. An analogue computer circuit is developed for calculating loop transients. Analytical predictions of stability and transient response are compared with A.P.E.D. Heat Transfer Loop test results. Analogue computations were made of the effect on the T-7 core of a 20% of normal gravitational acceleration increase, and of the effect of a 20% heating increase in channel 1 of 2 coupled parallel channels similar to T-7 core channels. Conclusions drawn on the factors which determine loop dynamics are: 1. The natural period of the loop is governed by the transit time of fluid across the two-phase vertical section. If oscillatory, the period will be between 4/3 T and 2 T, where T is the transit time; 2. The primary cause of loop instability is subcooling with high steam voids, because subcooling makes the natural circulation driving head decrease when the inlet water velocity increases, and vice-versa. A design line of subcooling limit as a function of operating pressure is given; 3. Unstable flow loops can be stabilized by velocity head losses, such as at an orifice in the downcomer, and by the use of long downcomer pipes and consequent high single phase fluid inertia; and 4. Friction pressure drops and velocity head losses in the riser can help to stabilize, provided inlet subcooling is not excessive. If it is excessive, the riser friction pressure drop and head losses actually decrease when inlet water velocity increases. The result is a negative incremental pressure drop which destablizes.

2762. Bromberg, R. and Martin, W. L.

DENSITY TRANSIENTS IN BOILING LIQUID SYSTEM, AECU-2169 (1952) 131 p.

A program has been undertaken to study the density response of a liquid-vapor system when subjected to a change in the magnitude of a distributed heat source. The density transients are caused by the initiation, growth, and collapse of the vapor bubbles and by their travel into or out of the specified volume. A description of the apparatus used to create and record (by means of an x-ray densitometer and motion pictures) density transients at pressures from atmospheric to 1000 psia is given, and preliminary results on acidic and alkaline solutions are presented. Time lags, from the initiation of a heating pulse to the start of a density transient, of the order of 0.25 sec were most commonly observed in solutions of KOH at atmospheric pressure. In an attempt to correlate liquid superheat with system-density response, a static superheat apparatus and procedure have been developed, and a variety of superheat data obtained on H_2O and KOH solutions in glass and stainless steel is presented. The analytical phase of the program is directed toward deriving equations to describe bubble initiation and growth. Equations from Döring's theory have been applied to water at elevated pressures, and the resultant calculated superheats are compared with the experimental measurements. In order to eliminate some of the approximations in the analytical work, a molecular approach has been used to evaluate the effects of surface tension on liquid superheat.

2763. Chilton, H.

A THEORETICAL STUDY OF STABILITY IN WATER FLOW THROUGH HEATED PASSAGES, J. Nuclear Energy, 5, 273-284 (1957).

Criteria defining the stability of forced water circulation through heated passages are introduced. A general method is derived for predicting stability criteria for a system with any form of variation of heat input with respect to passage length. A convenient method for calculating pressure loss is developed. Criteria and integrated functions are presented for the forms of heat input distribution commonly encountered in reactor design, and their application is demonstrated in a worked example.

2764. Christensen, Helge

POWER-TO-VOID TRANSFER FUNCTIONS, ANL-6385 (1961) 148 p.

Variations in the distribution of steam bubble, the "void" distribution, in a boiling channel as a function of changes in heating power was studied.

A rectangular test tube, of 1.11 x 4.44-cm cross section and 127-cm height was inserted in a forced-circulation pressure loop. The tube was heated by passing an AC current through the tube walls. A power oscillator was built which could give a 10% peak-to-peak sinusoidal power modulation at any frequency in the interval from 0.01 to 10 cycles per second.

Variations in the volume fraction of steam were observed by means of a gamma densitometer built for the purpose. Accurate void profiles could be taken by traversing the test channel vertically and horizontally.

With the void detector stationary at a given height, the amplitude and phase delay of the steam void variations were measured in the frequency range mentioned. The signal from the gamma detector was passed to a harmonic analyzer built for the experiment. This instrument could pick out the void variations coherent with the power variation in the presence of much greater random signal variations caused by the boiling process.

The frequency response of steam voids was measured at 4 different pressures ranging from 27.2 to 68 atm., at conditions comparable to those in pressurized boiling water reactors. Void phase and void amplitude have been plotted as functions of frequency, and the data have also been presented in tables.

The most important result of the experiments is to show that the void response falls off at a frequency that is much lower than that predicted by theoretically derived power-to-void transfer functions used previously in reactor calculations. Also the void amplitude in the lower part of the channel was larger than expected.

By taking into account the pressure changes in the channel caused by the power variations, an expression was derived for the power-to-void transfer function that could be fitted very well to the data. A constant, associated with the completeness of the mixing in the direction perpendicular to flow, had to be chosen in order to fit properly the break frequency in the amplitude curve.

More experiments are needed to enable prediction of this constant in a given condition in order to arrive at firm procedures for the design of reactors.

2765. DeShong, J. A., Jr.

POWER TRANSFER FUNCTIONS OF EBWR OBTAINED USING A SINUSOIDAL REACTIVITY DRIVING FUNCTION, ANL-5798 (1957) 50 p.

A series of reactor frequency response measurements, relating flux or power level to a reactivity input function, were made to evaluate reactor stability for different values of power parameters. These parameters included: power level, steam pressure, and control rod position. The results were extrapolated to predict EBWR stability at higher operating powers. The experimental data may also be used to evaluate the thermodynamic and hydraulic constants.

2766. Dougherty, D. E.

A BOILING MODEL, TID-16750 (Oct. 21, 1960).

The microscopic dynamics of the boiling process was formulated into a differential equation for use in determining the steam void fraction which prevails in boiling channels. Details of formulation development are included. (NSA-62-33125).

2767. Forbes, S. G., Schroeder, F. and Nyer, W.

INSTABILITY IN THE SPERT-I REACTOR, PRELIMINARY REPORT, IDO-16309 (1956) 19 p.

Severe instability has been observed in the SPERT-I Reactor. This instability was manifested by a series of power pulses of such rapidly increasing amplitude that the safety of the reactor was jeopardized. The preliminary investigation of this instability is described with discussion limited to an account of the actual observations since confirming experiments were lacking at the time of publication. Plots of power and temperature behavior are included for five tests of this type.

2768. Fraas, A. P.

FLOW STABILITY IN HEAT TRANSFER MATRIXES UNDER BOILING CONDITIONS, CF-59-11-1 (1959) 17 p.

The stability of fluid flow for cases in which boiling occurs in parallel passages had posed questions of design feasibility recently in several areas including once-through steam generators for large gas-cooled reactors, water-cooled reactors such as the MTR, and small compact reactors cooled by a boiling alkali metal. A survey of the literature disclosed a number of treatments of the subject, but there appears to be no comprehensive presentation that makes it easy for the designer to envision the regions under which stable flow conditions would prevail. Most of the conditions of interest are covered with a few charts which were prepared to provide the necessary information for the designer. These charts are presented together with the method used to develop them. From Nuclear Sci. Abstr. 14, Abstr. No. 2519, (1960).

2769. Garlid, K., Amundson, N. R. and Isbin, H. S.

A THEORETICAL STUDY OF THE TRANSIENT OPERATION AND STABILITY OF TWO PHASE NATURAL CIRCULATION LOOPS, ANL-6381 (1961) 83 p.

Natural circulation loops have been applied in many domestic and industrial processes. Recently, new applications have been found in high-power generators, but under these conditions the operation of such loops, usually containing a mixture of vapor and liquid, has not always been predictable. In some of the proposed applications, unstable behavior could have dire effects, and for safety as well as economy, a better theoretical understanding of the loop operation is needed.

To this end, mathematical models of the time-dependent behavior of two-phase natural-circulation loops were derived from basic conservation equations and used to predict the operation and to explain the unusual instability sometimes observed. Lumped-parameter models, which essentially simulated the system as a series of cascaded missing cells, were used. Initial solutions were obtained by using a PACE analog computer and patterning the geometry and operating conditions after those of the University of Minnesota loop from which data have been reported. The solutions predicted oscillatory behavior similar to that reported with mean flow rates, temperatures, and qualitative trends in general agreement with experimental results. In order to obtain solutions, however, many simplifying assumptions were made, and the solutions, however, were not completely satisfactory.

The initial results were used in formulating subsequent models of greater complexity and improved accuracy for which solutions were obtained with the UNIVAC Scientific, a large digital computer. The resulting predicted transient behavior was in close agreement with the experimental results from the University of Minnesota low-pressure loop. When the geometry and operating conditions of a 300-psia, high-pressure loop were used in the model, unstable oscillatory behavior was predicted under certain conditions, and stable behavior under others. Closed unstable regions rather than limits were predicted, and the specifications of stability in terms of a single parameter was found to be impossible. The results showed qualitative agreement with experimental results obtained at several laboratories and oscillatory frequencies of the same magnitude as those observed, but so little experimental data were available that a complete comparison was not possible. The slip ratio and the nature of its variation were found to be critical in determining the predicted loop behavior. The model finally used was versatile, reasonably fast, and quite complete.

A comparison of the causes of the oscillatory behavior at low and at high pressure indicated that they were essentially the same, and that the great difference in oscillatory frequencies that has been experimentally noted was due largely to a system geometry, and partially to the nature of the oscillations themselves. The criterion for the absence of oscillations was found to be similar to one of the criteria for stability of chemical reaction systems.

2770. Gruber, A. H. and Hyman, S. G.

FLOW DISTRIBUTION AMONG PARALLEL HEATED CHANNELS, AIChE Journal 2, 199-205 (1956).

The coolant flow distribution among parallel tubes in a nuclear reactor (or boiler or heat exchanger) can be very sensitive to variations in heat input dimension, etc. Analytical expressions are given for partial derivatives which measure flow variations for several situations. The utility of orifices and valves in reducing flow sensitivity is discussed. Numerical results are reported for a system using water at supercritical pressures with an eightfold expansion from inlet to outlet.

2771. Johnson, S. O., Curlee, N. J. and Reihing, J. V.

SIMULATION OF HOT CHANNEL BOILING IN WATER COOLED REACTORS, WAPD-T-388 (1957) 67 p.

The problems encountered in a study of the transient response of a heat transfer system in which the coolant experiences a phase change are discussed. A mathematical model of the system is developed and the partial differential equations governing the transient response are derived. The equations are then transformed to differential-difference equations

suitable for solution on an electronic analog computer. The analog computer circuit is developed from the equations and the peculiarities of the circuit are described in detail. Analog results of a typical coolant flow transient are presented.

2772. Jones, A. B.

HYDRODYNAMIC STABILITY OF A BOILING CHANNEL, KAPL-2170 (1961) 138 p.

Experimental observations have been made of spontaneous flow rate oscillations within a coolant channel heated sufficiently to produce boiling. The possibility of burnout or other damage is suggested if such oscillations are sufficiently strong. The derivation is described of a mathematical model for predicting whether such oscillations will occur. A digital computer program is outlined for mechanizing the solution of the equations. The single check against experiment which has been performed to date is described. In this single check, excellent agreement between model and experiment was obtained.

2773. Jones, A. B. and Dight, D. G.

HYDRODYNAMIC STABILITY OF A BOILING CHANNEL, KAPL-2208 (Apr. 20, 1962).

STABLE-3 is an extension of the STABLE-2 Philco 2000 digital computer program for examining the hydraulic stability of a single boiling coolant channel in parallel with many other channels. Only the modifications of STABLE-2 resulting in the program called STABLE-3 are discussed. The modifications were made primarily to simplify the input-output effort required of the user, to minimize the magnitude of a discontinuity occurring in a certain friction factor correlation, and to approximately accommodate the simultaneous existence of both nonboiling and subcooled boiling regimes in the subcooled region of the coolant channel. A program listing and instructions for running the program are included. (NSA-62-29085).

2774. Ledinegg, M.

INSTABILITY OF FLOW DURING NATURAL AND FORCED CIRCULATION, Transl. from Warme 61, 891-8, AEC-tr-1861 (1938).

The flow in parallel-connected heated boiler tubes lying between two collecting tubes can become unstable under certain conditions. For forced-circulation and filter boilers or for pre-evaporators the course of the tube-friction losses play the most important role; for cooling mantles on heat chambers with natural circulation, the buoyancy relations are the most important. The conditions for the appearance of instability are studied for both cases.

2775. Ledinegg, M.

UNSTABLE OSCILLATIONS IN BOILING-WATER REACTORS, Translated from: Atomkern energie, 4, 132-135, DEG Information Series, 98(R) (1959).

In boiling water reactors oscillations of the steam production and of the pressure can occur which, under certain conditions, exhibit increasing amplitudes and are therefore unstable. In the present article the phenomenon is investigated in detail, and formulas are derived which permit an estimation of the starting point of the instability.

2776. McNeillis, J.

REVIEW OF BOILING HEAT TRANSFER WITH PARTICULAR REFERENCE TO UNSTABLE FLOW, Engineering, 183, 686-7 (May 31, 1957).

Conditions under which unstable flow will occur; various regimes of boiling are shown in characteristic boiling curve; boiling in tubes and annuli. Digest of paper before Brit. Assn. August 30, 1956.

2777. Panasenko, M. D.

THE ROLE OF THE VOLUME OF WATER IN THE BOILER ON THE FORMATION OF SPLASHES, Izv. Vses. Tep. Inst. (V.T.I.), no. 5, 1947.

2778. Quandt, E. R.

ANALYSIS OF PARALLEL CHANNEL TRANSIENT RESPONSE AND FLOW OSCILLATIONS, WAPD-AD-TH-489 (1959).

An analysis has been developed which relates, for a small transient in power, the inlet flow of a parallel channel to the surface heat flux in that channel. This result has been obtained by examining the effect of a small flux disturbance on the inlet flow. The partial differential equations describing the channel variables are linearized and solved by approximations spatially and continuously in time by Laplace Transformation. Consequently, the result is a transfer function of the form:

$$\frac{\Delta V_i}{\Delta \phi} = G(s) = - \frac{as^2 + bs + c}{s^2 + ds + w_n^2}$$

in which the constants are determined by steady-state operating conditions. Linear system control theory implies that when d = 0, the response will be oscillatory, or the flow will oscillate to an increase in heat flux. When the terms which determine d are evaluated for d = 0, the following equation results which describes the exit quality conditions necessary for a flow oscillation:

$$x_e = \frac{v_f}{v_{fg}} \left[f \frac{L}{D} + 1 + \frac{2 x_e}{v_f / v_{fg} + x} \right]$$

This equation is a direct result of the analysis, which contains several assumptions as to the nature of the channel flow, and has not been compared with a wide range of experimental data. Consequently, its validity has not yet been confirmed completely. In the past, it has been the practice to predict flow oscillations by noting the existence of a negative slope of the ΔP-flow characteristic for the channel. Since the present results offer a different explanation, a lengthy discussion of the ΔP-flow plot is included. It is concluded from this examination that such a steady-state characteristic does not provide a physically reasonable explanation for flow oscillations.

2779. Quandt, E. R.

ANALYSIS AND MEASUREMENT OF FLOW OSCILLATIONS, Chem. Eng. Prog. Symp. Series No. 32, 57, 111-126 (1961).

The paper presents the results of an analytical and experimental investigation of flow instabilities. The analysis starts from the four basic transient equations for two-phase flow in a heated channel; energy, continuity, state, and momentum. Small perturbations are applied to each variable, and assumptions are made regarding the spatial form of the flow and enthalpy perturbations. The perturbed equations are integrated in the flow direction, and the Laplace transforms of the integrated equations taken. A constant pressure drop boundary condition is applied. Algebraic elimination of variables then permits solution for a transfer function relating the flux and inlet flow perturbations, which is of second order. The criteria for flow instabilities may be determined from the transfer function in terms of the initial fluid conditions, channel geometry, and heat flux distribution.

2780. Richardson, M. and Alexander, L. G.

BOILING EXPERIMENT TRANSIENT EFFECTS, CF-55-1-104 (1955) 13 p.

A preliminary investigation of transient effects to power, pressure, and flow of unsteady boiling conditions was made. These experiments indicate substantial equilibrium of circulation rate and driving forces.

2781. Schmitz, R. A.

AN ANALYTICAL STUDY OF THE TRANSIENT BEHAVIOR AND STABILITY OF TWO-PHASE CHEMICAL REACTING SYSTEMS, Ph.D. Thesis, U. of Minn. 235 p. (1962).

2782. Wallis, G. B. and Heasley, J. H.

OSCILLATIONS IN TWO PHASE FLOW SYSTEMS (Annual Winter Meeting the Am. Soc. of Mech. Eng., Nov./Dec. 1960) WA-209 Paper No. 60.

A mathematical analysis is given of three modes of oscillation of a simple two-phase flow, natural-circulation system, together with qualitative results of experiments with a small-scale loop model.

2783. Wissler, E. H.

THE TRANSIENT BEHAVIOR OF A TWO-PHASE NATURAL CONVECTION LOOP, Ph.D. Thesis, University of Minnesota (1955).

2784. Wissler, E. H., Isbin, H. S. and Amundson, N. R.

THE OSCILLATORY BEHAVIOR OF A TWO-PHASE NATURAL-CIRCULATION LOOP, AIChE J. 2, 157-162 (1956).

A natural circulation loop with water as the circulating fluid was studied for a range of operation covering two-phase flow. The work reported is concerned with the periodic oscillations of the flow rate and fluid temperature. The oscillations occurred even with constant heat input and constant cooling-water properties for the heat exchanger. The analytical approach includes a theoretical analysis of an open ended system and numerical solutions obtained with an analogue computer for a simplified loop system. Also presented are the equations of motion, continuity, and energy, which were developed for a transient two-phase flow model for adaptation to more detailed numerical evaluations.

2785. California University, Los Angeles Dept. of Engineering

DENSITY TRANSIENT OF BOILING LIQUID SYSTEM, AECU-2169 (1952) 131 p.

A program has been undertaken to study the density response of a liquid-vapor system when subjected to a change in the magnitude of a distributed heat source. The density transients are caused by the initiation, growth, and collapse of the vapor bubbles and by their travel into or out of the specified volume. A description of the apparatus used to create and record (by means of an x-ray densitometer and motion pictures) density transients at pressures from atmospheric to 1000 psia is given, and preliminary results on acidic and alkaline solutions are presented. Time lags, from the initiation of a heating pulse to the start of a density transient, of the order of 0.25 sec were most commonly observed in solutions of KOH at atmospheric pressure. In an attempt to correlate liquid superheat with system-density response, a static superheat apparatus and procedure have been developed, and a variety of superheat data obtained on H_2O and KOH solutions in glass and stainless steel is presented. The analytical phase of the program is directed toward deriving equations to describe bubble initiation and growth. Equations from Doring's theory have been applied to water at elevated pressures, and the resultant calculated superheats are compared with the experimental measurements. In order to eliminate some of the approximations in the analytical work, a molecular approach has been used to evaluate the effects of surface tension on liquid superheat.

2786. Technische Hogeschool, Eindhoven, Netherlands.

HEAT TRANSFER AND STABILITY STUDIES IN BOILING WATER REACTOR, Quarterly Progress Reports III and IV, July 1, 1961 to Jan. 1, 1962, EURAEC-276 (Jan. 1962).

Experiments performed with a model of the first core loading of the Halden reactor were worked out. Slip factors and two-phase friction factors were determined and compared with the results of other investigations. Also nonboiling lengths, exit void-fraction and steam qualities were calculated. The results were compared with theoretical calculations. Some calibrations and cold tests were carried out. The development of a fast differential pressure gauge for detecting flow instabilities, was successful. Some measurements, concerning the control characteristics of the rectifier-unit, were carried out. It seems that a fluctuation up to about 8 Hz. can be excited with amplitudes of 10 to 30% of average power. In one series of tests a glass shroud was used with open ends, while the heat flux had a step-wise distribution. The void fraction and circulation

rate were measured as a function of pressure up to 30 atmosphere and of power up to 150 kilowatt. It appeared that the maximum flow rate for constant temperatures occurred at power readings of about 20 to 30 kilowatt, thus at a much lower power than that previously obtained with an aluminum shroud with inlet holes in the hull. Also, the slope of the circulation rate versus the power curve beyond the maximum flow rate was much more negative. Experiments were made at high heat fluxes for clearing the Halden Boiling Water Reactor for operation at 10 megawatt and 30 atmosphere. These experiments were carried out with the single rod test section with aluminum shroud as used previously at three temperatures: 140, 200, and 230°C. Burnout was not obtained in the tests. A heat flux of 220 watt/cm^2 was safely transmitted to water at 30 atmosphere pressure (230°C saturation temperature), 115 cm/sec channel inlet velocity, 5.7% steam quality at the exit and 1.7 to 3.9% at the position of maximum heat flux. In these experiments a qualitative measurement was made of the void fraction using a capacitative gauge at 90% of the channel height. It was observed that the mean deflection on the oscilloscope increased with channel power. The oscillations present in the void fraction signal were recorded. There was some indication of hydraulic instability in the region of high power. Use was made in tests of a rod cluster element simulating a second core loading fuel channel of the Halden Boiling Water Reactor. The purpose of these tests was to demonstrate that the flow conditions in the reactor at 10 megawatt and 30 atmosphere were stable. These tests were carried out at the same temperatures as the others. Recordings were made of void fraction and flow rate using capacitative gauges. It was concluded that beyond the maximum flow rate the oscillations observed were larger than for the model of the first core loading fuel channel. Also, the pressure drop across the inlet holes was considerably higher. The absolute and differential pressure gauges and the void gauge using capacitative methods were further developed. They were used in the pressurized boiling loop up to 230°C. A theoretical study was made concerning the possibilities of an accoustical method for the determination of void fraction and bubble dimension. A study was started to investigate in detail the measuring and recording technique for noise and oscillation of low frequencies and the analysis of such signals to supply data from which transfer functions can be obtained.

TURBULENT FLOW

2787. Gambill, W. R. and Bundy, R. D.

HFIR HEAT TRANSFER STUDIES OF TURBULENT WATER FLOW IN THIN RECTANGULAR CHANNELS, ORNL-3079 (1961).

In support of the High Flux Isotope Reactor program, experimental determinations were made of friction factors, burnout heat fluxes, and average and local nonboiling heat-transfer coefficients for forced-convection flow of water through this aluminum and nickel rectangular channels under the following conditions: heat flux = 0.1 x 10^6 to 7.4 x 10^6 Btu/hr ft^2, velocity 10 to 85 fps, Reynolds number = 9,000 to 270,000, pressure = 1 to 39 atmospheres absolute, flow gap = 0.043 to 0.057 in., and heated length = 12 and 18 in. A few tests were made to ascertain the effect of an axially oriented cylindrical spacer strip on surface temperature distribution and burnout heat flux. The results of these studies are in reasonably good agreement with accepted correlations. The friction factors are in satisfactory agreement with the Moody chart for the relative roughness of the test sections used, the burnout heat fluxes are well reproduced by the Soviet Zenkevich-Subbotin correlation, and the local and average heat-transfer coefficients are slightly larger than values predicted by the Hausen and Sieder-Tate equations. Miscellaneous experimental and analytical HFIR heat-transfer studies are included. (NSA-15-23623).

2788. Kreith, F. and Margolis, D.

HEAT TRANSFER AND FRICTION IN SWIRLING TURBULENT FLOW, Heat Transfer and Fluid Mechanics Institute Proceedings, p. 126-142 (1958).

This paper reports on an extension and an application of a theoretical analysis presented by the senior author at the 1953 Heat Transfer and Fluid Mechanics Institute. The original analysis showed that a substantial increase in the heat transfer coefficients obtains when the heat flows from a concave surface to a fluid compared to the coefficient from a flat surface to the same fluid. This phenomenon was studied experimentally by inducing various degrees of swirling motion in a fluid flowing through a pipe and heating the fluid by condensing steam on the outer pipe surface.

It was observed that inside surface heat transfer coefficients in swirling flow increase as much as four-fold over the coefficients observed at the same velocity in purely axial flow. The heat transfer coefficients were found to depend on the centrifugal force component. However, at comparable Reynolds numbers and swirling motions the heat transfer coefficients for water were found to be larger than the coefficients for air. The reason for this difference is not definitely known, although it is qualitatively compatible with the flow phenomena in a vortex type flow.

The observed phenomena are analyzed qualitatively. It is shown that they are the result of a free convection motion induced by the centrifugal force due to the temperature difference in the rotating fluid.

2789. Kuethe, A. M. and Raman, K. R.

SOME DETAILS OF THE TRANSITION TO TURBULENT FLOW IN POISEUILLE FLOW IN A TUBE, AFOSR-TR-59-84 (June 1959).

Measurements of velocity fluctuations, Reynolds stresses, and shearing stresses at the wall in the transition region of a tube are presented. The measurements were made in a tube at a Reynolds number of 6000 behind 3 disturbance generators placed in the fully developed laminar flow 620 diameters from the entrance. The results show the way in which some of the statistical details of the transition depend on the nature of the disturbance generated. The Reynolds stresses and the shearing stress at the wall can reach very high values during the

early stages of transition. Implications are pointed out regarding possible causes for the high temperature recovery factor during transition in high speed flow over surfaces.

2790. Soo, S. L., et al.

DETERMINATION OF TURBULENCE CHARACTERISTICS OF SOLID PARTICLES IN A TWO-PHASE STREAM BY OPTICAL AUTOCORRELATION, Rev. Sci. Instrum. 30, 821-824 (1959).

Application of optical autocorrelation techniques enables determination of Lagrangian correlation, scale, and intensity of turbulent motion of solid particles in a two-phase stream. This method allows measurement of both longitudinal and transverse correlations.

2791. Soo, S. L. and Tien, C. L.

EFFECT OF THE WALL ON TWO PHASE TURBULENT MOTION, Jour. Appl. Mech., Trans. ASME 82, 5 (1960).

2792. Soo, S. L., Ihrig, H. K., Jr. and Kouh, A. F. El

EXPERIMENTAL DETERMINATION OF STATISTICAL PROPERTIES OF TWO PHASE TURBULENT MOTION, Jour. of Basic Eng., Trans. ASME 82, 609 (1960).

2793. Stirba, C. and Hurt, D. M.

TURBULENCE IN FALLING LIQUID FILMS, AIChE Journal, 1, 178-184 (1955).

On the basis of fluid dynamic and heat transfer studies on falling-film towers by various investigators, it has been commonly accepted by most workers that the liquid flow is essentially streamline in nature for liquid film Reynolds numbers under 1,800 to 2,000; consequently it would be expected that the rate of physical gas absorption in such liquid films could be predicted directly from a knowledge of molecular diffusion rates.

Measurements of the absorption of pure gases in falling liquid films at low Reynolds numbers substantiated the findings of other investigators that the mass transfer rates were manyfold greater than could have been predicted if molecular diffusion were the only transfer process. Increased interfacial area due to rippling of the liquid films could not account for the large increase in mass transfer rates found, and experiments with the addition of a dye stream to the liquid at the free interface indicated turbulence. Dissolution rates of slightly soluble solids coated on the tube wall to liquid films were measured.

2794. Ward, H. C. and Sallavalle, J. M.

COCURRENT TURBULENT-TURBULENT FLOW OF AIR AND WATER-CLAY SUSPENSIONS IN HORIZONTAL PIPES, Chem. Eng. Progr. Symposium Ser. 50, No. 10, 1-14 (1954).

Although progress has been made recently in the fields of cocurrent-gas Newtonian liquid flow and of turbulent flow of non-Newtonian materials, relatively little is known theoretically about these complex types of flow. For this reason results of studies in these fields cannot be applied with certainty to the cocurrent flow of a gas and a non-Newtonian material, a type of flow which occurs in many industrial operations. An investigation of this type of flow was therefore considered desirable. In the present study, air was used as the gas phase, and 4 concns. of kaolin clay in water were used as the non-Newtonian materials. Two of these suspensions behaved as pseudoplastics; the other 2 exhibited Bingham plastic properties. Pressure-drop measurements were made in $\frac{3}{4}$-, 1-, and $1\frac{1}{2}$-in. horizontal pipes for each of these suspensions flowing alone and cocurrently with air. Suspension flow rates were varied from 0.15 to 16 lb/sec, and air-flow rates from 0.0015 to 0.025 lb/sec in the turbulent-flow region the usual Newtonian-friction-factor-Reynolds-no. relationship was found to be valid, confirming the work of previous investigators in this field. The pressure-drop data obtained on the cocurrent flow of air and these suspensions in the turbulent-turbulent region were correlated within the range of ±20% by the Φ-X method of Lockhart and Martinelli (cf. C.A. 43, 2046a).

VERTICAL TUBE FLOW

2795. Alad'ev, I. T., Dodonov, L. D. and Udalov, V. S.

HEAT TRANSFER IN BOILING WATER IN TUBES, Teploenergetika 4, 64-6 (Sept. 1957).

Tests carried out at pressures of 180 atm, heat loads up to 4.10^6 k-cal/m^2, hr circulation velocities up to 10 m/sec and water of saturation temperature from 1 to 140 C.

2796. Anderson, G. H., Haselden, G. G. and Mantzouranis, B. G.

TWO-PHASE (GAS-LIQUID) FLOW PHENOMENA. III. THE CALCULATION OF HEAT TRANSFER IN A VERTICAL LONG-TUBE EVAPORATOR, Chem. Eng. Sci., 16, 222-30 (December 1961).

The theory for the upward, annular flow of a liquid in a vertical tube in the presence of a gas or vapor is developed for the prediction of heat transfer coefficients to a liquid boiling in a vertical tube. The theory is tested on the experimental data of Dengler and Lee.

2797. Armand, A. A., Konkov, A. and Tarasova, N.

AN INVESTIGATION OF HEAT TRANSFER IN A PIPE FOR THE BOILING OF SUB-COOLED WATER AND STEAM/WATER MIXTURE, Teploenergetika No. 1, p. 93 (1958).

2798. Bertoletti, S., et al.

HEAT TRANSFER AND PRESSURE DROP WITH STEAM-WATER SPRAY, Centro Informazioni Studi Esperienze Report R 36, April 1961, Milan, Italy.

2799. Boelter, L. M. K.

ENGINEERING RESEARCH PROGRESS REPORT NO. 1 ON BOILING STUDIES, COO-7 (1949) 173 p.

The primary objectives of this investigation are to obtain heat-transfer and pressure drop data in the higher ranges of pressure, temperature, and velocity for water flowing in an electrically heated vertical tube and to attempt to evolve a technique for measuring average fluid densities across the tube at a given axial station. The ranges of parameters are: pressures to 4,000 or 4,500 psi, velocities to 50 ft/sec, temperatures (of water fluid) to 750°F; heat flux densities to 4 x 10^6 Btu/ft^2 hr; tube diameters $\frac{1}{8}$ in. to $\frac{1}{4}$ in., L/D = 100. The principal interest is in the ranges: pressures 1,000 to 2,000 psi; temperatures to 600°F; heat flux rates into the nucleate boiling region. Associated basic research on boiling and related phenomena are being concurrently pursued. Appropriate sections of this report describe the status of these studies. A large part of the work to data has been involved in obtaining information on which to base the design of test equipment and associated instrumentation, and the subsequent design, specification; and procurement or construction of the items. Chapter I is a general discussion relating the specific basic studies undertaken to the general objectives and outlining the problems as now envisioned, studies of which are essential to interpreting and validating the significance of the data to be obtained in the major test installation. Chapter II describes the work done with a preliminary test installation utilizing existing laboratory equipment to launch a study and gain experience by which designs, plans, procurement, and operation of the major test installation could be accelerated and the instrumentation problems attacked. Other chapters are concerned with the determination of the electrical sensitivity of the heating tube, thermal conductivity of the heating tube, special instruments and devices, determination of air concentration in the circulating water, density measurements, preliminary concepts concerning the mechanism of heat transfer in forced convection local boiling, mechanism of bubble initiation and growth, visual and auxiliary studies, and design of main test installation.

2800. Bonnet, W. E. and Gerster, J. A.

BOILING COEFFICIENTS OF HEAT TRANSFER. C_4 HYDROCARBON-FURFURAL MIXTURES INSIDE VERTICAL TUBES, Chem. Eng. Progr. 47, 151-8 (1951).

Results of this paper show the order of magnitude of the increase in boiling coeffs. of heat transfer which can be expected with increasing vaporization of small amts. of a volatile component from a mixt. contg. large amts. of a slightly volatile component. The vaporization caused an increase in both the turbulence and in the boiling temperature of the remaining liquid, the latter effect being so large that it required a large fraction of the heat being transferred. A correlation of the results of this study showed that under the conditions of variable total pressure the vo. of vapor generated was the factor affecting increase in the coeff. of heat transfer. More fundamental studies in which local boiling coeffs. are measured along the tube length are greatly to be desired to provide basic reboiler design information. (CA-45-3662d).

2801. Cathro, K. J. and Tait, R. W. F.

HEAT TRANSFER TO LIQUIDS BOILING INSIDE TUBES, I. THE CLIMBING FILM EVAPORATOR, Australian J. Appl. Sci. 8, 279-304 (1957).

A detailed discussion, with photographs of the boiling action in a climbing-film evaporator is given. Quant. data are obtained for 8 liquids and 4 tubes; the equation $[h_b D/k]/[(DG/\mu)^{0.25}(D\rho_\ell \lambda J/\sigma)^{0.48}(L/D)^{0.7}(D/K)^{0.5}] = \Phi(\Delta t_b C/\lambda)$, where h_b is the boiling-film heat-transfer coeff., D is the diam. in ft., k is the thermal cond., G is the mass flow, μ is the viscosity, ρ is the d., ℓ refers to the liquid phase, λ is the latent heat of evapn., J is the conversion factor (778 ft.-lb. = 1 Btu), σ is the surface tension, L is the tube length, K is a const., Φ is a math. function, Δt_b is the boiling-film temp. difference, and C is the sp. heat, correlates these data, those of Stroebe, et al. (CA-33-2369[8]) and those of Coulson and Mehta (CA-48-6751i) to within ±30%. There is slight evidence that the exponent 0.25 on the Reynolds number applies only at values of N_{Re} above a certain crit. value. The equation applies only to pure liquids but a method of modification for aq. solns. is suggested.

2802. Dengler, C. E. and Addoms, J. N.

HEAT TRANSFER MECHANISM FOR VAPORIZATION OF WATER IN A VERTICAL TUBE, Chem. Eng. Progr., Symposium Ser. 52, No. 18 (1956).

The mechanism of boiling in tubes was investigated. The principal conclusions are as follows: (1) The mechanism of heat transfer during vaporization in tubes is primarily convective. Nucleate boiling is dominant only under conditions of low liquid velocity and is gradually suppressed by the effects of vapor-induced forced convection. (2) The operating variables exert independent and often opposing effects on each of these mechanisms. (a) Increase in pressure may increase the heat transfer coeffs. by its effects on nucleate boiling or decrease them in the range of two phase convection by raising the av. fluid d. and thereby lowering the velocity. (b) Increase in temp. difference promotes nucleate boiling but has no direct effect on the convective coeffs. (c) Increase in total mass throughout increases the convective heat transfer but decreases the nucleate boiling heat transfer by lowering the available effective temp. driving force for nucleation.

2803. English, D., Blacker, P. T. and Simmons, W. E.

BOILING AND DENSITY STUDIES AT ATMOSPHERIC PRESSURE, AERE-ED/M-20 (April 21, 1955) 37 p.

Experimental data are presented for heat transfer to water in rectangular channels. Heat flux and hydraulic conditions likely to occur in a reactor runaway were reproduced as nearly as possible in the experiments. Water was passed upward through a heated tube, and the density of the water or water-steam mixture was determined along the length of

the tube by β-ray absorption measurements. In the nonboiling region the usual heat transfer correlations were found to be valid. Results of burnout tests and density determinations are presented graphically.

2804. Groothuis, H., et al.

HEAT TRANSFER IN TWO PHASE FLOW, Chem. Eng. Science, 11, 212 (1959).

Heat-transfer measurements for two-phase flow of water-air and gas oil-air mixts. in a vertical tube were made over a wide liquid mass flow range and a 200-fold range of gas to liquid-phase vol. The addn. of air to the flowing liquids increases the heat-transfer coeff. The results can be simply correlated over most of the range by interrelating the Nusselt and Prandtl nos. based on the phys. properties of the liquid phase with a Reynolds no. obtained by adding the liquid and gas Reynolds nos., both based on superficial velocities. At higher gas-to-liquid ratios, a max. in the heat-transfer coeff. is observed.

2805. Haselden, G. G.

THE PROBLEM OF PREDICTING HEAT TRANSFER TO TWO-PHASE (VAPOUR-LIQUID) FLUIDS AT MODERATE PRESSURES, Paper No. 2, Symposium (Preprint of Proceedings) on Two-Phase Fluid Flow, Inst. Mech. Engrs., London, England, February 7, 1962.

The discussion is generally restricted to conditions under which there is no subcooling of the feed, the heating surface is the inside wall of a vertical tube, and the temperature of the wall is not so great as to cause film boiling. The pressure range covers values up to about one-third of the critical pressure of the fluid.

The several boiling regimes resulting from the different flow conditions in the tube are differentiated. It is shown that a complete prediction of heat-transfer rates must embrace (a) nucleate boiling and its suppression by fluid flow, (b) conditions for the onset of annular film flow, and the calculation of local high-temperature coefficients in this region, and (c) the onset of dry wall conditions.

These factors are discussed, particularly in relation to the results of experiments made in the Chemical Engineering Department of Imperial College, London.

2806. Kirschbaum, E.

NEW DATA ON HEAT TRANSFER WITH AND WITHOUT CHANGE IN STATE, Chem.-Eng.-Tech. 24, 393-400 (1952).

A comprehensive study covering condensation boiling (evapn.), heating, and cooling. A universal app. was developed for studying heat-transfer phenomena in a vertical tube. Details of the app. and a diagram are given. Special techniques used to get accurate wall temps. are described. Data are presented for film and dropwise condensation of steam, heat-transfer coeffs. for air and water, the latter for upward and downward flow, and for boiling in a vertical tube with and without foaming. (CA-46-8906g).

2807. Kreith, F. and Summerfield, M.

INVESTIGATION OF HEAT TRANSFER AT HIGH HEAT FLUX DENSITIES: LITERATURE SURVEY AND EXPERIMENTAL STUDY IN ANNULUS, Progress Report No. 65, Jet Propulsion Laboratory, Calif. Inst. of Tech. (Feb. 20, 1948).

In order to make it possible for the designer of regeneratively cooled rocket motors to predict more accurately the heat-transfer coefficients at heat-flux densities above 0.5 Btu/(in.^{2})(sec) and to determine the feasibility of cooling rocket motors by boiling heat transfer with a minimum of friction drop in the coolant flow passages, an experimental investigation of these problems was initiated. A brief review of the literature and an outline of the problems to be studied are given. Results are given for a series of tests to determine the convective film conductance in a 0.062-in. annulus at a heat-flux density of about 1.0 Btu/(in.^{2})(sec).

The convective conductances of water and of aniline containing 20% furfuryl alcohol were measured in the velocity range from 8 to 30 fps. It was found that the experimental convective film conductances were larger than the value predicted by conventional equations. The experimental Nusselt moduli in the range of bulk Reynolds no. from 6,000 to 25,000 and Prandtl no. from 3 to 10 could be correlated within ±5%.

2808. Lottes, P. A.

BOILING STUDIES AT ARGONNE RELATIVE TO BOILING REACTORS, Proc. Conf. Nuclear Eng. A1-A7 (1955).

Pressurized boiling d. tests, the behavior of water during transient boiling and expulsion from tubes, general equation and limitations on natural boiling calcns. are discussed. A description of the test app. and data charts are included. Max. power density reported is 50 kw/l. or 100,000 Btu/hr sq ft heat flux. (CA-49-15515d).

2809. Lottes, P. A.

BOILING WATER REACTOR TECHNOLOGY STATUS OF THE ART REPORT. VOLUME I. HEAT TRANSFER AND HYDRAULICS, ANL-6561 (Feb. 1962) 189 p.

Information on heat transfer and hydraulics pertinent to the design and operation of boiling water reactor power plants is presented. The following areas of discussion are covered: heat transfer, two-phase density studies, two-phase pressure drop, critical heat flux and burnout, boiling stability, calculation procedures for boiling systems, and thermal-hydraulic design procedures for boiling water reactors.

2810. Miller, R. I.

STEADY-STATE TWO-DIMENSIONAL FLOW OF WATER WITH BOILING IN NON-UNIFORMLY HEATED RECTANGULAR DUCTS, p. 91-7 of Bettis Technical Review. Reactor Technology, WAPD-BT-18 (1960) 137 p.

MITE-02, and IBM-704 FORTRAN code, calculates the two-dimensional steady-state flow distribution within a vertical rectangular channel. The two-dimensional transfer of mass, momentum, and energy are described throughout the subcooled, nucleate boiling, and bulk boiling regions of the coolant. The model was experimentally verified and is intended for use as a design tool.

2811. Novosad, Zdenek

HEAT TRANSFER IN THE TWO PHASE SYSTEM LIQUID GAS, Chem. Listy 48, 946-70 (1954).

Heat transfer between the wall and the liquid inside vertical tubes, in the presence of a bubbling gas, has been studied. The exptl. heat-transfer coeffs. may be correlated by means of a modified Reynolds no.: $Re = du_g\rho/\eta\sqrt{z}$, where d = diam. of the tube, u_g = linear velocity of the gas, z = vol. ratio of the gas to the liquid + gas in the tube, ρ, η = d. and viscosity of the liquid, resp. When u_g increases, 2 flow types were observed: in the first of them, designated as a bubble-range, the heat-transfer coeff. increases rapidly; above certain crit. velocity, in the so-called flow range, the heat-transfer coeff. increases much more slowly and in some cases even decreases. In the flow range the coalescence of bubbles takes place and gas streams are formed. A general relation valid in the bubble range has been derived: $Nu = Nu_0/(1 + 30\sqrt{z}) + 2.28\ Re^{0.7}Pr^{1/2}$, where Nu, Pr, and Re are the Nusselt, Prandtl, and Reynolds nos., resp.; Nu_0 is the Nusselt no. in the absence of the gas.

2812. Parker, J. D. and Grosh, R. J.

HEAT TRANSFER TO A MIST FLOW, ANL-6291 (1961) 245 p.

An experimental and analytical study was made of the heat transfer characteristics of a mist flow of steam and water droplets flowing vertically upward in a round tube. A simplified analytical model, based on momentum, mass, and energy considerations, was developed which shows qualitatively that severe temperature fluctuations are characteristic of such flows under constant wall heat flux conditions.

The experimental investigation was made with steam at 30 psia flowing through an electrically heated one-inch ID copper tube, four feet in length. The quality was varied by the injection of water into the steam prior to its entry into the heated section. Total mass flow rates of 200, 300, and 400 lbs. per hour were maintained for the tests. Heat fluxes were varied from 3,020 to 20,700 Btu/hr square feet, and inlet qualities were varied from 89 to 100 per cent.

The experimental data showed that the analytical model gave a fairly accurate qualitative description of the tube wall temperature variation with length. The analysis of the data seemed to indicate that the assumptions of equilibrium between phases and constant values for the mass transfer coefficient for droplets were incorrect.

An electronic spray analyzer used in the investigation proved to be useful for the detection of droplets but was of little value in determining droplet spectrums.

Very high values of heat transfer coefficient were found for the annular-mist flow region that exists just upstream from the mist flow region. In the mist flow region two distinct types of heat transfer were noted, depending upon whether the spheroidal state existed for the droplets striking the heated tube wall. For wall temperatures below a certain value heat transfer coefficients were almost identical to those for dry steam, even with considerable moisture present in the mist.

2813. Poletavkin, P. G. and Shapkin, N. A.

HEAT TRANSFER IN SURFACE BOILING OF WATER, Translated from Teploenergetika 5, No. 5, 49-54, AERE Lib/Trans 813 (1958).

New experimental results on surface boiling are given and compared with previous results. The vertical experimental section was a stainless steel tube of internal diameter 5.6 mm, 225 mm long. The tests on heat transfer and steam quality were made simultaneously. Measurements were made on the tube wall temperature at three places along its length. Tests were run at pressures of 7.16 and 41 atm, heat flow rates of up to 2.5×10^6 kcal/m^2hr, underheating of 3 to 120°C, and circulation rates of 0.7 to 11.5 m/sec.

2814. Rachko, V. A.

INVESTIGATION OF THE EFFECT OF SURFACE ROUGHNESS ON THE HEAT TRANSFER COEFFICIENT OF BOILING LIQUIDS, SKTS, (Reports of the Kirovgrad Alloys Plant), 11 (1940).

2815. Rachko, V. A.

INVESTIGATION OF HEAT TRANSFER TO BOILING WATER IN A VERTICAL TUBE, Zhur. Tekh. Fiz. 11, No. 5, 13-14 (1941).

2816. Rachko, V. A.

THE EFFECT OF TUBE DIAMETER ON THE HEAT TRANSFER COEFFICIENT WHEN BOILING WATER, Zhur. Tekh. Fiz., 16, No. 6 (1946).

2817. Sani, R. L.

DOWNFLOW BOILING AND NONBOILING HEAT TRANSFER IN A UNIFORMLY HEATED TUBE, UCRL-9023 (1960) 88 p.

The local heat-transfer coeff. in forced convection downflow boiling and nonboiling, was detd. by using an elec. heated stainless-steel tube. Av. forced-convection heat-transfer gradients in 2-phase flow were also detd. Data are presented for the boiling of distd. H_2O with mass fluxes of 51 to 165 lb/sec sq ft, heat fluxes from 13.8×10^3 to 49.8×10^3 Btu/hr sq ft, pressures from 15.8 to 30.9 lb/sq in abs., and qualities up to 14%. 16 references.

2818. Shcherbakov, V. K.

HEAT TRANSFER IN ANNULAR CHANNELS WITH SURFACE BOILING OF WATER, Izvestiya vysshikh uchebnykh zavedeniy. Energetika, no. 5, 1962, 93-100.

In order to determine the heat transfer coefficient for surface boiling of distilled water in a vertical annular channel with the direction of heat transfer towards the center, an experimental investigation was carried out at the Heat Transfer and Gas Dynamics Laboratory of the Kiyev Polytechnical Institute. The heat transfer surface was provided by a stainless steel seamless tube with outside diameter 13.1 mm and inside diameter 10.5 mm with length 160 mm. The tube was heated electrically. The width of the annular gap was varied over a range 3.5 to 14.5 mm. The water flow was varied from 0.6 to 5.0 m/sec and the pressure from 1.5 to 5.0 atm. with an under heat from 12 to 60-70°C. The thermal flux was varied from 0.2×10^6 to 5.7×10^6 kcal/m^2h. A comparison of the experimental data indicates that a changeover in the curvature of the heat transfer surface (concave in tubes and convex in annular channels) does not markedly affect heat transfer with surface boiling of flowing underheated water. The experimental values obtained within the range of water velocities 0.6 - 5.0 m/sec, width of annular channel 3.5 - 14.5 mm, pressure 1.5 - 5.0 atm and under heat 12 - 65°C can be described with a dispersion of ±15% by the empirical Eq. (4):

$$\alpha_k = 2.3\, p^{0.15} q^{0.7}$$

(α_k being the coefficient of heat transfer with surface boiling, p the pressure and q the heat flux). The heat transfer coefficients are in satisfactory agreement with calculated from the criterion formula (4) for large-volume boiling. In the transition range from convective heat exchange to surface boiling the relationship of wall temperature to heat flux can be taken as linear between $t_w = t_s$ and t_w (t_w being the wall temperature and t_s being the water saturation temperature at the given pressure). There is 1 table and 6 figures.

2819. Singh, K. P. and Havemann, H. A.

TRANSPORT OF HEAT BY CONVECTION AND BOILING IN LIQUIDS ENCLOSED IN VERTICAL TUBES, Proceedings of third congress theor. Appl. Mech. Begalore, India, Indian Soc. Theor. Appl. Mech., Indian Inst. Technol., Kharagpur, p. 277-292 (1957).

This is a continuation of work described in preceding review with a greater number of liquids and tube diameters and lengths. Data near the critical state are also obtained. It was found that there is considerable increase in heat transfer near the critical state.

2820. Tarasova, N. V., Armand, A. A. and Kon'kov, A. S.

HEAT TRANSFER TO SUBCOOLED WATER AND WATER STEAM MIXTURES BOILING IN A TUBE, Teploobmen pri Vysokikh Tepl., Nagruzkakh i Drugikh Spets. Ugloviyakh, Sb. Statei, 6-22 (1959).

An exptl. investigation of heat transfer by boiling subcooled H_2O and water-steam mixts. in a vertical Ni pipe, 8 mm. inner diam. and 650-320 mm. long, is described. The pressure used was 170 atm. The heat flux changed from 200×10^3 to 800×10^3 kcal/sq m-hr and the wt. rate from 1000 to 2800 kg/sq m sec. The max. value of subcooling (in expts. with water) was 78°C. In expts. with water-steam mixt., the steam content varied from 0 to 1.0.

2821. Tolubinskii, V. I.

HEAT TRANSFER DURING BOILING OF WATER IN VERTICAL TUBES AT LOW HEAT FLUXES, Trudy Inst. Teploenerget. No. 10, 12-14 (1953) Referat. Zhur., Khim (1955) Abstr. No. 57368.

The results of expts. for detg. the coeff. of heat transfer during boiling of water in vertical pipes at heat fluxes of 8000-14000 kcal/sq m hr and different hydrodynamic conditions are reviewed. Curves for the coeff. of heat transfer α along the length of the boiler tube with different liquid levels and also for the change of the av.coeff. $\alpha_{av.}$ are given.

2822. Woods, W. K.

HEAT TRANSFER FOR BOILING INSIDE TUBES, Sc. D. Thesis, MIT (1940).

VISUAL OBSERVATIONS

2823. Beighley, C. M. and Dean, L. E.

STUDY OF HEAT TRANSFER TO J.P.4 JET FUEL, Jet. Prop. 24, 180-186 (1954).

An electrically heated stainless steel tube with an annular transparent test section was used to study heat transfer to jet engine fuel. Data were obtained for various regions of nonboiling and nucleate boiling for velocities from 3 to 40 ft/sec. and pressures of 30 to 500 lb/sq in.abs. Burnout data are also presented. Coking was studied by means of colored films.

2824. Benecki, R. J. and Morse, M.

VISUAL STUDIES OF BOILING IN VERTICAL TUBES, Cambridge, Mass. Institute of Technology, M.S. Thesis (1951).

2825. Chernobylskii, I. I. and Tananaiko, Yu. M.

AN INVESTIGATION OF THE HEAT TRANSFER TO BOILING WATER FLOWING THROUGH NARROW ANNULAR OPENINGS IN THE PRESENCE OF MODERATE HEAT FLUXES, Izvest. Kiev. Politekh. Inst. 17, 61-74 (1956).

The values of the heat transfer coefficient of water boiling in annular slits are obtained. The problem of the influence of the width of the slit on the coefficient of heat transfer at moderate thermal loads is investigated, and the process of boiling of the water in the slit is observed visually. Equations for the heat transfer coefficient are also obtained.

2826. Clark, J. A.

STATEMENT OF PROGRESS FOR THE PERIOD 1 April to 15 May 1951, NP 3164 (1951) 3 p.

Apparatus for the visual study of forced convection boiling from a (1/2 x 4 in.) stainless-steel strip at a pressure of 1 atm was put into operation. Two photographs are included, showing the effect on bubble population of q/A, velocity, and subcooling.

2827. Henry, G., Raymond, M. W. and Walsh, J. R.

BOILING HEAT TRANSFER PROJECT MONTHLY PROGRESS REPORT, NP 4218 (Nov. 1952) 6 p.

The collection of visual density data has been completed for a velocity of 10 fps, channel height of $\frac{1}{2}$ in., for temperatures up to 550°F, and 500, 1000, and 1500 psia pressures. The data are not recorded in this report. In order to determine the effect of vapor volume on average density of the total mass above the heater strip a relation for the ratio of the average density to liquid density was derived. Operation of the equipment is discussed. A proposal was submitted outlining a program directed toward the gathering of more information on the deposition of foreign matter on heat-transfer surfaces (crud program). Apparatus is being designed to study the heat transfer in forced convection from wires to water under conditions of local boiling (small-scale boiling studies). Provision for photographic observation of the boiling water is being made for density calculation and for the study of bubble formation and growth.

2828. Henry, G., et al.

BOILING HEAT TRANSFER PROJECT, MONTHLY PROGRESS REPORT, NP 4230 (Dec. 1952) 26 p.

Visual-density data in liquids are reported for a bubble velocity of 10 fps at pressures from 500 to 1500 psia and temperatures from 345 to 562°F. Results indicate that increases in heat flux bring about similar increases in vapor volume which in turn produce greater effects on the mixture density.

2829. Henry, G. and Raymond, M. W.

BOILING HEAT TRANSFER PROJECT PROGRESS REPORT, NP-4723 (Jan. 1953) 6 p.

Visual density data for 30 fps were recorded for pressures and temperatures up to and including 1500 psia and 550°F. The profile data corresponding to top-view conditions were taken for the velocities of 20 and 30 fps. This completes the program for the 0.500-in. channel height, contingent upon successful developing and printing of the negatives. The density data for 20 fps were processed through the state of vapor-volume calculation.

2830. Henry, G.

BOILING HEAT TRANSFER PROJECT PROGRESS REPORT, NP 4588 (March and April, 1953) 12 p.

The channel height in the visual test section was reduced from 0.500 to 0.180 in., and runs were made at 1000 psia. Data could not be analyzed as the bubble photographs were not clear enough. Data are presented from the crud program on one boiling and one nonboiling run at pressures of 2000 psia, velocities of 1 fps, and temperatures of 435°F.

2831. Henry, G.

BOILING HEAT TRANSFER PROJECT PROGRESS REPORT, NP 4713 (May 1953) 10 p.

Photographic data taken for the 1/2-in. channel height under the revised degassing technique for pressures of 500 and 1000 psia at velocities of 20 and 30 fps and for the 1500 psia pressure at 20 fps were statistically analyzed for the vapor volume and mixture-density quantities. The results are reported in the form of mixture-density ratio vs. heat-flux plots for the five pressure velocity combinations. Graphs showing density ratio vs. heat flux are included.

2832. Jeffery, R. W.

VISUAL STUDY OF WATER FLOWING OVER A FLAT PLATE AT HIGH RATES OF HEAT TRANSFER WITH SURFACE BOILING (1952) 64 p.

The procedure for investigating the mechanism of heat transfer to water undergoing surface boiling consisted of fixing the system pressure, inlet temperature and velocity and then photographing the resulting bubble pattern caused by electrically heating a flat plate of stainless steel. The distilled, degassed water flowed upward in the test section and was kept chemically pure by an ion exchanger. High-speed motion pictures (4000 fps), as well as ultra short exposure still pictures (exposure time - 10^{-6} sec) were taken at various conditions. Because of experimental difficulties, it was impossible to reach saturation temperature of the desired operating pressure (2000 psia). Thus, runs were made at comparatively low pressures (100 to 500 psia) with moderate subcooling of the water and a few were made at high pressure (1000 to 2000 psia) with very large heat flux and high subcooling, neither of which conditions were of primary interest. The pictures taken were valuable for developing photographic and bubble-studying techniques, however.

2833. Kinney, G. R., Abramson, A. E. and Sloop, J. L.

INTERNAL-LIQUID-FILM-COOLING EXPERIMENTS WITH AIRSTREAM TEMPERATURES TO 2000°F IN 2-AND 4-INCH-DIAMETER HORIZONTAL TUBES, NACA-1087 (1952) 21 p.

An experimental investigation of internal-liquid-film cooling was conducted in 2- and 4-inch-diameter straight metal tubes with air flows at 600°F to 2000°F and Reynolds numbers from 2.2 to 14 x 10^5. The coolant was water at flows of 0.8 to 12 per cent of air flow. Visual observations of liquid-film flows were made in transparent tubes with air flows at 80° and 800°F and Reynolds numbers from 4.1 to 29 x 10^5. Flows of water, water-detergent solutions, and aqueous ethylene glycol solutions were investigated. Liquid-coolant films were established and maintained around and along the tube wall in concurrent flow with the hot air. The tube wall was kept below the boiling temperature of the coolant. Coolant films were relatively smooth unless the coolant flow was sufficiently high so that the liquid film was thick enough to enter the region where turbulent forces predominate over viscous forces; wavelike disturbances then developed on the liquid film. These disturbances resulted in increased loss of coolant from the film and reduced effectiveness of the coolant.

2834. Malik, J.

PHOTOGRAPHIC STUDY OF BOILING IN VERTICAL TUBES, Cambridge, Mass. Institute of Technology, B. S. Thesis (1951).

2835. Rohsenow, W. M. and Clark, J. A.

A STUDY OF THE MECHANISM OF BOILING HEAT TRANSFER, NP-3392 (Feb. 1, 1950) 28 p.

An analysis of the heat required to form a vapor bubble in a liquid is presented. High-speed motion pictures of boiling heat transfer in forced convection showing bubbles departing from a heated surface are analyzed and the net heat transferred to the bubbles is compared with the total heat transferred from the heated surface. It is found that the heat transferred to the moving liquid by the condensation of the bubbles is a negligible part of the total convective heat transfer. Therefore, it is proposed that the high rate of heat transfer assocd. with surface boiling in a sub-cooled liquid is due primarily to the violent agitation of the quiescent layers of liquid adjacent to the heated surface resulting from the motion of vapor bubbles being generated there. (CA-45-6881f).

2836. Sachs, P. and Long, R. A. K.

A CORRELATION FOR HEAT TRANSFER IN STRATIFIED TWO-PHASE FLOW WITH VAPORIZATION, Int. Journ. of Heat and Mass Transfer 2, 222-230 (1961).

A mechanism of vaporization is suggested for the case in which a saturated fluid flows vertically upwards through a heated annulus. Visual observations and measurements of vapor fraction on an experimental apparatus are recorded, and it is noted particularly that an annulus of vapor was seen to surround a thin liquid layer on the heater surface in the upper regions of the heated system. No nucleate boiling occurred in the liquid layer. The experiment was carried out in the temperature-difference range 18° to 40°F, and the liquid mass flow rate was varied from 1 to 5 lb per minute. At high heat fluxes in this stratified flow zone it is demonstrated that it may be possible to consider the heat transfer to be entirely convective. A hypothesis is developed analytically and is substantiated in this experiment by the good correlation of the heat and mass transfer results by means of a standard expression for forced convection.

2837. Taylor, C. E. and Steinhaus, J. F.

HIGH FLUX BOILING HEAT TRANSFER FROM A FLAT PLATE, UCRL 5414 (1958) 47 p.

Flat copper plates, $\frac{1}{8}$ in. thick, were heated on one side by electron bombardment of a $1\frac{1}{2}$ in. diameter area and cooled on the opposite side by water flowing in a 0.050 to 0.090-in. wide passage. Data were obtained on plate temperature vs. heat flux, "burnout" heat flux vs. water velocity and the effects of various surface finishes. High-speed photographs were taken of the boiling phenomena. Audible sounds were observed and sound frequencies measured. Water velocity ranged from 2 to 41 ft/sec, water pressure from 36 to 120 psia, and heat flux to 31 kw/in.^{2} (15.2 x 10^6 Btu/hr-ft^2).

2838. Treshchov, G. G.

EXPERIMENTAL INVESTIGATION OF THE MECHANISM OF HEAT TRANSFER IN SURFACE BOILING OF WATER, Teploenergetika 4, No. 5, 44-8 (1957), Translation avail: See Tech. Trans. 3, No. 8, 542 (1960).

Experimental investigation of heat exchange mechanism of surface boiling of water by means of microsecond photography.

2839. Walsh, J. B.

BOILING HEAT TRANSFER PROJECT, PROGRESS REPORT FOR JUNE AND JULY 1953, NP-4925, 11 p.

The channel height in the visual test section was reduced from 0.500 to 0.180 in., and runs were made at 1000 psia. Data could not be analyzed as the bubble photographs were not clear enough. Data are presented from the crud program on one boiling and one nonboiling run at pressures of 2000 psia, velocities of 1 fps, and temperatures of 435°F.

2840. Walsh, J. B. and Raymond, M. W.

BOILING HEAT TRANSFER PROJECT, PROGRESS REPORT FOR AUGUST AND SEPTEMBER, 1953, NP-4926, 6 p.

A successful illumination system has been developed for the 0.180-in. channel height. Effort is now being concentrated on breakage problems associated with the flash lamp and the channel-height windows. No data are reported for this period.

2841. Walsh, J. B. and Raymond, M. W.

BOILING HEAT TRANSFER PROJECT, PROGRESS REPORT FOR OCTOBER, 1953, NP-4987, 6 p.

Progress is reported on modification and testing of equipment for use in the visual-density and burnout programs. No specific data are given.

2842. Walsh, J. B. and Raymond, M. W.

BOILING HEAT TRANSFER PROJECT PROGRESS REPORT FOR DECEMBER, 1953, NP-5063, 3 p.

Progress is reported on the visual-density and burnout programs. Reasons for failures in each of the programs are enumerated. No specific data are given.

2843. Westwater, J. W. and Santangelo, J. G.

PHOTOGRAPHIC STUDY OF BOILING, Ind. Eng. Chem., 47, 1605-10 (1955).

The photographic equipment and techniques used to obtain motion pictures of nucleate, transition, and film boiling are described. (NSA-9-6253).

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