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Changing the World's Energy Future

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INTRODUCTION

Microreactor is a type of nuclear reactor that is intended to produce thermal energy from the micro and integrated design. Among various microreactor roadmaps, microreactor with heat pipes is one of the promising designs that under active development. At Idaho National Laboratory (INL) and supported by the Department of Energy (DOE) Microreactor Program (MRP), a Single Primary Heat Extraction and Removal Emulator (SPHERE) was developed [1,2]. The main purpose of SPHERE is to understand thermal performance of heat pipe in the conjunction of heat source without using nuclear material. The heat pipe used in the SPHERE has sodium as a working fluid, with Argon gas in the vapor region, thus this heat pipe is a Variable Conductance Heat Pipe (VCHP). The volume of non-condensable gas changes with power and elapsed time, so the area covered by non-condensable gas changes. This gives an effect that passively controls the cooling capability of condenser section.

This preliminary experiment was intended to perform a gap conductance experiment that reveals heat transfer characteristics of gas at the gap around the heat pipe. However, there are not many experimental data that deals with heat transfer of the gas at the gap around heat pipe.

In this research, the preliminary experimental result regarding to the heat pipe performance with different composition of gas at the gap, level of power is presented. The experimental data will be used for the validation study of SOCKEYE as a future plan.

EXPERIMENTAL SETUP

The experimental setup was changed from the previous setup of SPHERE [1,2]. There was a quartz tube outside of hex-block and system to visually observe the test section. Recently, this quartz tube was changed to stainless steel (SS) casing to prevent the heat loss from the heat pipe to outside by installing insulation parts inner and outer side of the tube. Figure 1 shows the test section configuration for heat pipe, hex-block, calorimeter, and SS casing. The evaporator section of heat pipe is in the hex-block with a length of 0.4953m. At the end of the heat pipe, cooling shroud is installed to measure the heat removal rate from the condenser part. Between the hex-block and heat pipe, there is a gas gap existing to allow certain thermal expansion of the components during the high operating temperature. This gap is also open to the whole system, so thermal energy is dispersed to the system through convective heat transfer. Total length of the heat pipe is 2.0m. Both the hex block and adiabatic section are covered with insulation made of zirconia wool of 1 inch thick to further reduce the heat loss.

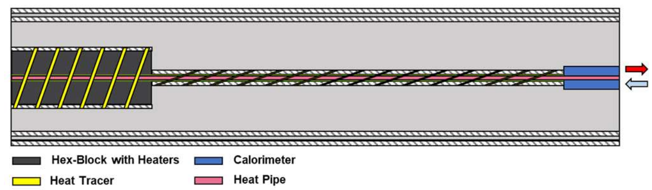

Figure 1. SPHERE Test Section Configuration

In this pilot study, 7 thermal couples were inserted to the thermowell of liquid metal heat pipe as shown in Figure 2. Those thermal couples capture temperature of vapor inside of heat pipe during the operation. Each thermal couple (TC) is 7 inches apart. The first thermal couple TC7 is located near the beginning of evaporator section.

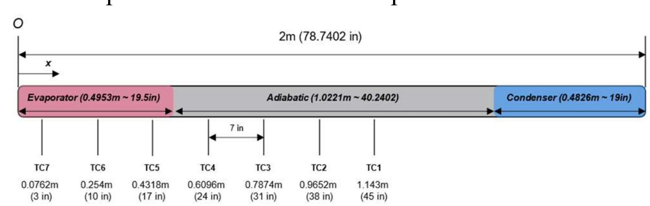

Figure 2. Location of Thermal Couples

The preliminary test cases are listed in Table 1. The power, gas pressure of the test section, heat tracer temperature is included to specify the boundary conditions. The first

Table 1. Preliminary Test Matrix

CASE	GAP GAS	POWER [W]	GAS PRESSURE [Psia]	HEAT TRACER TEMPERATURE [C] (Block / Heat pipe)
		500		303 / 504
1	Vacuum	400	0.38	287 / 479
		300		276 / 458
		500		172 / 439
2	Argon	400	13.2	169 / 416
		310		161 / 393
		500		165 / 405
3	Nitrogen	400	13	154 / 379
		300		126 / 361
		500		140 / 391
4	Helium	400	12.5	135 / 376
		300		132 / 359

vacuum case was made with pressure of 0.38 psia. For Argon (Ar), Nitrogen (N_2), and Helium (He) cases, test section was filled with each corresponding gas under atmospheric pressure. The power was controlled to from 300 to 500W. In each case, temperature of heat tracer was adjusted to minimize radiative heat loss. The heater was operated for 20 hours, so the temperature distribution for steady-state heat pipe operation was obtained.

RESULTS AND DISCUSSIONS

The start-up phase of VCHP was investigated at first. In the initial state, vapor region of heat pipe is filled with Ar. The non-condensable gas (Ar) is expanded to the beginning of evaporator section as partial pressure of working fluid is small. As heat pipe gets heated, the volume of Ar decreases and that of sodium vapor increases taking up the volume of heat pipe. The sodium vapor region is an active region, and the other part is classified as an inactive region where thermal conductivity is very low at the order of 0.01 W/m-K. The effective condenser area is determined by the location of interface between the vapor and Ar.

As heat pipe is heated, the expansion of active region is observed through the evolution of vapor temperature. Figure 4 shows the expected trend of vapor temperature. As time passes, the temperature at each thermal couple rises sequentially from TC 7. The length of active region can be determined from the temperature of thermal couple. In He case, the temperature of TC1 did not reach to the operation temperature, which means TC1 is in the inactive region. In N_2 case, all the thermal couples reached to operation temperature except for TC7. This result comes from the heat floss from the hex-block to the ambient that is out of test section.

The active region of heat pipe varies with heater power, time, and gas composition. Figure 5 presents temperature distribution along the heat pipe thermowell for every cases. Each result was obtained at the time when temperature distribution reached steady state. Overall, the operating temperature appears in the reverse order to the thermal conductivity of the gas. He gas has relatively higher thermal conductivity as shown in Figure 6. N_2 and Ar gases have

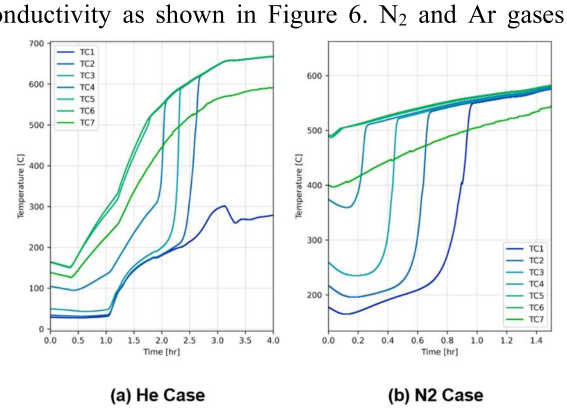

Figure 4. Temperature change at Thermowell during the Startup

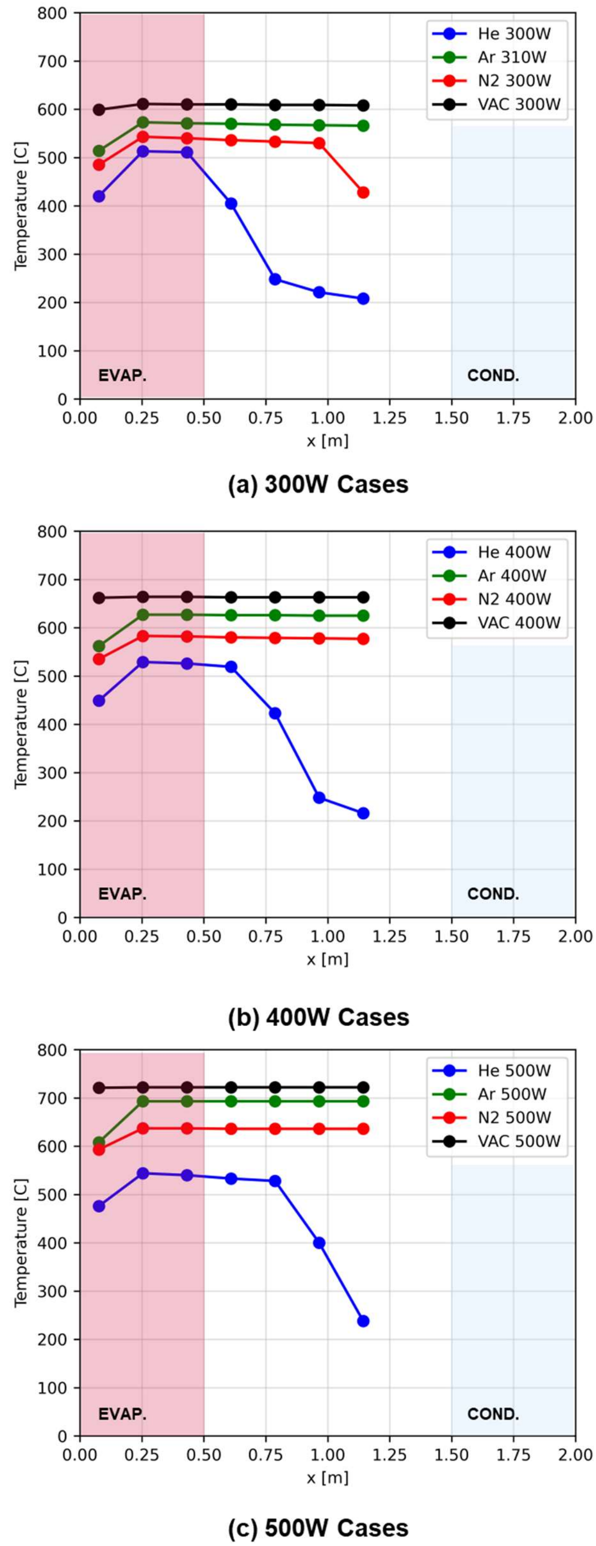

Figure 5. Temperature Distribution at Thermowell for Different Power Cases

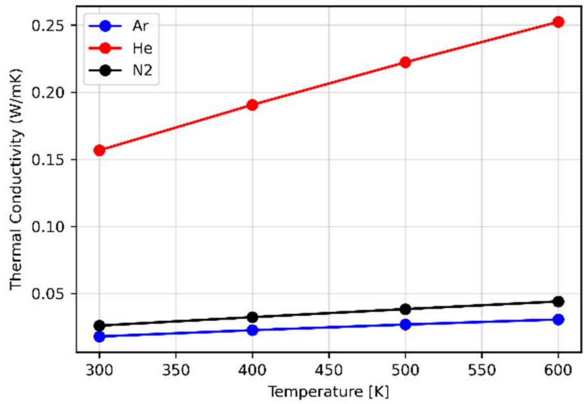

Figure 6. Thermal Conductivity of Gas with Temperature

similar thermal conductivity. The gap gas with pressure under atmosphere transfer heat to the space in test section by natural convection. Due to the heat loss through gap, He cases show decrease active region than other cases. In 300W cases, the active length of He cases only placed in the evaporator section. On the other hand, vacuum cases where heat transfer is only made through radiative heat transfer maintain the highest temperature as expected.

This experimental result also indicates that even the gas under the atmosphere pressure can disperse thermal energy to the system through natural convection. And the He has a best heat transfer performance thanks to its higher thermal conductivity.

A comparison of temperature distribution between experimental data and SOCKEYE model is illustrated in the Figure 7. This calculation case contains only radiative heat transfer in the input. For other cases like Ar, N_2, and He, the convective heat transfer should be considered in the model setup. As the future work, the SOCKEYE modeling will be conducted with detailed analysis on the convective heat transfer at the gap.

CONCLUSION AND FUTURE WORK

In this study, a preliminary analysis of SPHERE gap conductance test was made. The outer tube was changed from quartz to stainless steel casing to decrease heat loss of the system. From the experimental data, the progress of interface between vapor and non-condensable gas was observed, and different operating temperature of heat pipe due to different conductance of gap gases was found. The result shows that heat pipe operating temperature decreases with increase thermal conductivity of gas at the gap.

Future work will include the modeling of gap conductance experiment using SOCKEYE. To model the convective heat transfer of gas, the boundary conditions will be defined based on the temperature distribution at structure block and condenser temperature.

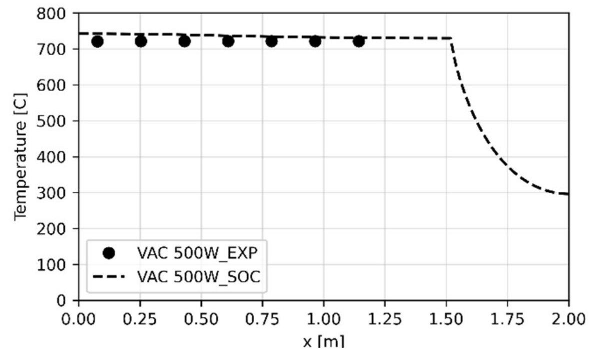

Figure 7. Comparison of temperature distribution between experimental case and SOCKEYE model

ACKNOWLEDGEMENTS

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