

Steam Reforming 6-inch Bench-Scale Design and Testing Project – Technical and Functional Requirements Description

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Project – Technical and Functional Requirements
Description**

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ABSTRACT

Feasibility studies and technology development work are currently being performed on several processes to treat radioactive liquids and solids currently stored at the Idaho Nuclear Technology and Engineering Center (INTEC), located within the Idaho National Engineering and Environmental Laboratory (INEEL). These studies and development work will be used to select a treatment process for treatment of the radioactive liquids and solids to meet treatment milestones of the Settlement Agreement between the Department of Energy and the State of Idaho. One process under consideration for treating the radioactive liquids and solids, specifically Sodium-Bearing Waste (SBW) and tank heel solids, is fluid bed steam reforming (FBSR). To support both feasibility and development studies a bench-scale FBSR is being designed and constructed. This report presents the technical and functional requirements, experimental objectives, process flow sheets, and equipment specifications for the bench-scale FBSR.

SUMMARY

Feasibility studies and technology development work are currently being performed on several processes to treat radioactive liquids and solids stored at the Idaho Nuclear Technologies and Engineering Center (INTEC), located within the Idaho National Engineering and Environmental Laboratory (INEEL). These studies and development work will be used to select a treatment process for treatment of the radioactive liquids and solids in compliance with the Settlement Agreement between the Department of Energy and the State of Idaho.

Fluid bed steam reforming (FBSR) is being considered as a process to solidify sodium-bearing waste (SBW) and, potentially, tank heel solids at the INEEL. The primary goal is to produce a waste-form acceptable for direct disposal in the Waste Isolation Pilot Plant (WIPP) site in New Mexico.

To support both feasibility and development studies, a bench-scale FBSR is being designed and constructed. The primary objective of the Steam Reforming Bench Scale Design and Testing Project is to investigate the applicability of steam reforming to the treatment of sodium-bearing wastes stored at INTEC. This project includes the design, fabrication, and testing of a bench-scale steam reformer.

Within the realm of FBSR there are private companies holding patents to certain combinations of process conditions and ingredient amendments. Tests of one or more private company fluid bed steam reforming process conditions, in addition to independent INEEL configurations of a non-proprietary nature, will be conducted.

This report presents the research objectives that the bench-scale FBSR is expected to address, the functional and operational requirements of the unit, a process flow description, and equipment specifications for the major pieces of process equipment.

The FBSR equipment includes a fluidized bed reactor system, a fines capture and reinjection system, a bed heating system, the off-gas treatment system, the reductant addition system, the feed conditioning and metering system, the product removal system, and ancillary equipment such as the steam superheater, off-gas blowers, electrical controls, pumps, filters, instrumentation, and process control equipment.

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ACRONYMS

AW-101	a simulant of one Hanford Low Activity Waste
CEM	continuous emissions monitor
DOE	U.S. Department of Energy
FBSR	Fluid bed steam reforming
HEPA	high efficiency particulate air (filter)
HR-120	a high temperature nickel alloy
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
IS/IH	industrial safety/industrial hygiene
NO _x	nitrogen oxides
P&ID	Process and Instrument Diagram
PLC	Programmable Logic Controller
PPE	personal protective equipment
RCRA	Resource Conservation and Recovery Act
SBW	sodium-bearing waste
SCFM	standard cubic feet per minute
VOCs	volatile organic carbons
WIPP	Waste Isolation Pilot Plant
WM-189	a simulant of one INEEL SBW

Steam Reforming 6-in. Bench-Scale Design and Testing Project – Technical and Functional Requirements Description

1. INTRODUCTION

Fluid bed steam reforming (FBSR) is being considered as a process to solidify sodium-bearing waste (SBW) and, potentially, tank heel solids at the Idaho National Engineering and Environmental Laboratory (INEEL). The primary goal is to produce a waste-form acceptable for direct disposal in the Waste Isolation Pilot Plant (WIPP) site in New Mexico. Several other treatment processes are also under consideration for treatment of SBW and tank heel solids. FBSR treatment performance data specific to SBW are required so that an informed decision of the best treatment process can be made.

In order to support decisions on the disposition of SBW at the INEEL, bench-scale steam reforming tests are planned. The Steam Reforming Bench-Scale Design and Testing Project includes the design, fabrication, and testing of a bench-scale steam reformer. The bench-scale steam reformer tests will be conducted using non-radioactive surrogates of SBW.

Within the realm of FBSR there are private companies holding patents to certain combinations of process conditions and ingredient amendments. A test of one or more private company fluid bed steam reforming process conditions, in addition to independent INEEL configurations of a non-proprietary nature, will be conducted. Based on the results of all tests, a preferred FBSR configuration and design will be selected (i.e., equipment configuration and operating parameters/conditions).

This report presents the research objectives that the bench-scale FBSR is expected to address, the functional and operational requirements of the unit, a process flow description, and equipment specifications for the major pieces of process equipment.

2. EXPERIMENTAL OBJECTIVES

The primary objective of the Steam Reforming Bench-Scale Design and Testing Project is to investigate the applicability of steam reforming to the treatment of sodium-bearing wastes stored at INTEC. Of the various candidate treatment technologies, steam reforming is considered the least technically mature (even though it is being used commercially in various private sectors) because there are insufficient data available for applications similar to the treatment of radioactive SBW. The fabrication and testing of a steam reforming unit, using simulated waste, will provide valuable data concerning the nature of the product(s), secondary waste streams, and process operability so that the technology can be compared with other candidate treatment technologies.

A further objective of the bench-scale FBSR is to provide a “neutral bias” test apparatus in which both private vendors and national laboratory personnel can perform testing. The neutral bias test bed will allow direct comparison of results from differing equipment configurations and operating parameters/conditions. Utilizing common feed preparation systems, common equipment scale, and common analytical systems, will greatly enhance comparability of tests.

A specific objective of the bench-scale FBSR is to be able to perform an elemental and molecular mass balance around the steam reforming unit so that there is a complete understanding of product and off-gas composition. Understanding the fate of Resource Conservation and Recovery Act (RCRA) constituents, destruction of volatile organic carbons (VOCs), and radioactive elements (non-radioactive

surrogates of radioactive elements will be used) will allow enhancement of mathematical models of the steam reforming process.

Another objective of the bench-scale FBSR is to demonstrate process operability with respect to bed performance and product separation. Issues such as bed agglomeration, product separation, fines carryover, and the recycling of solids will be quantified.

It should be noted that the objective of the bench-scale FBSR is to study the steam reforming unit operation, and it is not an objective at this time to create an integrated pilot plant. Off-gas components installed on the bench-scale FBSR will be used to mitigate air emissions from the unit, but may not represent off-gas systems of an actual treatment plant. Further refinement of off-gas system components may be integrated at a later date if the steam reforming unit operation is successful.

A secondary objective is to provide a platform that can be used for waste treatment studies for sister DOE sites. Other sites, such as the Hanford Site, are also considering utilization of FBSR.

3. TECHNICAL AND FUNCTIONAL REQUIREMENTS

To meet the experimental objectives listed above, a set of technical and functional requirements were established for the bench-scale FBSR. This set of requirements was compiled by a team of development engineers and scientists familiar with performing research on fluid bed reactors and performing work using SBW simulants. Additionally, engineers and scientists familiar with state-of-the-art characterization of complex off-gases were consulted. The functional and operational requirements of the bench-scale FBSR are listed below:

- The reactor will have a nominal bed diameter of 6 in.
- The bench-scale unit will have a nominal 2,000-hour design life
- The reactor bed temperature will have a nominal operating temperature of 750°C, and a maximum design temperature of 800°C
- The reactor bed volume will be such that a height to diameter ratio of at least 5/1 is achieved
- The bench-scale unit will have the ability to add gases in the exhaust expansion section of the reactor
- The bench-scale unit will have the ability to accommodate feed types, including AW-101 simulant and SBW WM-189 simulant
- The bench-scale unit will operate in continuous steady-state operating mode for a maximum of 100 hours
- The bench-scale unit will utilize automated continuous waste feed
- An automated semi-continuous bed material feed system will be used
- An automated semi-continuous reductant/amendment feed system will be used
- The bench-scale unit will have a variable metered flow of surrogate feed with a maximum feed rate of 8 L/hr

- The steam generator for the unit will have the ability to produce 25 lb/hr steam at 750°C and 1 atmosphere pressure
- The solids feed system will be capable of a solids feed rate twice the flow sheet nominal feed rate
- The distributor pressure drop of the reactor will be greater than 10% of theoretical bed pressure drop
- The reactor bed pressure will be controlled such that the entire bed length is sub-atmospheric
- The reactor bed will be externally heated
- The reactor bed will have provisions for introducing gases such as helium and air into the bed and disengaging section
- The bench-scale unit will have provision for the collection of fines without interrupting the steam reformer unit
- The bench-scale unit will have provision for semi-continuous (or continuous) segregation of granular product and bed material
- The solids-handling system will be configured to assure solids are free-flowing
- All off-gas filtration systems will be configured to allow continuous operation of the steam reformer unit (HEPA as well)
- The filtration system final particulate removal efficiency will be greater than 99%
- The bench-scale unit will provide for a discharge of off-gas below a dew point of 0°C
- The bench-scale unit will include continuous emissions monitor (CEM) capability supporting emissions monitoring, safety systems, process control, and data output for test objectives
- The bench-scale unit will have the ability to obtain solid/liquid samples during operation
- The bench-scale unit will have the ability to obtain gas-phase samples during operation
- The bench-scale unit will utilize PC-based process control (console/work station) with data acquisition
- The process control and data acquisition system will be easy to program
- The process control and data acquisition system will interface with the CEM (RS232, Dell Optiplex GXi) and the mercury monitor (RS232, PC Center)
- The process control and data acquisition system will monitor real-time data
- The process control and data acquisition system will have a graphical user interface with flowchart views of the process

- The process control and data acquisition system software will allow easy download of process data to a spreadsheet
- An operator must be able to see the steam reforming unit within the enclosure
- Operator industrial safety/industrial hygiene (IS/IH) issues must be mitigated without personal protective equipment (PPE), other than safety glasses, under normal operating conditions while outside the enclosure
- The bench-scale unit will have the ability to collect and store all wastes and products generated from 100 hours of runs
- The bench-scale unit will have the ability to be operated on a continuous basis with two operators for the steam reformer and one operator for the CEM
- The bench-scale unit will have an emergency shut down system that turns off feed and engages an inert atmosphere purge of the reactor
- The bench-scale unit will meet air emissions requirements of applicable codes and regulations
- The bench-scale unit will have a pressure relief system that will prevent any damage to all process unit operations but maintain vacuum capability
- The bench-scale unit will be configured so that minimally-trained observers can be in attendance (but not involved in the run) while it is running
- The bench-scale unit will be assembled in modules such that the unit can be moved/transported via commercial transport hauler.

4. PROCESS DESCRIPTION AND FLOW SHEET

Process flow diagrams representing the bench-scale FBSR unit are included in Appendix A. There are three process flow diagrams: one for surrogate feed preparation and feed to the reactor, one for the steam reformer and solids management system, and one for off-gas treatment and pressure control. These flow diagrams and the associated process parameters were based on known FBSR process principles. The description given below provided a basis for the process flow sheet.

4.1 Fluidized Bed Steam Reformer Process Principles

In a fluidized bed, solid particles are suspended by a fluidizing gas. Because of drag forces on the particles, they are neutrally buoyant and can easily move about. The large surface area and mass of the bed particles make the fluidized bed ideal for gas-solid reactions and heat transfer. Hence the fluidized bed is a well-mixed heterogeneous reactor with excellent mixing and heat transfer characteristics. In the proposed FBSR process, the bed is fluidized with superheated steam. The feed solution is sprayed onto the bed particles where the high thermal mass of the bed instantly dries and denitrates the solution. The waste feed solution and additives react to form a sodium-aluminum silicate ceramic. The particular form and phase of the sodium-aluminum silicate ceramic depend on the relative amounts and forms of sodium and process additives. If the reaction takes place in a reducing atmosphere, the nitrogen oxides (NO_x) produced by denitration are reduced to nitrogen and water. Organics react with the steam via the water-shift reaction to produce carbon monoxide and hydrogen, which contribute to the reducing

atmosphere. A carbon source such as methane, sucrose, or activated carbon can be used to achieve this reducing atmosphere if there are insufficient organics in the feed. Halides and sulfur present in the waste are incorporated into the solid product or react to produce acid gases. Fine particulates produced by attrition of bed particles or spray-drying of feed solution are captured in a high-efficiency cyclone and returned to the bed.

The production of carbon monoxide and hydrogen in the FBSR requires that the off-gas go through a secondary combustion system to convert the synthesis gas to oxidation products (e.g., carbon dioxide and water). The concentrations of CO and H₂ are not high enough to be explosive in the very low O₂ reducing atmosphere of the FBSR, but could become explosive if mixed with air. For this reason the FBSR will be operated under sub-atmospheric pressure. Negative pressure is maintained in the reformer and product gas processing equipment through the use of an induced draft blower or steam eductor, depending upon design and implementation. It should be noted that the proposed bench-scale unit will not have a secondary combustion system, but it is recognized that one would be required on a full scale unit. Flammability/explosion issues will be managed by a combination of pressure control, continuous flammability monitoring, and emergency nitrogen blanket/purge.

Provisions to account for energy requirements of the synthesis gas reactions and reformation of the feed must be considered. Some energy to the steam reformer process can be provided by the superheated steam fluidizing gas. While the sodium-aluminum silicate forming reactions occurring within the vessel are slightly exothermic, the water shift and denitration reactions are endothermic. Energy also must be added to vaporize the water in the feed slurry. Usually the fluidizing steam cannot supply all the energy needs of the process. Thus, it is necessary to add energy to the fluidized bed to keep it at operating temperature. Several methods are available to add this energy to the reactor. One technology utilizes the addition of controlled amounts of oxygen to the fluidized bed, resulting in additional exothermic oxidation of carbon-containing compounds. Another technology makes use of internal electric heaters to control the temperature of the bed. The bed temperature varies depending on the technology used, but is in the range of 570-800°C.

The FBSR will convert the SBW into a sodium-aluminum silicate solid. Nitrate and nitrite will be converted to nitrogen gas, and sulfates, chlorides, and fluorides will be incorporated into the solid product or converted to acid gases and removed as part of the off-gas. Finally, all organic materials will be reacted to synthesis gas products.

Inputs to the reformer vessel can be classed into three categories: bed materials, waste feed and additive inputs, and gas inputs. Bed materials are comprised of three components: bed particles, a reductant (e.g., charcoal, sucrose or other carbon source), and, in some cases, proprietary catalysts or other additives. The bed material will vary depending upon the vendor and implementation of the technology selected. The catalyst and bed media are conserved within the vessel and are not consumed in the chemical reaction. As such, these are charged to the vessel and only small additions are required during operation. The reductant reacts with the steam to produce carbon monoxide and hydrogen, which maintains a reducing atmosphere in the fluidized bed and converts NO_x to nitrogen and water.

The waste feed to the reformer is comprised of the aqueous SBW solution together with additives mixed with the feed prior to charging to the reformer. As the desired solid form for the solidified SBW product following reforming is a sodium-aluminum silicate, additives are expected to be compounds promoting the preferential production of desired sodium-aluminum silicate products. The feed additives will vary depending upon the vendor and implementation of the technology selected. The specific additives and quantities thereof will be optimized during research activities.

The primary outputs from the reformer are the solid product and off-gas that exit the vessel. The composition of the generated product solids will depend upon the vendor and implementation selected, and the operating conditions of the reformer. The specific composition of the product solids will be determined as part of research activities.

The gas phase of the reformer product is expected to be comprised primarily of:

- Water (as superheated steam)
- Nitrogen gas
- NO_x
- Carbon monoxide
- Hydrogen
- Hydrogen fluoride (HF acid gas)
- Hydrogen chloride (HCl acid gas)
- SO_x
- Carbon dioxide
- Ammonia.

The composition of the generated off-gas will depend upon the vendor and implementation selected, and the operating conditions of the reformer. The specific composition of the product gas will be determined as part of research activities.

4.2 Fluidized Bed Steam Reforming Equipment

The FBSR equipment includes the fluidized bed reactor system, a fines capture and reinjection system, a bed heating system, the off-gas treatment system including secondary oxidation, the reductant addition system, the feed conditioning and metering system, the product removal system, and ancillary equipment such as the steam superheater, off-gas blowers, electrical controls, pumps, filters, instrumentation and process control equipment.

Off-gas management for the bench-scale unit is dependant on the location where the unit will be installed (driven by air permit factors). At the date of this report the installation location has not been finalized. Off-gas exiting the FBSR will contain synthesis gas products, water, acid gases, and carbon dioxide. Treatment of this off-gas is required prior to release to the atmosphere. The treatment system, which will be comprised of commercially available equipment, will likely consist of some configuration of the following components:

- Scrubber system
- High-efficiency mist eliminator
- Induced draft jet or blower

- Super heaters
- Condensers
- High-efficiency particulate air filter
- Secondary oxidation system.

Further details on all equipment items are included in the equipment specification section of this report.

5. EQUIPMENT SPECIFICATIONS AND DESIGN CONSIDERATIONS

To facilitate construction of the bench-scale FBSR a decision was made to construct the FBSR reactor vessel at the INEEL and to have other process components constructed at local vendors. The INEEL has primary responsibility for instrumentation and control, but significant integration with local vendors is required. Detailed below are the equipment specifications for the steam reformer vessel, process equipment and skids, utility, and instrumentation and control.

5.1 Steam Reformer Vessel

A detailed specification and associated design detail for the steam reformer vessel is provided in Appendix B.

The steam reformer vessel general construction uses standard pipe sizes and fabrication practices. Because of the hostile nature of the reaction environment, the material of the reformer vessel will be HR-120, which is a high temperature nickel alloy. The vessel consists of four separate pieces that are bolted together using 150-lb pipe flanges. The bottom section is a reducer that connects the 6-in. bed section to the 2-in. product take-off. Immediately above the reducer is a steam plenum that distributes steam into the bed section. The bed section contains the reaction, and is made with 6-in. pipe. It has six feed and recycle ports and five pressure/temperature taps. It is connected to the rest of the vessel using 150-lb flanges. Above the bed section is a freeboard which prevents excessive fines elutriation. The freeboard section of the reactor is made of 12-in. pipe and is 60 in. high. It has two gas feed ports, a rupture disk, three pressure/temperature taps, and an exhaust port. The reformer vessel will be pressure limited by a rupture disk set at 15 psig.

5.2 Process Equipment and Skid Specifications

A detailed specification of the remainder of the FBSR process equipment and the associated skids upon which they will be mounted is included in Appendix C.

Skids will be fabricated from steel, designed to maintain integrity over the design life of 2,000 hours. They will be able to be disassembled, transported over the Interstate highway system, and reassembled at another location. All process piping will be stainless steel, schedule 40S, unless noted otherwise. All electrical circuits will be run in raceway and in accordance with NEC. Wire and cable will be rated for the temperatures expected. The process control system will be easily modified. Personnel protection from heat and hazardous chemical emissions will be provided. Dry powder systems will be enclosed in a stainless steel or painted steel enclosure, to control fugitive dusts and gases.

5.3 Utility Specifications

Detailed utility specifications for the FBSR unit are included in Appendix D.

Electrical power required for the steam reforming skids will be supplied through a single point connection, using a plug/receptacle or other means, so as to allow easy connection and disconnection. Approximately 100 kVA of power will be required for the reformer process.

Process water required for the steam reforming skids will be supplied through a single point, using a quick-connect or other means, so as to allow easy connection and disconnection.

Process air required for the steam reforming skids will be supplied through a single point, using a quick-connect or other means, so as to allow easy connection and disconnection. The air supply to the Air Jet shall be run through a 10 μ filter medium. Air required for steam reformer operation will be oil-free, supplied at a pressure of 100 psig, able to maintain a minimum flow of 100 standard cubic feet per minute (SCFM).

Nitrogen required for the steam reforming skids will be supplied through a single point, using a quick-connect or other means, so as to allow easy connection and disconnection without interruption of gas flow. Nitrogen pressure will be supplied at a minimum pressure of 30 psig, at a flow rate of at least 80 SCFM, in support of process runs of up to 100 hours.

Oxygen required for the steam reforming skids will be supplied through a single point, using a quick-connect or other means, so as to allow easy connection and disconnection. Oxygen pressure will be supplied at a minimum pressure of 50 psig, at a flow rate of at least 10 SCFM, in support of process runs of up to 100 hours.

5.4 Data Acquisition and Control System

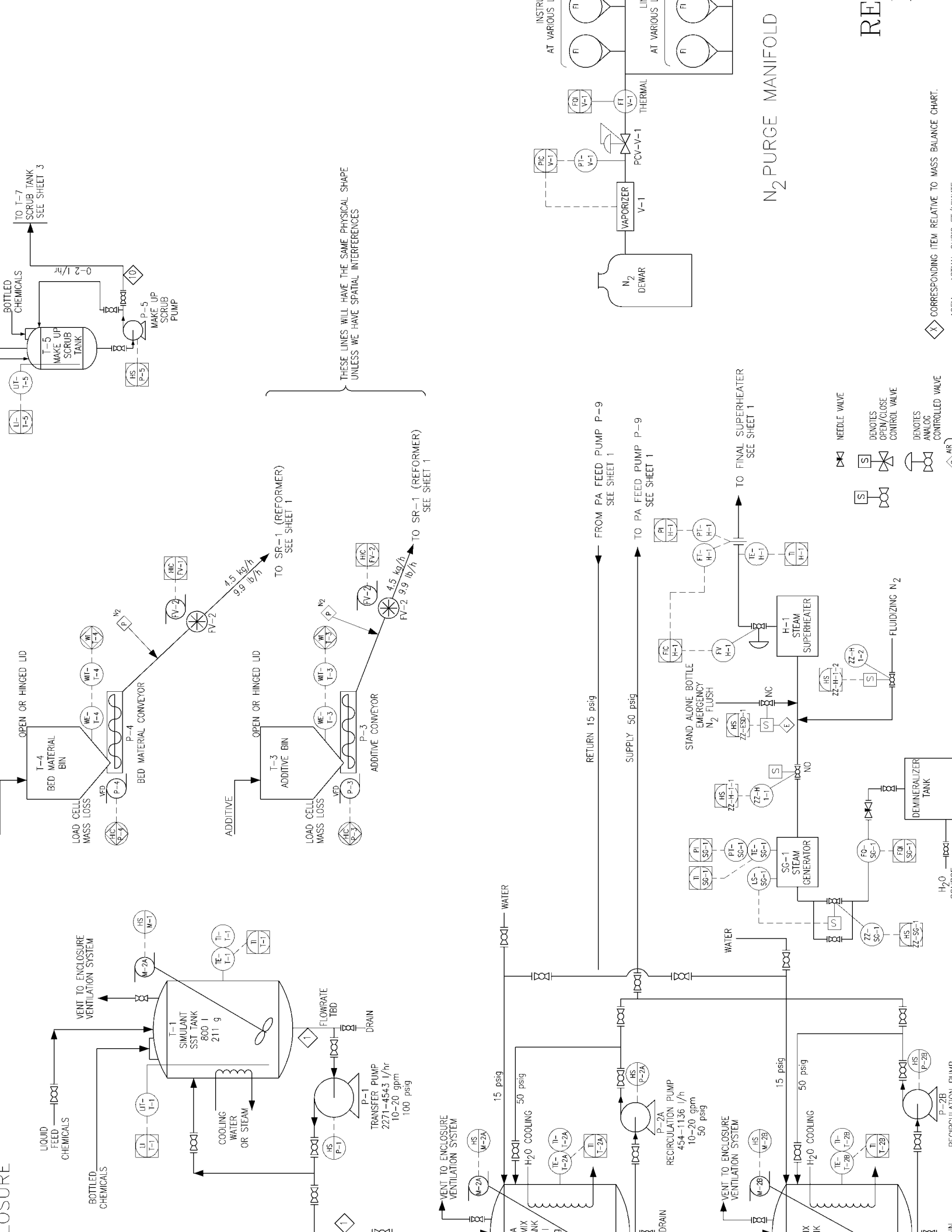
Detailed function of the data acquisition and control system is included in Appendix E.

Control for the system will be based on a single Allen Bradley, ControlLogix 1756 Series controller with local and remote I/O. Controlnet communications will be used for the I/O and controller. ControlLogix 5000 from Rockwell Software will be used to configure and program the system, and will run on an INEEL standard PC. The Human Machine Interface (HMI) for the control system will be RSView 32 from Rockwell Software. It will run on an INEEL standard PC, and will communicate with the Programmable Logic Controller (PLC) via Controlnet. The Process and Instrument Diagram (P&ID), instrument Loop Descriptions, and contents of Appendix E will be used as the basis for the configuration and programming of the system.

A Sequel database will be used to archive the data generated by the system during a run. RSSQL from Rockwell Software will be used to control the data transfer between the HMI, and the Sequel database. The Sequel database will run on an independent PC and will replicate to another independent PC as a redundant backup. The HMI and the independent PCs running Sequel will communicate on a private ethernet network. Each record in the database will include the tag-name for the data-point, the value, and a time-stamp.

APPENDIX A

Process Flow Diagrams



APPENDIX B

Steam Reformer Vessel Equipment Specifications

Steam Reformer Bench Scale Design and Testing

Reformer Vessel Design Specification

General

The steam reformer vessel contains the reaction of superheated water vapor with feed streams in a fluidized bed. General construction uses standard pipe sizes and fabrication practices. The reforming vessel consists of four separate pieces that are bolted together using 150# pipe flanges.

The bottom section is a reducer that connects the 6" bed section to the 2" product take-off. Immediately above the reducer is a steam plenum that distributes steam into the bed section. The steam plenum is 2" thick and the same diameter as a 6" pipe flange. The plenum is made with 1" pipe in an X shape and four bubble caps that distribute the steam.

The bed section contains the reaction, and is made with 6" pipe. It has six feed and recycle ports and five pressure/temperature taps. It is connected to the rest of the vessel using 150# flanges. Above the bed section is a freeboard which prevents excessive fines elutriation. The freeboard is 12" pipe and 60" high. It has two gas feed ports, a rupture disk, three pressure/temperature taps, and an exhaust port.

The reformer vessel will be pressure limited by a rupture disk set at 15 psig. This and the general design preclude qualification of the vessel within ASME code. Temperature, stress, and corrosion resistance are adequately addressed through the selection of materials and limitation of pressure.

Materials

Because of the highly experimental nature of the interior environment, the material of the reformer vessel will be HR-120. HR-120 is a high temperature nickel alloy that was designed as an upgrade from stainless steels and some nickel alloys without becoming cost prohibitive. HR-120 appears to be a good compromise of environmental resistance and cost for a prototype research vessel. HR-120 would not be appropriate for use in a production vessel, but is adequate for the projected life of the prototype.

HR-120 retains strength very well at elevated temperatures and the limited stresses in the reformer vessel do not require any special considerations. Maximum pressure-driven stress will be far below yield and tensile strengths and provide more than the industry minimum 3/1 yield and 5/1 tensile safety factors.

AWS ER3556 weld rod is recommended for welding HR-120 alloy under weld procedure AWS A5.9. GTAW, GMAW, and/or SMAW are all acceptable welding procedures. This welding procedure and weld rod are not covered by INEEL welding procedures, and all welding will be done under an exemption granted for research and development work.

Because HR-120 is not a readily available alloy, pipe and flange components will be ordered through a specialty shop that is capable of rolling, welding, and forging the necessary parts. Pipe will be hot rolled and welded (HRW). The weld seam is expected to provide equivalent performance to the rest of the vessel because of the alloy compatibility and higher alloy content than the base material.

Flange bolts should be made from Nitronic 60. This stainless alloy has superior galling resistance that is especially important for breakable joints at the operating temperatures of this process. Standard 18-8 stainless steel nuts and washers can be used. The flanges on the freeboard section that do not provide access for a rear nut will be threaded to accept the Nitronic bolts. If galling or seizing does

occur, it is easier to drill out and re-thread a hole than to re-insert a stud. The bolting procedure is discussed in the flange sealing section below.

Quality

The steam reformer vessel is covered under the general quality designation and record for the Steam Reforming Bench Scale Design and Testing project. It will employ consumer grade materials and fabrication techniques. Because the vessel is not under jurisdiction of any ASME Boiler and Pressure Vessel codes, no code stamp or quality inspections will be used. Materials will be ordered with certified material test reports (CMTR's) to help ensure that the correct alloys are used.

Flange Sealing

Due to the high temperatures of the vessel, all seals will be made using flanged connections and high temperature gaskets. The gasket of choice is a spiral wound Flexitallic gasket using Thermiculite as the sealing medium. It is highly resistant to the temperature, seals better than ceramic, and is more oxidation resistant than graphite. To help prevent thermal expansion induced gasket failure, the gasket compression will be controlled using a gland on one side of a mating surface. Bolt torque can then be brought high enough to hold thermal expansion to a minimum without crushing the gasket.

The gasket will be sized to match the to the pipe flange diameter of the specific seal. Each gasket will have an inside diameter equal to the outside diameter of the pipe. This will keep the gasket flush with in the interior surface of the flanged joint. Each gasket will have a cross section .250" wide and .125" thick. The spiral wound gasket is recommended compressed to .090" by the manufacturer, and the gland depth will be .090" + .005", -0". This prevents over-compression of the gasket and possible breakdown of the seal. The spiral-wound design promises less compression set than most high temperature solid or corrugated gaskets and should tolerate minimal thermal expansion better.

The gasket gland will require a surface finish no more coarse than 125-250 micro-inches rms. Furthermore, this finish should be produced on a lathe ensuring all machining marks exist only in a circumferential direction. Bolt torque will have to be determined experimentally. Because this design is intended to seal with both flange faces flush with one another, the gasket compression will be independent of bolt torque. It is only important to ensure that the flange faces stay in contact.

Thermal expansion presents the largest problem with maintaining flange contact. The material of the flanges expands approximately 10% slower than the Nitronic 60 bolts used for the connections. To be conservative, the assumption is made that the bolts thermally stretch while the flange remains constant. This requires sufficient stretch in the bolted connection to absorb thermal stretch and remain tight at process temperatures. Unfortunately the modulus of the Nitronic bolts will stretch them beyond yield before they are stretched enough to absorb thermal expansion.

To overcome the problems with thermal expansion, Belleville washers will be used in conjunction with the bolts to provide sufficient stretch to absorb thermal effects. Component lay up will be done using feeler gauges to determine the necessary tolerances. Each bolt will be installed with Belleville washers or a stack of washers and tightened until the flanges are in contact. Contact will be defined that a .005" feeler gauge cannot be inserted radially at any point along the flange. With the flanges in contact, a .030" feeler gauge will be tested between the washer and nut or bolt head. If there is at least .030" of compression left in the washer and the flange faces are in contact, the washer stack is sufficient to absorb the thermal expansion at temperature. . The expected change in bolt length due to thermal expansion is 0.030 inches. Once the washer stack is determined, all bolts should be tightened until the Belleville washers are flat.

Some pipe flanges behave oddly at high temperature and provide some relaxation due to the loads imposed by squeezing the gasket. These loads will be absorbed in this system by continuous contacting flanges and pre-loading of the flange bolts.

Component Descriptions

Freeboard:

The freeboard section is the upper portion of the vessel and is constructed from 12" pipe. It will be capped with a standard 12" blind flange. The freeboard reduces to 6" pipe at the bottom and bolts to the bed section using a 150# flat face flange. The reducer will have to be fabricated in house unless it can be ordered expeditiously from the materials supplier.

The freeboard serves mainly to minimize elutriation of product fines before the off-gas is exhausted. It will, however, have two gas feed ports for optional auxiliary product oxidation. The oxygen ports are at the 180 degree position with elevations 22" and 48". Exhaust exits at the 0 degree position and 60" elevation. A rupture disk is opposite the exhaust port at 180 degrees and 60" elevation. The last port is a 6" hand hole for manual access to the vessel and is located at 90 degrees and 10.5" elevation. This puts the hand access immediately above the reducing section. All elevations are measured from the bottom flange face of the freeboard, and the attached drawing should be referenced.

The oxygen ports and rupture disk port are 2" standard pipe with 150# flanges flush to the vessel wall. The exhaust port is 3" standard pipe and also is flush with the vessel wall. The hand hole is 6" pipe flange flush with the wall. All the exit flange faces will have a gasket gland cut to accept a custom Flexitallic spiral wound gasket with Thermiculite. The bottom flange connecting to the bed section is considered an entry flange and does not have the gasket gland. See the "flange sealing" section for details on the flange joints.

The FBSR vessel will be supported by four stainless steel brackets on the outside of the freeboard section. The size and location of these brackets will be determined by discussions with the vendor.

Bed Section:

The bed section is 6" nominal pipe with 150lb flanges on both ends. The bed section is sandwiched between the steam plenum below and the freeboard above. It has six feed and recycle ports and will be the primary reaction chamber. All ports extend out from the bed sufficiently to accommodate electric clamshell heaters that will be placed on the exterior of the bed section wall. The upper flange face is machined for the gasket gland.

Three ports are on the 210 degree plane, two of which enter horizontally and the last one at 60 degrees off horizontal. The inclination of the last port is to facilitate drainage and reduce collection of bed solids. The two horizontal ports must be kept horizontal to accept the liquid and slurry feed nozzles. The two horizontal ports are 2" nominal pipe at elevations 4" and 13" from the bottom flange face of the bed section. The top angled port enters the interior wall at 22" and is 1 ½" pipe.

The opposite three ports enter at the 330 degree plane and are all angled at 60 degrees off the horizontal to facilitate drainage. Penetration elevations for those three ports are 4", 13", and 22". They are all 1 ½ " nominal pipe diameter. All ports are flanged with 150# flat faced flanges and are treated with the gasket gland.

Five pressure/temperature (P/T) taps also exist on the side of the vessel wall at the 90 degree plane. The bottom P/T tap extends to the center of the vessel at zero elevation relative to the bed section. This is about 0.250" above the steam plenum outlet and will serve as half of a differential pressure measurement on the steam plenum. The other four taps extend only an inch inside the vessel wall and are at elevations 6", 12", 18", and 24". All pressure taps enter at 60 degrees from the horizontal and are 3/8" pipe.

Steam Plenum:

The steam plenum is packaged in a 2" thick plate section and the same diameter as a 6" pipe flange. Its location is between the bed section above and the bottom reducer below. One 1" pipe with a 150# flange extends radially from the side to accept superheated steam from the steam generator. The 1" feed pipe and top of the plate piece both have a gasket gland.

The 1" pipe extends through the plate section and forms a cross to distribute steam to the bubble caps. Bubble caps are positioned on a diameter such that the area inside and outside the bubble cap diameter is identical. This was done to help ensure even steam distribution into the bed. Each bubble cap is 1" in diameter and sits on a saddle welded to the pipe. The space between the cap and the saddle is .015" to prevent bed material from entering the steam plenum. Each bubble cap is feed by four 0.089" holes through the saddle and into the pipe to provide steam. The underside of the bubble cap has a recess that provides a type of secondary bubble cap plenum and this recess is drained by the 0.015" space between the bubble cap and the saddle.

Bottom Reducer:

The bottom reducer collects solids as they are discharged from the bottom of the bed. These solids will be below the distributor manifold and will not be fluidized. The reducer reduces from 6" pipe at the steam plenum to 2" pipe at the exit. Both flanged connections will be given a gasket gland. One pressure/temperature tap penetrates to the center of the reducer at 60 degrees off horizontal and on the 0 degree plane.

Reformer Vessel

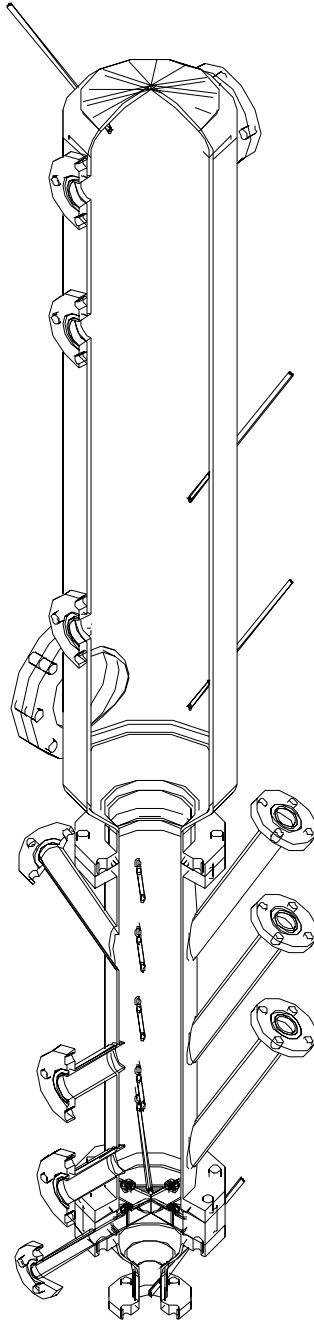


Figure B-1. Full Length Vessel.

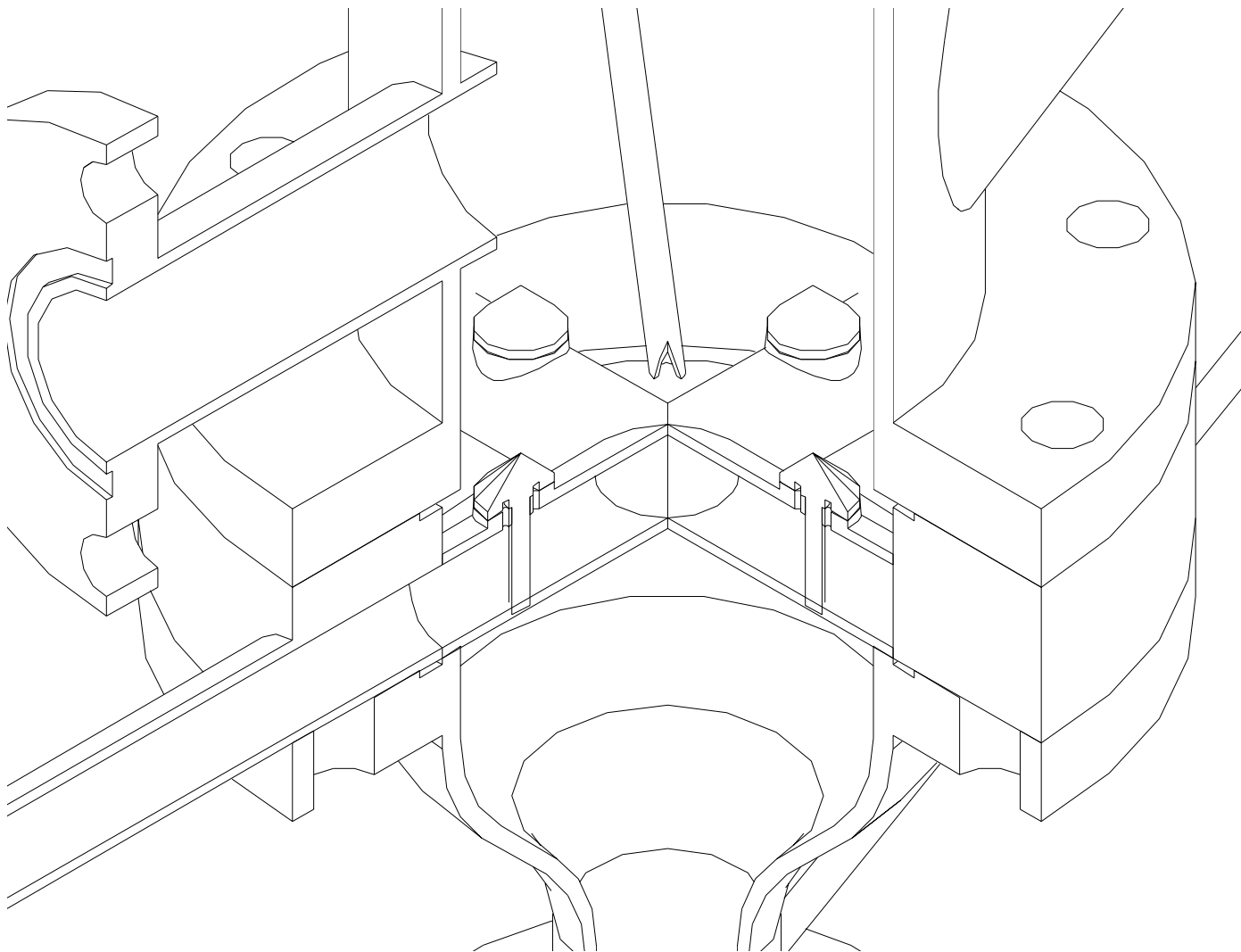


Figure B-2. Bed Section.

Material Properties

Average Tensile Data, Solution Heat-Treated (Plate)						
Test Temperature		Ultimate Tensile Strength		Yield Strength at 0.2% Offset		Elongation in 2 in. (50.8 mm)
°F	(°C)	Ksi	MPa	Ksi	MPa	%
Room	Room	106.5	735	45.6	375	50
1000	(540)	80.4	555	25.7	175	61
1200	(650)	73.0	505	24.9	170	60
1400	(760)	64.1	440	25.4	175	50
1600	(870)	47.5	325	27.0	185	51
1800	(980)	27.9	190	19.4	135	81
2000	(1095)	15.1	105	9.1	63	89
2200	(1205)	4.9	34	3.9	27	89

Figure B-3. HR-120 Tensile Data.

Mean Coefficient of Thermal Expansion

	Temp., °F	British Units	Temp., °C	Metric Units
Mean Coefficient of Thermal Expansion	78-200	7.95 microinches/in.°F	25-100	14.3 m/m-°C
	78-400	8.29 microinches/in.°F	25-200	14.9 m/m-°C
	78-600	8.56 microinches/in.°F	25-300	15.3 m/m-°C
	78-800	8.80 microinches/in.°F	25-400	15.8 m/m-°C
	78-1000	8.98 microinches/in.°F	25-500	16.1 m/m-°C
	78-1200	9.24 microinches/in.°F	25-600	16.4 m/m-°C
	78-1400	9.52 microinches/in.°F	25-700	16.9 m/m-°C
	78-1600	9.72 microinches/in.°F	25-800	17.3 m/m-°C
	78-1800	9.87 microinches/in.°F	25-900	17.6 m/m-°C
			25-1000	17.8 m/m-°C

Figure B-4. HR-120 Thermal Expansion.

Elevated Temperature Tensile Properties (Cold Swaged 54% to 0.700" [17.8 mm] ϕ)

Test Temp. F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4XD	Reduction of Area, %
RT	230 (1586)	216 (1489)	12	55
200 (93)	215 (1482)	205 (1413)	12	54
300 (149)	206 (1420)	199 (1372)	11	52
400 (204)	200 (1379)	194 (1338)	11	51
500 (260)	195 (1344)	191 (1317)	11	48
600 (316)	193 (1331)	188 (1296)	11	47
700 (371)	191 (1317)	176 (1213)	10	47
800 (427)	190 (1310)	184 (1269)	9	46
900 (482)	187 (1289)	177 (1220)	11	44
1000 (538)	179 (1234)	166 (1145)	11	47
1100 (593)	162 (1117)	144 (993)	13	52
1200 (649)	112 (772)	72 (496)	11	25

Figure B-5. Nitronic 60 Tensile Data.

Mean Coefficient of Thermal Expansion

Temperature, F (C)	in/in/°F ($\mu\text{m}/\text{m} \cdot \text{K}$)
75- 200 (24-93)	8.8×10^{-6} (15.8)
75- 400 (24-204)	9.2×10^{-6} (16.6)
75- 600 (24-316)	9.6×10^{-6} (17.3)
75- 800 (24-427)	9.8×10^{-6} (17.6)
75-1000 (24-538)	10.0×10^{-6} (18.0)
75-1200 (24-649)	10.3×10^{-6} (18.5)
75-1400 (24-760)	10.5×10^{-6} (18.9)
75-1600 (24-871)	10.7×10^{-6} (19.3)
75-1800 (24-982)	11.0×10^{-6} (19.8)

Figure B-6. Nitronic 60 Thermal Expansion.

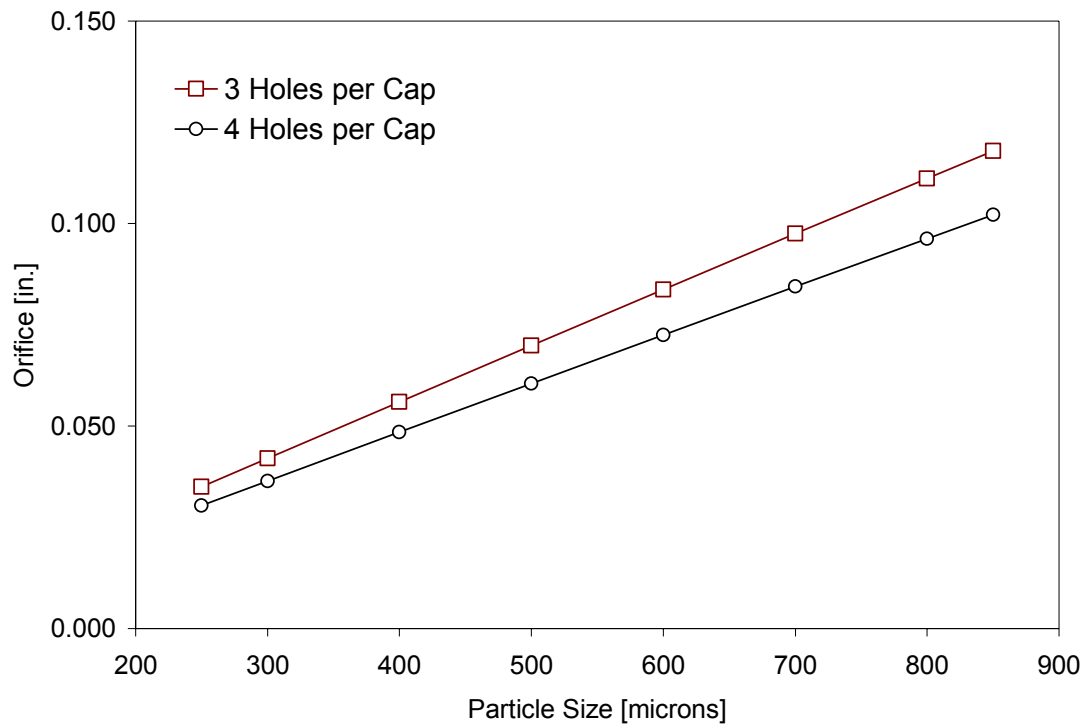


Figure B-7. Orifice Size for FBSR Bubble Caps.

APPENDIX C

SKID REQUIREMENTS

GENERAL

The Steam Reformer process will involve high temperatures, hazardous chemicals and abrasive process fluids. All equipment shall be designed to function for non-interrupted process runs of up to 100 hours, with an overall design life of 2,000 hours, as required in the Functional and Operational Requirements.

The service connection points for skid power, control, instrumentation and utilities shall be brought to a common location on the skids and terminated appropriately. All wiring shall be brought to terminal strips in a terminal box and labeled. All piping, conduit and connectors shall be labeled to allow easy identification.

The installation shall be able to be cleaned and ready for a new process run in a “normal” workweek or less, and shall allow for ease of adjustment and/or replacement of components and equipment.

Codes

The skids for the Steam Reformer Project shall be designed, constructed and assembled per the following codes and standards:

- American Society of Civil Engineers (ASCE)
- American Society of Mechanical Engineers (ASME)
- National Electrical Code (NFPA 70)
- American Institute of Steel and Iron (AISI)
- American Society for Testing and Materials (ASTM)

Reference Drawings

- 522402 Reformer Vessel Fabrication – Sheets 1, 2, 5, and 6
- 522403 Steam Reformer P&ID – Sheets 1-3

Requirements

Skid envelopes shall be sized to transport over commercial highway without special permits.

Skids shall be fabricated from steel, designed to maintain integrity over the design life of 2,000 hours. They shall be able to be disassembled, transported over the Interstate highway system, and reassembled at another location. All carbon steel shall be painted with epoxy paint.

All process piping shall be stainless steel, schedule 40S, unless noted otherwise. Pipe connections shall be either welded or flanged. Piping runs shall be orthogonal (i.e., parallel or perpendicular to the skid footprint) as much as possible.

All electrical circuits shall be run in raceway and in accordance with NEC. Wire and cable shall be rated for the temperatures expected. The process control system must be easily modified.

Personnel protection from heat and hazardous chemical emissions shall be provided. Dry powder systems shall be enclosed in a stainless steel or painted steel enclosure, for control fugitive dusts and gases.

The final superheater shall be in close proximity to the reformer vessel. This may necessitate locating it within the enclosure. If an enclosure is utilized to protect personnel from heat and hazardous chemicals, the enclosure must be ventilated to provide a minimum 125 linear ft/sec airflow, including an open personnel door.

Instrumentation, including pressure and differential pressure transmitters, shall be mounted such that excessive heat does not impact operations.

Provisions for visual inspection of and access to the process shall be included. If an enclosure is utilized, inspection capability without making a manned entry into the enclosure shall be included in the enclosure assembly. The enclosure must allow for access of personnel in support of the removal and maintenance of equipment. Piping, instruments and vessels must be positioned so as to provide access to the equipment for maintenance, sampling and adjustment.

Government Furnished Equipment (GFE)

The following pieces of equipment will be GFE:

- Reformer Vessel
- Controller programming.

STEAM REFORMING BENCH SCALE DESIGN TESTING PROJECT

1. Skid Number 1 Dimensions

Skid envelope maximum dimensions = 8.5-feet wide x 25 feet long x 12 feet high

(Skid must fit a Lo-boy tractor trailer for over-the-road transport).

2. General Specifications

Isolation Valves:

- a. All major equipment shall have flanged type isolation ball valves for 150 lb WOG (water, oil, or gas) service
- b. Valves shall be specified to control corrosive and abrasive materials
- c. Ball valves shall be of full flow design relative to the various pipeline sizes of the feed system
- d. Operating temperature range shall be 288 degrees C minimum (550 degrees F)
- e. Operating pressure range 1.03 mPa (150 psig)
- f. Valve construction material shall be 316 Stainless steel
- g. Valve seals to be determined by subcontractor for the specified service (probably metal seals).

Piping All piping shall be 316 stainless steel (unless noted otherwise)

Connections All pipe and tank connections should be flanged whenever possible for easy assembly and maintenance

Flanges All flange connections shall be 316 stainless steel (unless noted otherwise).

3. SR-1 Fluidized Bed Steam Reformer

- a. Reformer Bed Section
 - (1) 6 inch schedule 40, 316-SST pipe
 - (2) Length = 30 inches
 - (3) 6-inch 150-pound flanges both ends of bed section

- (4) Number of port penetrations = 6.
(refer to INEEL Drawing Number 522402 for further information).
 - (a) 4 ports of 1.25-inch 316-SST pipe with 150 pound flanges
 - i. Pipe and attached flanges shall be angled 30-degrees upward from the vertical centerline at the vertical penetration point with the bed section
 - ii. Flange centerline face distance horizontal to bed section = 8-inches.
 - (b) 2 ports of 1.25-inch 316-SST pipe with 150 pound flanges perpendicular to the bed section
 - i. Flange centerline face distance horizontal to bed section = 8-inches.
 - (c) Distance between each group of penetrations = 9-inches
 - (d) Bottom group section elevation location from lower end of bed section = 4-inches.
- (5) Instrumentation Ports welded to the bed section
(refer to INEEL Drawing Number 522402 for further information and dimensions)
 - (a) 5 ports of 0.125-inch 316-SST schedule 40 pipe shall penetrate and be welded to the bed section.
 - i. Ports shall be located at 3-inch increments starting 6-inches above the lower flange of the bed section
 - ii. Ports shall be angled 30-degrees upward from the vertical centerline at the vertical penetration point with the bed section
 - iii. Ports shall be used for temperature or pressure readout of the bed section.
 - Temperature readout shall be located at 6-inch intervals from bottom to top of the bed section
 - Pressure readout shall be located at top and bottom of the bed section.
- (6) An externally mounted custom electric heater with insulation shall encapsulate the bed section
 - (a) Electric heater power shall be 480 VAC, 60 hz, and 13 KW
 - (b) The heater shall be mounted between upper and lower flanges on straight pipe
 - (c) Heaters shall consist of vacuum-formed ceramic fiber insulation with embedded high temperature heating elements

- (d) Bottom group section elevation location from lower end of bed section = 6-inches
 - i. Insulation thickness shall be TBD inches
 - ii. Insulation shall not interfere with flange bolt access.
 - iii. Insulation thickness shall not interfere with penetration flanges or instrumentation port access.
 - (e) Bed heater design shall be coordinated with the design of the spoolpiece configuration
 - (f) Heaters to be designed in three circular sections so each section will cover 1/3 of the spoolpiece circumference.
- (7) A power controller shall be provided for the bed heaters controlled by the HMI (Human Interface) to maintain bed temperature at the desired setpoint
 - (a) Bed temperature will be measured by five different thermocouples providing input to the HMI.
- (8) Design Parameters
 - (a) Bed temperature: 750 degrees C (1382 degrees F)
 - (b) Vessel maximum wall temperature: 800 degrees C (1472 degrees F)
 - (c) Power input to bed: 13 KW.
- b. Reformer Freeboard Section Design
 - (1) 12-inch schedule 40, 316-SST pipe
 - (2) 88-inch length
 - (3) A 12 × 6-inch 150-pound conical reducer will be welded to the bottom of the freeboard section
 - (4) A 6-inch flange shall be welded to the bottom of the conical reducer for connection to the reformer section
 - (5) A 12-inch 150 lb slip on flange shall be welded to the top of the section
 - (6) Number of port penetrations = 4 placed at different elevations on the freeboard section (refer to INEEL Drawing Number 522402 for further information)
 - (a) Three 1.25-inch Flanges welded directly to the pipe section
 - (b) One 4-inch flange welded to the interface between the bottom reducer flange and the pipe section.

- (7) Number of instrumentation ports shall be 3 as located per INEEL Drawing No. 422402
 - (8) Two 3/8-inch flanged ports shall be provided in the vertical pipe section for Oxygen flow
 - (9) A 12-inch blind flange shall be bolted to the top 12-inch welded flange of the section with the following penetrations
 - (a) One Pressure relief port
 - (b) One flanged penetration for off-gas and fines transport to the Cyclone (C-1).
 - (10) A heater system similar to the one mounted on the reformer section shall be installed on the freeboard section for temperature management
 - (11) Design Parameters
 - (a) Bed temperature: 750 degrees C (1382 degrees F)
 - (b) Vessel maximum wall temperature: 800 degrees C (1472 degrees F)
 - (c) Power input to freeboard section heater: 13 KW.
- c. Flange Spacer Design
- (1) A 6-inch horizontal spacer of stainless steel shall be placed between the flanges of the steam bed reformer and lower spool piece
 - (1) Provision shall be made for steam insertion with a horizontal 1-inch pipe and flange
 - (2) A vertical 1-inch pipe and horizontal flange shall be attached to the pipe upstream of the steam port flange as a spare (designated F on INEEL Drawing 522402)
 - (3) The spare horizontal flange shall be blanked off with a blind flange for future use
 - (4) The same design parameters for the reformer bed exist for the flange spacer and appertenance.
- d. Lower Steam Reformer Spoolpiece Design
- (1) The lower spoolpiece shall be constructed of 2-inch schedule 40 - 316 stainless steel pipe about 12-inches long
 - (2) Use 316 stainless steel material for all parts
 - (3) A 6 × 2-inch reducer shall be welded to the top end of the 2-inch pipe
 - (4) A 6-inch flange shall be welded to the top end of the 6 x 2-inch reducer
 - (5) A 2-inch flange shall be welded to the bottom end of the 2-inch pipe (designated H on INEEL Drawing 422402)

- (6) A 2-inch pipe and flange shall be horizontally welded to the vertical spoolpiece 2-inch pipe at a 2-inch elevation above the bottom 2-inch flange for as a spare (designated G on INEEL Drawing 422402)
- (7) An instrument penetration of 0.125-inch schedule 40 pipe will be required one-inch below the upper reducer at 30 degrees from the vertical centerline of the spoolpiece
- (8) The same design parameters for the reformer bed exist for the lower spoolpiece and appertenances.

4. P-4 Feed Pump

Function	The feed pump (P-4) will be a peristaltic metering pump used to extract the feed mixture from the recirculated feed mixture pipeline (pressurized by recirculation pump - P-3) for transfer to the steam reformer (SR-1). This pump shall be placed as close to the steam reformer as possible considering the other pipeline components.
Flow Rate	8 to 19 Liters/hour (0.03 to 0.08 gpm)
Temperature:	20 to 24 degrees C (68 to 75 degrees F)
Pressure	103 kPa (15 psig)
Material	316 Stainless steel
Type	Peristaltic metering pump
Pump design	Pump shall be compatible with corrosive and abrasive solutions of liquid slurry with approximately 33 wt% solids. Pump shall have 150 lb flanged inlet and outlet ports and be capable of 150 lb WOG service.
Control	Local.

5. S1 Product Separator

Function	The separator is used to separate the fine from the coarse products below the bottom of the fluidized bed, the flange spacer, and lower spoolpiece.
Flow Rate	40 kg/hr
Volume	480 liters (127-gallons) for 6 hour collection of fines (Assumption)
Separator Size	2.5 ft diameter x 2.5 ft high includes conical fines collection bottom section (assumption)
Temperature	500 degrees C (932 degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Process Material	NaAlSiO ₄ , KAlSiO ₄ , and NaFeO ₂ (corrosive and abrasive)
Output Flow Rates	Granular solids: 2.5 kg/hr - Fines: 5.9 kg/hr (from mass balance calculations)
Material Density	Granular solids: 1.2 to 1.5 g/cc, Fines: 0.5 g/cc (from mass balance calculations)

Separator Mat'l	316 stainless steel
Design	<p>The separator is a circular bin with a collection drum for oversized product a sloped bottom for fines collection, and a vibratory screen to segregate oversized bed product particles and agglomerates from the undersized particles and fines.</p> <p>Oversized particles are collected in the product drum and then transferred to the product cooler (HE-1). The finer fraction is collected in the separator bottom for pressurized nitrogen transport to the bed solids bin (T-4). The product drain is equipped with a pipe flange and product sampling capability to monitor the process.</p>
Control	PLC only
Metering	Yes.

6. HE-1 Product Cooler

Function	The product cooler is a heat exchanger used to cool the separated coarse product segregated by the product separator.
Flow Rate	8.4 kg/hr
Volume	7.0 liters (1.85-gallons)
Cooler Dimensions	TBD by subcontractor
Temperature In	500 degrees C (932 degrees F)
Temperature Out	20 to 24 degrees C (68 to 75 degrees F)
Pressure	90 psig (assumed)
Process Material	NaAlSiO ₄ , KAlSiO ₄ , and NaFeO ₂ (corrosive and abrasive)
Material Density	<p>Granular solids: 1.2 to 1.5 g/cc (from mass balance calculations)</p> <p>Fines 0.5 g/cc (from mass balance calculations)</p>
Separator Mat'l	316 stainless steel
Design	<p>Configuration and size TBD by subcontractor</p> <p>Install port for filtered cooling air input</p> <p>Install port for heated air output</p> <p>Product shall be removed from the bottom of the cooler via a valve into 55-galon waste drums (assumed).</p>
Control	Air flow rate - both PLC and Local control.

7. C-1 Cyclone

Function	The cyclone collector will collect off-gas and process fines from the steam reformer and separate the solid material from the off-gas stream the collected solids will be returned to the reformer for further agglomeration.
Flow Rate	78 cubic ft/min
Volume	6.9 liters (1.87 gallons)
Cyclone Dims	5-inch diameter schedule 40 pipe × 22-inches long (not including conical bottom section)
Temperature	350 to 500 degrees C (662 to 932 degrees F) for collection of Cs from the reformer off-gas stream
Pressure	73 kPa (10.58 psi)
Process Material	NaAlSiO ₄ , KAlSiO ₄ , NaFeO ₂ , Mercury, and Cesium (corrosive and abrasive) fines, water vapor, process gases
Material Density	0.5 g/cc (from mass balance calculations)
Cyclone Mat'l	316 stainless steel
Design	<p>Typical commercial cyclone design except for 500 degree C (932 degrees F) temperature requirement</p> <p>The basic vessel will be circular with a conical bottom section to collect fines and other materials</p> <p>The bottom of the vessel will be provided with a flange (size TBD) to connect to a flanged wheel valve</p> <p>The top end of cyclone will be flanged (5-inch) for connection to a blind flange and allow clean out</p> <p>Blind flange provided with flanged penetration for off-gas flow continuance to the Sintered Metal Filter (F-1) and pressure relief</p> <p>Instrumentation penetrations per instrument list and P&ID for solids level, gas exit pressure, and vessel internal pressure</p> <p>Provide solid sample taps (locations and size TBD)</p> <p>The cyclone will require a heater with insulation (7 KW assumed) surrounding the unit to maintain internal temperature.</p>

8. Cyclone Rotary Valve

Function	This valve meters collected fines from the cyclone (C-1) to the Bed Solids Bin (T-6)
Flow Rate	Approximately 2.1 kg/hr (4.63 lbs/hr) from mass balance calculations
Volume/Rotation	TBD by subcontractor
Temperature	350 to 500 degrees C 662 to 932 degrees F for collection of Cs from the reformer off-gas stream
Pressure	73 kPa (10.58 psi) from mass balance calculations
Process Material	NaAlSiO ₄ , KAlSiO ₄ , and NaFeO ₂ (corrosive and abrasive) fines, water vapor, process gases
Material Density	0.5 g/cc (from mass balance calculations)
Cyclone Mat'l	316 stainless steel
Design	Commercial rotary valve to meet feed rate criteria and temperatures
Control	PLC, only
Metering	Yes.

9. F-1 Sintered Metal Filter

Function	The sintered Metal Filter (F-1) is used to clean the fines and other solids left in the off-gas leaving the Cyclone (C-1) except for Mercury which is not allowed to plating out within the filters
Flow Rate	60 cubic ft/min
Volume	297 liters (79 gallons) vessel less the volume of the 4 internal filters
Filter Dims	20-inch diameter × 60-inches long
Temperature	350 to 500 degrees C (662 to 932 degrees F) to prevent deposition/sorption of mercury vapors on the filter cakes and capture Cs salts
Pressure	70 kPa (10.2 psi)
Process Material	NaAlSiO ₄ , KAlSiO ₄ , NaFeO ₂ , and Cesium (corrosive and abrasive) fines, water vapor, process gases
Material Density	0.5 g/cc (from mass balance calculations)
Filter Mat'l	316 stainless steel
Design	<p>The basic vessel will be circular with a conical bottom section to collect fines and other materials</p> <p>The bottom of the vessel will be provided with a flange for connection to a flanged wheel valve for material transfer to the bed solids bin (T-6)</p> <p>Four 2.5-inch diameter × 36 inch long 2-micron sintered filters shall be fitted into the filter housing</p> <p>A baffle shall be placed between the filters near the upper ends to prevent dislodged filter cake from one filter contaminating an adjacent filter</p> <p>A filter stationing device will stabilize the vertical hung filters horizontally and prevent cross contamination</p> <p>The top end of the filter housing will be flanged for connection to a blind flange and allow clean out</p>

The blind flange will provide a flanged penetration for off-gas flow continuance to the Scrubber (EVS-1)

The blind flange will also provide penetrations for the Nitrogen gas blowback system for online filter cleaning

An alternating filter timed pulse blow back system will be provided so only one of the four filters will be pulsed in sequence or as required

Pulse blow back timing will be based on tests and will be adjustable with the sequence initiated at a preset pressure drop across the filters

Instrumentation penetrations installed per instrument list and P&ID

Instruments required are temperature, pressure of inlet and outlet gas, and solids level

Provide solids sample taps (locations and size TBD)

The filter will require a heater with insulation (7 KW assumed) surrounding the unit to maintain internal temperature

Use vibration probes because static packed beds cannot be measured using D/P probes

This vessel is GFE (government furnished equipment).

10. Cyclone Rotary Valve

Function	This valve meters collected fines from the sintered metal filter (F-1) to the Bed Solids Bin (T-6).
Flow Rate	Approximately 3.8 kg/hr (8.38 lbs/hr)
Volume/Rotation	TBD by subcontractor
Temperature	350 to 500 degrees C (662 to 932 degrees f)
Pressure	70 kPa (10.2 psi)
Process Material	NaAlSiO ₄ , KAlSiO ₄ , and NaFeO ₂ (corrosive and abrasive) fines
Material Density	0.5 g/cc (from mass balance calculations)
Cyclone Mat'l	316 stainless steel
Design	Commercial rotary valve to meet feed rate criteria and temperatures
Control	PLC, only
Metering	Yes.

11. T-6 Bed Solids Bin

Function	This is a storage bin used to collect all product fines from the cyclone (C-1), the sintered metal filter (F-1) and the product separator.
Capacity	480 liters (126-gallons) at six hours of holding volume at feed rate
Feed rate	40 kg/hr (88.2 lbs/hr)
Process Material	NaAlSiO ₄ , KAlSiO ₄ , NaFeO ₂ (corrosive and abrasive) fines
Material Density	0.5 g/cc (0.02 lbs/ci)
Material Weight	2239 kg (526 lbs) weight in bin
Tank Material	316 Stainless Steel
Tank Size	2.5 ft diameter × 4.75 ft high including 45 degree sloped bottom (Assumed)

Temperature	500 degrees C (932 degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Tank Design (by subcontractor)	<p>The bin will have a circular shape with a conical bottom head and flat cover</p> <p>Level indicator</p> <p>Flanged bottom outlet</p> <p>Flanged top chemical feed ports from cyclone (C-1, sintered metal filter (F-1), and off-gas flow to sintered metal filter</p> <p>Flanged auger flow port in upper vertical bin body from bed material bin (Skid 2)</p> <p>Flanged feed port in lower vertical bin body from product separator (S-1)</p> <p>Outlet flange in bottom of tank to connect to a isolation valve and bed solids conveyor (P-9)</p> <p>Instrumentation penetrations per instrument list and P&ID</p> <p>A bin level transmitter is required</p> <p>A bin weight load cell is required</p> <p>The bin will be Nitrogen purged and swept to allow product movement down to the bin conveyor.</p>

12. Bed Material Bin Conveyor

Function	Auger is used to transfer product fines from the bed solids bin (T-6) to the reformer or fines pot via a gravity flow flanged pipeline and three way valve during each test.
Process Material	NaAlSiO ₄ , KAlSiO ₄ , NaFeO ₂ , and Cesium (corrosive and abrasive) fines, water vapor, process gases
Material Density	0.5 g/cc (0.02 lbs/ci)
Design	<p>Auger to be operated semi-continuously. Maximum feed rate setting 50 kg/hr</p> <p>500 degrees C (932 degrees F) temperature.</p> <p>316 Stainless steel construction</p> <p>Electric motor drive</p> <p>Instrumentation penetrations and locations per instrument list and P&ID.</p>
Control	PLC, only
Metering	Yes

13. Fines Collection Pot

Function	The collection pot is part of the beds solids conveying system with level indication and will be located below the beds solids transfer pipe connecting the beds solids conveyor (P-9) with the reformer (SR-1). The collection pot is designed to accept materials from the bed solids bin that cannot be fed into the reformer and will cause overflow of the bed solids bin (T-6).
Capacity	480 liters (126-gallons) at six hours of holding volume at feed rate (assumed)
Feed rate	40 kg/hr (88.2 lbs/hr)
Process Material	NaAlSiO ₄ , KAlSiO ₄ , NaFeO ₂ (corrosive and abrasive) fines

Material Density	0.5 g/cc (0.02 lbs/ci)
Material Weight	2239 kg (526 lbs) weight in pot (assumed)
Tank Material	316 Stainless Steel
Tank Size	2.5 ft diameter × 4.75 ft high including 45 degree sloped bottom (assumed)
Temperature	500 degrees C (932 degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Tank Design (by contractor)	The pot will have a circular shape with a conical upper section with a welded flange feed port and flat bottom. A bin level transmitter is required. A bin weight load cell is required. Instrumentation penetrations per instrument list and P&ID.

14. P-9 Solids Conveyor

Function	This conveyor is used to transfer the process fine products from the product separator (S-1) to the bed solids bin (T-6).
Feed rate	<25 cfm Nitrogen gas as material propellant
Process Material	NaAlSiO ₄ , KAlSiO ₄ , NaFeO ₂ (corrosive and abrasive) fines
Material Density	0.5 g/cc (0.02 lbs/ci)
Design	System to be operated semi-continuously 500 degrees C (932 degrees f) temperature 316 Stainless steel construction Instrumentation penetrations and locations per instrument list and P&ID Nitrogen gas port in system.
Control	PLC, only
Metering	Yes.

15. EVS-1 Venturi Scrubber

Function	The purpose of the venturi scrubber is to remove dust that escapes the sintered metal filter system, scrub out acid gases, and to quench the off-gas
Flowrate	53 ACFH (Actual Cubic Feet/hour)
Scrub Flow	68 liters/hr (0.3 gpm) @ 18 degrees C (64 degrees F)
Operation	This device will be operated just below the dew point such that very little liquid is collected from the off-gas stream
Cooling	The recirculating scrub stream will be cooled to maintain proper operating temperature. The cooling medium will be TBD.

Design	<p>The venturi scrubber will be a low pressure drop design with a scrub solution nozzle in the venturi throat</p> <p>The exit stream will discharge within the scrub recirculation vessel with a mist eliminator at the vessel outlet</p> <p>The liquid jet scrubber shall be a 3-inch Elmridge or equivalent operated with a 40 psig pressure (approximately 0.75 M NaHCO₃ with NaOH as makeup)</p> <p>Inlet and outlet pressure ports</p> <p>Instrumentation penetrations and locations installed per instrument list and P&ID.</p>
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16. T-7 Scrub Tank

Function	This tank will be used as a collection vessel for the accumulation and recycle of the scrub solution.
Scrub Inflow	68 liters/hr (0.3 gpm) @ TBD degrees C (TBD degrees F)
Design	<p>Vessel size shall contain 30 liters (8 gallons) of scrub solution</p> <p>Vessel shall have a minimum of 18-inches of gas phase space above the gas inlet bottom with a mist eliminator at the outlet (wire mesh)</p> <p>Vessel solution temperature shall be controlled at a specified temperature based on the dew point of the gas entering the scrubber</p> <p>The tank will be of cylindrical configuration with a top and bottom ellipsoidal head</p> <p>The top head will be provided with welded flanges for connection to the scrubber (EVS-1) above and the condenser (HE-2)</p> <p>A flanged penetration into the tank shell near the bottom will be provided for connection to the scrub venturi pump (P-11)</p> <p>A flanged penetration into the tank shell will be provided for the make up scrub solution from the makeup scrub solution pump (P-8)</p> <p>A cooling loop shall be provided in bottom head with welded flanges to cool the tank with chilled water (Q=14,000 btu/hr)</p> <p>The scrub solution will be bled off as deemed necessary and makeup chemical will be added (about 4 liters 1M NaOH/hr after the first 10 hours of operation)</p> <p>Level, pressure, differential pressure, and temperature instrumentation shall be provided</p> <p>Instrumentation penetrations and locations installed per instrument list and P&ID.</p>

17. P-10 Scrub Venturi Pump

Function	The pump will be used to transfer the scrub solution out of the scrub tank (T-7) to the EVS-1 scrubber and recirculate the solution through the tank.
Flowrate	20 gpm at 90 ft TDH maximum
Design	This should be an off-the-shelf centrifugal pump
Control	PLC, only
Metering	Yes.

18. HE-2 Condenser

Function	This tank will be used to lower the dew point of the off-gas to ambient temperature, condense most of the water from off-gas flow and scrub most of the soluble gases from the off-gas stream. The purpose of condensing the off-gas is to provide a better material balance and prevent gross condensate formation in the bench scale off-gas discharge.
Design	<p>The heat duty should be 30,000 to 40,000 BTU/hr (assumed)</p> <p>With extra capacity included, the surface area should be about 5 square ft</p> <p>The condenser shall have vertical tubes with a tube sheet removable from the vessel top</p> <p>Cooling water shall flow inside the tubes with the off-gas flowing counter current around a center baffle</p> <p>Cooling water input temperature should be 15 degrees C @ 5-10 gpm</p> <p>Both the coolant and the gas enter and leave the vessel near the top of the vessel with the condensate leaving the tank from the bottom</p> <p>A commercial unit should be chosen for this application</p> <p>Temperature instrumentation is required for the cooling water and the entering and exiting gas stream</p> <p>Pressure instrumentation is required on the exiting gas stream</p> <p>Instrumentation penetrations and locations installed per instrument list and P&ID.</p>

19. T-8 Condensate Tank

Function	The condensate tank is the collection vessel and waste collection drum.
Flowrate	9-11 liters/hr is the expected flow into the tank
Volume	30 liters
Design	<p>The tank will be of cylindrical configuration with a top and bottom ellipsoidal head</p> <p>The top head will be provided with a welded flange for connection to the condenser (HE-2)</p> <p>(HE-2)</p> <p>The bottom head will be provided with a welded flange for connection to the waste collection piping</p> <p>A level transmitter is required for the tank</p> <p>Instrumentation penetrations and locations installed per instrument list and P&ID.</p>

20. SE-2 HEME (High Efficiency Mist Eliminator) Tank

Function	The mist eliminator vessel will be designed to collect over 99% of the mist in the off-gas stream flow.
Design	<p>Mist load on the vessel is TBD</p> <p>This vessel will be sized at twice the expected load</p> <p>The mist eliminator media shall be of a glass fiber design sized for low pressure drop</p> <p>The suggested vendor for this equipment is Koch York Otto Type IC-K</p> <p>The tank will be of cylindrical configuration with a top and bottom ellipsoidal head</p> <p>The bottom head will be provided with a welded flange for connection to the HEME liquid tank (T-9)</p> <p>Connection to the off-gas input pipeline shall be a welded flange near the top of the vertical tube body</p> <p>Connection the GAC-1 GAC bed and/or air jet will be near the top of vessel body opposite the off-gas input pipe penetration</p> <p>Instrumentation penetrations and locations installed per instrument list and P&ID.</p>

21. T-9 HEME Liquid Tank

Function	This is a small vessel used to collect the HEME liquid for sampling and mass measurement before transfer to waste containers.
Design	This tank can be an standalone or and extended bottom of the HEME vessel
Input Flowrate	TBD
Volume	TBD
Control	
Metering	

22. HE-4 Off-gas Sub Cooler

Function	The sub cooler cools the off-gas using chilled coolant for transport to the granular activated charcoal bed.
Design	<p>The sub-cooler chills the off-gas flow to 7 to 10 degrees C (45 to 50 degrees F) to assure the GAC bed and downstream equipment are above the dew point</p> <p>Surface area is TBD</p> <p>The off-gas sub-cooler shall be GFE. Chilled water supply temperature shall be 5 degrees C (41 degrees F) at TBD gpm</p> <p>A commercial heat exchanger should be available for this application.</p>

23. GAC-1 (Granular Activated Carbon Bed)

Function	The GAC is an encapsulated packed bed of sulfur-impregnated activated carbon having a particle size of 2 to 3 mm and sized to provide a gas residence time of not more than 10 seconds. This unit is expected to reduce the concentration of oxidized and elemental mercury to below the MACT limit of 4 micro-grams/m.
Off-gas Flowrate	The expected input air flow will be 34 cubic meters/hr (20 scfm)
Design	A commercial GAC should be available for this application.

24. AJ-1 Air Jet

Function	The air (gas) jet will serve as the pumping source for the off-gas outflow. It will also serve to quickly dilute the off-gas to a lower dew point and flammable concentration. The vacuum can be controlled by gas recycle and motive gas inlet pressure or a combination of both. (Although not as efficient, air jets are more reliable and versatile than rotary vacuum or turbine blade blowers.)
Design	<p>No electric power is required and the jet is very compact</p> <p>This is a GFE item</p> <p>The equipment recommended is a Penberthy 1-1/2-inch GL 316 SS</p> <p>Maximum required air flow would be 90 scfm @ 80 psig</p> <p>Expected air flow would be 78 scfm @ 60 psig.</p>

25. F-2 HEPA (High Efficiency Particulate Air Filter)

Function	The filter can remove 99% of particulates from the off-gas air flow. This filter will probably not be used for the off-gas system and will be sized if-and-only-if a HEPA filter is required.
Design	This should be an off-the-shelf item.

26. Mercury Monitoring and Abatement (from direct steam reformer attachment)

Function	Monitors the Mercury level in the steam reforming system and captures the material. Refer to Sketch of Mercury Monitoring of Off-Gas from Steam Reformer DWG# CURTIS1.
Capacity	Volume of Mercury TBD
Density	13.54g/cc (0.489 lbs/ci)
Weight	TBD based on volume
Construction Mat'l	316 stainless steel construction (all mechanical components)
Temp (heated sys.)	TBD
Temp (non-heated sys.)	
Pressure	TBD
Design	
Valves	<p>4-way solenoid valve, 0.25" OD Swagelock Tube Fittings Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p> <p>3-way solenoid valve (heated) 0.25" OD Swagelock Tube Fittings. Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p> <p>Vent valves, Swagelok needle valve</p>
Isolation valves	Swagelok needle valves
Pumps	<p>Heated pump 0 to 200cc/min with 0.25-inch OD tube fittings (must withstand 200 degrees C). Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p> <p>Non-heated pump 0 to 200cc/min with 0.25-inch OD tube fittings (must withstand 200 degrees C). Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p>
Filters	<p>Heated filters (must withstand 200 degrees C) Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p> <p>Non-heated filter. Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p>

GAC	Granulated Activated Carbon (GAC) Packed Bed Adsorption Column GFE item
Mercury Analyzer	Tekran Model 2537A, Tekran Inc., Toronto, Canada (Contact: Frank Schladich)
Sample Points	<ol style="list-style-type: none"> 1. Between sintered Metal Filter and EVS 2. Between EVS and Condenser 3. Between condenser and HEME tank 4. Between HEME tank and GAC system 5. Downstream of GAC system.

1. Skid No. 2 Maximum Skid Dimensions

Skid envelope maximum dimensions = 8.5-feet wide × 25 feet long × 12 feet high (Must fit a Lo-boy trailer for over-the-road transport)

2. General Design Information

Isolation Valves	All major equipment shall have flanged type isolation ball valves for 150 lb. WOG (water, oil, or gas) service or Swagelok tube fittings for tube applications. Valves shall be specified to control corrosive and abrasive materials (corrosivity value TBD). Ball valves shall be of full flow design relative to the various pipeline sizes of the feed system. Minimum Operating temperature shall be 288 degrees C (550 degrees F). Maximum operating pressure shall be 1.03 mPa (150 psig). Valve construction material shall be 316 Stainless steel (unless otherwise noted) Valve seals to be determined by subcontractor for the specified service (probably metal seals).
Tanks	All tanks (or bins) shall be 316 stainless steel (unless otherwise noted) and are not considered pressure vessels
Piping	All piping shall be 316 stainless steel (unless noted otherwise) per ASME/ANSI B31.3 Chemical Plant & Refinery Piping (Latest code)
Welding	All pipe welds shall be to the requirements of ASME/ANSI B31.3 Chemical Plant and Refinery Piping (Latest code)
Connections	All pipe, pump, and tank connections should be flanged whenever possible for easy assembly and maintenance
Flanges	All flange connections shall be 316 stainless steel (unless noted otherwise) conforming to ASTM A182 F316
Bolting	All stainless steel flange bolts shall conform to ASTM A193 Gr.B8c, Nuts to ASTM A194 Gr. 8C
Tubing	All tubing shall be 316 stainless steel with wall thickness to meet pressure and temperature requirements per system
Tube Fittings	Swagelok tube fittings shall be used exclusively for tube connections.

3. T-1 Simulant Tank

Function	This is a holding and mixing tank used in creating the steam reformer simulant of sodium bearing waste
Capacity	800 Liters (211 gallons)
Simulant Density	1.29 kg/l (10.77 lbs/gallon)
Simulant Weight	About 1,032 kg (2,273 lbs.) full tank estimated weight
Tank Material	316 Stainless Steel

3. (Cont.)

Temperature	18 to 24 degrees C (65 to 75 degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
pH Range	TBD
Tank Design (by subcontractor)	Designed to contain corrosive and abrasive solid and liquid feed ingredients, chemicals and demineralized water Circular shape with ellipsoidal heads top and bottom with envelope size TBD by subcontractor Flanged bottom outlet to transfer pump (P-1) and drain valve Flanged vent off-gas connection in top head Flanged top chemical feed port to receive solid and liquid feed chemicals Flanged solution recirculation connection port with flanged recirculation piping sized by subcontractor Instrumentation penetrations per instrument list and P&ID In-tank solution cooling/heating system externally flanged High - Low Level indicator Electrically driven mechanical agitator
Control	Agitator - PLC and local
Metering	Yes.

4. P-1 TRANSFER PUMP

Function	This pump is used to transfer simulant to the feed/mix tanks from the simulant tank and recirculate simulant through the tank to prevent dissolution of solid ingredients. The pump shall be mounted below the Simulant Tank.
Flow Rate	2271 to 4543 Liters/hour (10 to 20 gpm)
Simulant Density	1.29 kg/l (10.77 lbs/gal).
Temperature	18 to 24 degrees C (65 to 75 degrees F)
Pressure	689 kPa (100 psi)
pH Range	TBD
Material	316 Stainless steel
Pump Type	TBD by subcontractor
Pump Horsepower	TBD by subcontractor
Pump design	Pump shall be compatible with corrosive and abrasive solutions of liquid slurry with approximately 35 wt% solids. Pump shall have 150 lb flanged inlet and outlet ports and be capable of 150 lb WOG service.
Control	PLC and local control
Metering	Yes.

5. T-2A and 2B Feed Mix Tanks

Function	These two tanks are used to mix other ingredients into the simulant solution received from the simulant tank (T-1) as the steam reformer feed mixture and hold/recirculate the modified solution for transfer to the P-4 feed pump via recirculation pumps P-2A and P-2B.
Capacity	200 liters (53 gallons)
Material	316 Stainless steel
Temperature	18 to 49 degrees C (65 to 120 degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
pH Range	TBD
Tank Design (by subcontractor)	Tank to contain corrosive and abrasive solid and liquid feed ingredients, chemicals, and water. B. Circular shape with ellipsoidal heads top and bottom. Flanged bottom outlet. Flanged vent to SR-1 Enclosure ventilation system. Flanged top chemical feed port for simulant additives flow into tank. Flanged solution recirculation connection port (top side of tank in-line with bottom side outlet of recirculation piping). Flanged feed pump return port (top head or side of tank above the upper recirculation elevation). Instrumentation penetrations per instrument list and P&ID. High-Low Level transmitter. Differential transmitter. In-tank solution cooling/heating system externally flanged with isolation valve and flow control valve. Electrically driven mechanical agitator.
Control	Agitator - PLC and local.
Metering	Yes.

6. P-2A and P-2B Recirculation Pumps

Function	These pumps are used to recirculate the feed mixture through each relative tank and transfer the feed mixture from the recirculation flow upon demand to feed pump (P-4).
Flow Rate	2271 to 4543 Liters/hour (10 to 20 gpm)
Temperature	18 to 49 degrees C (65 to 120 degrees F)
Pressure	345 kPa (50 psig)
pH Range	TBD
Material	316 Stainless steel
Type	TBD by subcontractor

6. (Cont.)

Horsepower	TBD by subcontractor
Pump Design	Pump shall be compatible with corrosive and abrasive solutions of liquid slurry with approximately 35 wt% solids. Pump shall have 150 lb flanged inlet and outlet ports and be capable of 150 lb WOG service.
Control	PLC and local control
Metering	Yes

7. **T-4 Bed Material Bin**

Function	This bin is used to supply bed materials to the steam reformer for bed makeup via the bed material conveyor.
Bed Material	TBD
Capacity	11.5 liters (3-gallons)
Material Density	2.0 to 2.5 g/cc (0.07 to 0.09 lbs/C.I.)
Material Weight	48 to 62 lbs (weight in bin)
Bin Material	316 Stainless Steel
Bin Size	6-inch schedule 40 pipe × 24-inches long with a conical bottom and flat cover overall length TBD
Temperature	18 to 24 degrees C (65 to 75 degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Bin Design (by subcontractor)	Tank shall contain solid granular materials and fines of TBD bed materials Circular shaped bin with conical bottom head and flat hinged cover Bottom bin outlet to match bed material auger connection Top cover chemical feed port Instrumentation penetrations per instrument list and P&ID Load cell.

8. **P-12 Bed Material Conveyor**

Function	Conveyor is used to transfer fresh bed material (TBD) from the bed material bin (T-4) to the steam reformer penetration via a gravity flow chute and rotary valve during each test.
Flow Rate	0 to 10 kg/hr (0 to 22 lbs/hr) of bed material
Auger Material	316 stainless steel
Design	Conveyor to be operated semi-continuously Maximum flowrate setting 50 kg/hr Electric VFD motor drive
Control	PLC and local
Metering	Yes

9. Rotary Valve For Bed Material Discharge

Function	This valve meters fresh bed material from the bed material conveyor to the steam reformer (SR-1) penetration via a gravity flow flanged pipeline during each test.
Flow Rate	0 to 10 kg/hr (0 to 22 lbs/hr) of bed material
Volume/Rotation	TBD by subcontractor
Temperature	350 to 500 degrees C 662 to 932 degrees F) for collection of Cs from the reformer off-gas stream
Pressure	73 kPa (10.58 psi) from mass balance calculations
Process Material	NaAlSiO ₄ , KAlSiO ₄ , and NaFeO ₂ (corrosive and abrasive) fines, water vapor, process gases
Material Density	0.3 g/cc (0.011 lbs/C.I.)
Cyclone Mat'l	316 stainless steel
Design	Obtain a commercial rotary valve to meet size, feed rate criteria, and temperatures
Control	PLC, only
Metering	Yes.

10. T-3 Reductant Bin

Function	This bin is used to supply reductant material (briquette or granular) to the steam reformer (SR-1) for bed makeup.
Capacity	11.5 liters (3-gallons)
Material Density	2.0 to 2.5 g/cc (0.07 to 0.09 lbs/C.I.).
Material Weight	48 to 62 lbs (weight in bin).
Bin Material	316 Stainless Steel
Bin Size	6-inch schedule 40 pipe × 24-inches long with a conical bottom and flat cover, overall height TBD.
Temperature	Ambient, 18 to 24 degrees C (65 to 75 degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Bin Design (by subcontractor)	Tank shall contain solid carbonaceous materials and fines of TBD materials Circular shape with conical bottom head and flat hinged cover Bottom bin outlet to match bed material auger connection Top cover chemical feed port Instrumentation penetrations per instrument list and P&ID Load cell.

11. P-5 Reductant Bin Conveyor

Function	Conveyor is used to transfer dry reductant material from the reductant bin (T-4) to the steam reformer (SR-1) penetration via a gravity flow flanged pipeline during each test.
Flowrate	0 to 10 kg/hr (0 to 22 lbs/hr) of reductant material.
Auger Material	316 stainless steel:
Design	Conveyor to be operated semi-continuously Maximum flowrate setting 5 kg/hr Electric VFD motor drive Material port for reductant flow to match bottom bin outlet of reductant bin (T-3)
Control	PLC and local
Metering	Yes.

12. Rotary Valve For Reductant Material Discharge

Function	This valve meters reductant from the reductant bin conveyor to the steam reformer (SR-1) penetration via a gravity flow flanged pipeline during each test.
Flow Rate	0 to 10 kg/hr (0 to 22 lbs/hr range)
Volume/Rotation	TBD by subcontractor
Temperature	350 to 500 degrees C 662 to 932 degrees F) for collection of Cs from the reformer off-gas stream
Pressure	73 kPa (10.58 psi) from mass balance calculations
Process Material	NaAlSiO ₄ , KAlSiO ₄ , and NaFeO ₂ (corrosive and abrasive) fines, water vapor, process gases
Material Density	0.3 g/cc (0.011 lbs/C.I.)
Cyclone Mat'l	316 stainless steel
Design	Obtain a commercial rotary valve to meet size, feed rate criteria, and temperatures
Control	PLC, only
Metering	Yes.

13. Demineralizer

Function	Supply demineralized feedwater to the Bed Feedwater (BFW) metering pump.
Specifications	Rent or buy from Culligan Water systems 9-inch mixed bed deionization system 0 to 500 ml/min (0 to 0.13 gpm) flow rate 345 kPa (50 psig) minimum pressure 50 ppm maximum dissolved solids allowable Electric power TBD Water supply pressure 40 to 60 psig Demineralized water - 5 meg ohm resistivity maximum.

14. SG-1 Steam Generator

Function	This unit automatically supplies steam to a steam superheater (H-1) and then the steam reformer (SR-1) requiring no direct input from the DCS.
Specifications	Possibly use a Chromalox electric Compact Steam Boiler, Model CMB-9 or equal 27 lbs/hr steam capacity 90 psig maximum pressure 480VAC, 3 phase electric power 9 kW power Connections shall be flanged to the inlet and outlet piping and isolation valves 316 Stainless steel material Envelope dimensions, inches, 20 × 30 × 37 high (Assumed) Level switch to control water level Pressure controller Power controller Steam flow control valve Demineralized water supply - 5 meg ohm resistivity maximum.

15. H-1 Steam Superheater - First Stage

Function	Superheater ensure single phase steam flow though the steam piping into the steam reformer (SR-1).
First Stage:	
Specifications	Chromalox Circulation Heater Model TBD
Equipment	Power controller controlled by the DCS to control steam temperature between flow control valve and final superheater
Final Stage	Chromalox Circulation Heater Model TBD
Design	760 degrees C outlet temperature
Parameters	150 degrees C inlet temperature 24 lbs/hr maximum steam flow 2 lbs/hr minimum steam flow 4.5 kW maximum power required 1/2-inch schedule 40 Inconel 625 (or TBD material) × TBD long flanged at each end.
Heaters	Heaters for pipe should be FIBROTHAL half cylinders (or TBD) surrounding the pipe
Parameters	HAS 70/500/115 material designation 70 mm Inside diameter 20 mm outside diameter 500 mm length 900 W electric power 115 VAC 5 meg ohms resistivity maximum 1150 degrees C maximum heating element temperature Insulation material to surround the heaters is TBD.

16. H-2 Steam Superheater - Second Stage

Function	The second stage superheater is installed in the steam generation system to ensure single phase steam flow through the steam piping into the steam reformer (SR-1).
Second Stage:	
Specifications	Chromalox Circulation Heater Model TBD
Equipment	Power controller controlled by the DCS to control steam temperature between flow control valve and final superheater
Final Stage	Chromalox Circulation Heater Model TBD
Final Design Parameters:	760 degrees C outlet temperature 150 degrees C inlet temperature 24 lbs/hr maximum steam flow 2 lbs/hr minimum steam flow 4.5 kW maximum power required 1/2-inch schedule 40 Inconel 625 (or TBD material) × TBD long flanged at each end.
Heaters	Heaters for pipe should be FIBROTHAL half cylinders (or TBD) surrounding the pipe.
Parameters	HAS 70/500/115 material designation 70 mm Inside diameter 20 mm outside diameter 500 mm length 900 W electric power 115 VAC 5 meg ohms resistivity maximum 1150 degrees C maximum heating element temperature Insulation material to surround the heaters is TBD.

17. T-5 Make Up Scrub Tank

Function	Provides make up scrub solution to the Scrub tank (T-7) via the make up scrub pump (P-8).
Capacity	5 liters (1.3 gallons) for 25 hours of make up scrub solution
Material	316 Stainless steel
Temperature	Ambient, 18 to 24 degrees C (65 to 75 degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)

Tank Design (by subcontractor)	<p>Tank to contain sodium hydroxide liquid from bottled source</p> <p>Vertical circular shape with ellipsoidal heads top and bottom</p> <p>Flanged bottom outlet to connect to scrub pump P-8</p> <p>Flanged top cover needle valve pressure relief and vent to off-gas connection</p> <p>Flange near top of tank for recirculation of scrub solution</p> <p>Flanged top head penetration for filling tank from bottled chemicals</p> <p>Flange in top head for water connection with isolation valve</p> <p>Instrumentation penetrations per instrument list and P&ID</p> <p>High-low Level transmitter.</p>
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18. P-8 Make Up Scrub Pump

Function	The make up scrub pump is used to pump scrub solution (sodium hydroxide) to the scrub tank (T-7) on a separate skid (Number 1) within the skid containment.
Flow Rate	0.10 to 0.50 l/min (4.4E-04 to 2.2E-02 gpm)
Temperature	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Pressure	100 kPa (14.5 psi)
Material	316 Stainless steel
Type	Use a turbine flowmeter/totalizer with a range from 1.7 ml/min to 8.3 ml/min (4.4E-04 to 2.2E-02 gpm)
Horsepower	TBD by subcontractor
Pump Design	<p>Pump shall be compatible with sodium hydroxide</p> <p>Pump shall have Swagelok 316 stainless steel tube fittings on inlet and outlet ports</p>
Needle Valve	A Manual flanged Needle Valve with Swagelok fittings shall be provided to control the flow of sodium hydroxide to the turbine flowmeter.
Control	PLC and local control.
Metering	Yes.

19. Air Filtration Unit

Function	Unit provides filtered air to the Product Cooler (HE-1).
Flow Rate	100 scfm (estimate).
Temperature	18 to 24 degrees C (65 to 75 degrees F).
Pressure	90 psig.
Material	Commercial materials.
Filter Medium	HEPA (99.95% clean air).
Horsepower	TBD by subcontractor.
Pump Design	Purchased as part of off-the-shelf system.

1. Skid Number 3 Maximum Dimensions

Maximum skid envelope dimensions = 8.5-feet wide x 25 feet long x 12 feet high (actual size **TBD** by subcontractor).(Skid must fit a Lo-boy tractor trailer for over-the-road transport)

2. General Specifications

Isolation Valves	All major equipment shall have flanged type isolation ball valves for 150 lb. WOG (water, oil, or gas) service or Swagelok tube fittings for tube applications Valves shall be specified to control corrosive and abrasive materials (corrosivity value TBD) Ball valves shall be of full flow design relative to the various pipeline sizes of the feed system Minimum Operating temperature shall be 288 degrees C (550 degrees F) Maximum operating pressure shall be 1.03 mPa (150 psig) Valve construction material shall be 316 Stainless steel (unless otherwise noted) Valve seals to be determined by subcontractor for the specified service (probably metal seals)
Tanks	All tanks (or bins) shall be 316 stainless steel (unless otherwise noted) and are not considered pressure vessels.
Piping	All piping shall be 316 stainless steel (unless noted otherwise) per ASME/ANSI B31.3 Chemical Plant & Refinery Piping (Latest code).
Welding	All pipe welds shall be to the requirements of ASME/ANSI B31.3 Chemical Plant & Refinery Piping (Latest code).
Connections	All pipe, pump, and tank connections should be flanged whenever possible for easy assembly and maintenance.
Flanges	All flange connections shall be 316 stainless steel (unless noted otherwise) conforming to ASTM A182 F316.
Bolting	All stainless steel flange bolts shall conform to ASTM A193 Gr.B8c, Nuts to ASTM A194 Gr. 8C.
Tubing	All tubing shall be 316 stainless steel with wall thickness to meet pressure and temperature requirements per system.
Tube Fittings	Swagelok tube fittings shall be used exclusively for tube connections.

3. EVS-1 Venturi Scrubber

Function	The purpose of the venturi scrubber is to remove dust that escapes the sintered metal filter system, scrub out acid gases, and to quench the off-gas. The scrubber can be mounted directly to the Scrub Tank (T-7).
Flowrate	85 ACFM (Actual Cubic Feet/min) at inlet & 55 ACFM at outlet
Scrub Flow	68 liters/hr (0.3 gpm) @ 18 degrees C (64 degrees F)
Inlet Pressure	78 kPa (11.3 psig)
Outlet Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)

Temperature	350 to 400 degrees C (662 to 752 degrees F)
Operation	This device will be operated just below the dew point such that very little liquid is collected from the off-gas stream
Cooling	The recirculating scrub stream will be cooled to maintain proper operating temperature The cooling medium will be TBD
Design	The venturi scrubber will be a low pressure drop design with a scrub solution nozzle in the venturi throat The exit stream will discharge within the scrub recirculation vessel with a mist eliminator at the vessel outlet The liquid jet scrubber shall be a 3-inch Elmridge or equivalent operated with a 40 psig pressure (approximately) 0.75 M NaHCO ₃ with NaOH as makeup Inlet and outlet pressure ports Instrumentation penetrations and locations installed per instrument list and P&ID.

4. T-7 Scrub Tank

Function	This tank will be used as a collection vessel for the accumulation and recycle of the scrub solution.
Scrub Inflow	68 liters/hr (0.3 gpm) @ TBD degrees C (TBD degrees F)
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Inlet Temperature	350 to 400 degrees C (662 to 752 degrees F)
Outlet Temperature	30 degrees C (86 degrees F)
Design	Vessel size shall contain 30 liters (8 gallons) of scrub solution Vessel shall have a minimum of 18-inches of gas phase space above the gas inlet bottom with a mist eliminator at the outlet (wire mesh) Vessel solution temperature shall be controlled at a specified temperature based on the dew point of the gas entering the scrubber The tank will be of cylindrical configuration with a top and bottom ellipsoidal head The top head will be provided with welded flanges for connection to the scrubber (EVS-1), the vessel off-gas system, and low and high level transmitters A flanged penetration into the bottom head will be provided for connection to the scrub venturi pump (P-11) A flanged penetration into the top end of the tank shell will be provided for make up scrub solution from the makeup scrub solution pump (P-8) [See Sheet 2 or Skid 2] A cooling loop shall be provided in the bottom head with welded flanges to cool the scrub solution with chilled water (Q=14,000 btu/hr) The scrub solution will be bled off as deemed necessary and makeup chemical will be added (about 4 liters 1M NaOH/hr after the first 10 hours of operation) Instrumentation penetrations and locations installed per instrument list and P&ID.

5. P-11 Scrub Venturi Pump

Function	The pump will be used to transfer the scrub solution out of the scrub tank (T-7) to the EVS-1 scrubber and recirculate the solution through the tank.
Flowrate & Head	10 gpm at 130 ft TDH maximum
Temperature	30 degrees C (86 degrees F)
Design	This should be an off-the-shelf centrifugal pump
Control	PLC, only
Metering	Yes.

6. HE-2 Condenser Tank

Function	This tank will be used to lower the dew point of the off-gas to ambient temperature, condense most of the water from off-gas flow, and scrub most of the soluble gases from the off-gas stream. The purpose of condensing the off-gas is to provide a better material balance and prevent gross condensate formation in the bench scale off-gas discharge.
Design	<p>The heat duty should be 30,000 to 40,000 BTU/hr (assumed)</p> <p>With extra capacity included, the surface area should be about 10 square ft.</p> <p>The condenser shall have vertical tubes with a tube sheet removable from the vessel top</p> <p>Cooling water shall flow inside the tubes with the off-gas flowing counter current around a center baffle</p> <p>Cooling water input temperature should be 15 degrees C @ 5-10 gpm</p> <p>Both the coolant and the gas enter and leave the vessel near the top of the vessel with the condensate leaving the tank from the bottom</p> <p>A commercial unit should be chosen for this application</p> <p>Temperature instrumentation is required for the cooling water and the entering and exiting gas stream</p> <p>Pressure instrumentation is required on the exiting gas stream</p> <p>Instrumentation penetrations and locations installed per instrument list and P&ID.</p>
Control	Cooling water, PLC.

7. T-8 Condensate Tank

Function	The condensate tank is the collection vessel for condensed liquids and the waste collection drum.
Flowrate	9-13 liters/hr (2.4 to 2.9 gal/hr) is the expected flow into the tank
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Temperature	25 degrees C (77 degrees F)
Volume	30 liters (7.9 gallons)

Design	<p>The tank will be of cylindrical configuration with a top and bottom ellipsoidal head (vertical orientation)</p> <p>The top head will be provided with a welded flange for connection to the condenser (HE-2)</p> <p>The bottom head will be provided with a welded flange for connection to the waste collection piping</p> <p>High/low level transmitters are required for the tank</p> <p>Instrumentation penetrations and locations installed per instrument list and P&ID.</p>
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8. Seal Pot

Function	The seal pot acts as a gas trap to ensure that gases do not enter the liquid waste transferred to waste containers and are returned to the off-gas system.
Flowrate	9-13 liters/hr (2.4 to 2.9 gal/hr) is the expected flow into the tank
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Temperature	25 degrees C (77 degrees F)
Volume	TBD
Design	TBD

9. SE-2 HEME (High Efficiency Mist Eliminator) Tank

Function	The mist eliminator vessel will be designed to collect over 99% of the mist in the off-gas stream flow.
Pressure	Ambient (12.7 psi @ 5,000 foot elevation - Idaho Falls, ID)
Temperature	25 degrees C (77 degrees F)
Design	<p>Mist load on the vessel is TBD</p> <p>This vessel will be sized at twice the expected load</p> <p>The mist eliminator media shall be of a glass fiber design sized for low pressure drop</p> <p>The suggested vendor for this equipment is Koch York-Otto Type IC-K</p> <p>The tank will be of cylindrical configuration with a top and bottom ellipsoidal head (vertical orientation)</p> <p>The bottom head will be provided with a welded nozzle for connection to the HEME liquid tank (T-9)</p> <p>Connection to the off-gas input pipeline shall be a welded flange near the top of the vertical tube body</p> <p>Connection the GAC-1 GAC bed and/or air jet will be near the top of vessel body opposite the off-gas input pipe penetration</p> <p>Instrumentation penetrations and locations installed per instrument list and P&ID.</p>

10. T-9 HEME Liquid Tank

Function	This is a small vessel used to collect the HEME liquid for sampling and mass measurement before transfer to waste containers.
Input Flowrate	TBD
Volume	TBD
Design	This tank can be a standalone unit or an extended bottom of the HEME vessel.

11. HE-4 Off-Gas Sub Cooler

Function	The sub cooler cools the off-gas using chilled coolant for transport to the granular activated charcoal bed.
Design	The sub-cooler chills the off-gas flow to 7 to 10 degrees C (45 to 50 degrees F) to assure the GAC bed and downstream equipment are above the dew point Surface area is TBD. C. The Off-gas Sub-cooler shall be GFE Chilled water supply temperature shall be 5 degrees C (41 degrees F) at TBD gpm A commercial heat exchanger should be available for this application.
Control	Cooling water - PLC.

12. GAC-1 (Granular Activated Carbon Bed)

Function	The GAC is an encapsulated packed bed of sulfur-impregnated activated carbon having a particle size of 2 to 3 mm and sized to provide a gas residence time of not more than 10 seconds. This unit is expected to reduce the concentration of oxidized and elemental mercury to below the MACT limit of 4 micro-grams/min.
Off-gas Flowrate	The expected input air flow will be 34 cubic meters/hr (20 scfm)
Design	A commercial GAC should be available for this application.

13. AJ-1 Air Jet

Function	The air (gas) jet will serve as the pumping source for the off-gas outflow. It will also serve to quickly dilute the off-gas to a lower dew point and flammable concentration. The vacuum can be controlled by gas recycle and motive gas inlet pressure or a combination of both. (Although not as efficient, air jets are more reliable and versatile than rotary vacuum or turbine blade blowers.)
Source	GFE
Design	No electric power is required and the jet is very compact The equipment recommended is a Penberthy 1-1/2-inch GL 316 SS Maximum required air flow would be 90 scfm @ 80 psig Expected air flow would be 78 scfm @ 60 psig.

14. F-2 HEPA (High Efficiency Particulate Air Filter)

Function The filter can remove 99.5% of particulates from the off-gas air flow. This filter will probably not be use for the off-gas system and will be sized if-and-only-if a HEPA filter is required.

Design This should be an off-the-shelf item.

15. Mercury Monitoring and Abatement (from direct steam reformer attachment)

Function Monitors the Mercury level in the steam reforming system and captures the material. Refer to Sketch of Mercury Monitoring of Off-Gas from Steam Reformer DWG# CURTIS1.

Capacity Volume of Mercury TBD

Density 13.54g/cc (0.489 lbs/C.I.)

Weight TBD based on volume

Construction Mat'l 316 stainless steel construction (all mechanical components)

Temp (heated sys.) TBD

Temp (non-heated sys.) TBD

Pressure TBD

Design

Valves 4-way solenoid valve, 0.25" OD Swagelok Tube Fittings
3-way solenoid valve (heated) 0.25" OD Swagelok Tube Fittings

Vent valves Swagelok needle valves
Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.

Isolation valves Swagelok needle valves
Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.

Pumps Heated pump
Non-heated pump

Filters Heated filters (must withstand 200 degrees C)
Non-heated filter

0 to 200cc/min with 0.25-inch OD tube fittings (must withstand 200 degrees C)

GAC GFE Item - Granulated Activated Carbon (GAC) Packed Bed Adsorption Column
Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.

Mercury Analyzer	<p>Tekran Model 2537A</p> <p>Tekron Inc., Toronto, Canada (Contact: Frank Schladich)</p> <p>0 to 200cc/min with 0.25-inch OD tube fittings (must withstand 200 degrees C)</p> <p>Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p>
Sample Points	<p>Between sintered Metal Filter and EVS</p> <p>Between EVS and Condenser</p> <p>Between Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p> <p>Between HEME tank and GAC system</p> <p>Downstream of GAC system Apex Instruments, Holly Springs, N.C. or Environmental Supply Co., Durham N.C.</p>

APPENDIX D

UTILITY REQUIREMENTS

GENERAL

The Steam Reformer process will involve high temperatures, hazardous chemicals and abrasive process fluids. All equipment shall be designed to function for process runs of up to 100 hours, as required in the Functional and Operational Requirements.

The installation shall be able to be cleaned and made ready for a new process run in a “normal” workweek or less, and shall allow for ease of adjustment, modification, and/or replacement.

DRAWINGS

The following reference drawings will be available from the Contractor:

- 522402 Reformer Vessel Fabrication (Sheets 1, 2, 4, and 6)
- 522403 Steam Reformer P&ID's (Sheets 1 – 3)

POWER

Electrical power required for the Steam Reforming skids shall be supplied through a single point connection, using a plug/receptacle or other means, so as to allow easy connection and disconnection. All wiring shall be run in raceway per the NEC.

Codes

The electrical, instrumentation and control system for the Steam Reformer Project shall be designed, constructed and assembled per the following codes and standards:

- ANSI/NFPA 70, National Electrical Code (NEC)
- NEMA Standards
- UL Standards and Product Directories
- ANSI Y32.2/IEEE 315-75 & 315A-86, Electrical and Electronics Graphic Symbols and Reference Designations

Requirements

Approximately 100 kVA of power will be required for the Reformer process. The assembly shall be such that this power can be supplied via a skid-mounted receptacle. Distribution to any remotely located loads shall be fed using a similar connection method.

All power distribution equipment, switches, transformers, motor starters, variable frequency drives, disconnects and associated electrical equipment shall be skid-mounted.

120 VAC power shall be supplied using a transformer sized to 125% of the calculated 120 VAC load required.

All motor controllers shall be equipped with enclosure-mounted wattmeters. Wattmeters will be able to totalize, and allow for remote readout.

WATER

Process water required for the Steam Reforming skids shall be supplied through a single point, using a quick-connect or other means, so as to allow easy connection and disconnection.

Codes

- ASME B31.1
- ASME, Fluid Meters Handbook

Requirements

Water should be ordinary industrial process water, able to be supplied at a pressure of 50 psig, at a rate of 50 gpm.

AIR

Process air required for the Steam Reforming skids shall be supplied through a single point, using a quick-connect or other means, so as to allow easy connection and disconnection.

The air supply to the Air Jet shall be run through a 10 μ filter medium.

Codes

- ASME B31.1
- ASME, Fluid Meters Handbook

Requirements

Air required for Steam Reformer operation shall be oil-free, supplied at pressure of 100 psig, able to maintain a minimum flow of 100 SCFM.

NITROGEN

Nitrogen required for the Steam Reforming skids shall be supplied through a single point, using a quick-connect or other means, so as to allow easy connection and disconnection without interruption of gas flow.

Codes

- ASME B31.1
- ASME, Fluid Meters Handbook

Requirements

Nitrogen pressure shall be supplied at a minimum pressure of 30 psig, at a flow rate of at least 80 SCFM, in support of process runs of up to 100 hours.

Provisions shall be made to allow for the storage of enough gas bottles to support a 100-hour test run.

OXYGEN

Oxygen required for the Steam Reforming skids shall be supplied through a single point, using a quick-connect or other means, so as to allow easy connection and disconnection.

Codes

- System shall be certified for oxygen use and cleaned in accordance with ASTM A380
- ASME, Fluid Meters Handbook

Requirements

Oxygen pressure shall be supplied at a minimum pressure of 50 psig, at a flow rate of at least 10 SCFM, in support of process runs of up to 100 hours.

Provisions shall be made to allow for the storage of enough gas bottles to support a 100-hour test run.

APPENDIX E

Specification for Modes of Operation

Normal Operations

Feed

Simulant Tank T-1

The Simulant Tank T-1 will be a make-up and hold tank for the simulant of a low activity waste. The level in the tank L-T-1 will include local indication to be used by the operator during makeup, and remote indication at the HMI with a LAL to alert the operator of a low level in the Simulant tank. The temperature in the tank T-T-1 will include remote indication at the HMI with adjustable temperature alarming (High or Low depending on Simulant). Alarming will alert the operator of the need to manually adjust the temperature using hand valves (Local-Manual control) on the Simulant Tank T-1 heat exchanger. Manual adjustments will be made to maintain the temperature (T-T-1) below the boiling point with cooling water or to increase solubility of specific chemicals during the mixing phase by increasing solution temperature with steam. A Mixer M-1 will be operated as needed before transfers are made to the feed/mix tanks. The mixer will be local control only. A transfer pump P-1 will be used to transfer simulant to the Feed/Mix tanks T-2A and T-2B, and may be used to circulate simulant to promote dissolution of solid ingredients. The Transfer Pump will be local control only.

See Preparation section for simulant make-up.

Feed/Mix Tanks T-2A and T-2B

Feed/Mix Tanks T-2A and T-2B are used to provide feed mixture to the steam reformer. The level in the tanks (L-T-2A and L-T-2B) will include local indication to be used by the operator during makeup, and remote indication at the HMI with a LAL to alert the operator of a low level in the Feed/Mix Tanks. The temperature in the tanks (T-T-2A and T-T-2B) will include remote indication at the HMI with adjustable temperature alarming (High or Low depending on Simulant). Alarming will alert the operator of the need to manually adjust the temperature using hand valves (Local-Manual control) on the Feed/Mix Tanks T-2A and T-2B heat exchangers. Manual adjustments will be made to maintain the temperature (T-T-2A or T-T-2B) below the boiling point with cooling during mixing. Mixers M-2A or M-2B will be operated continuously while Feed solution is in the tanks. The mixers will be local control only. Re-circulation Pumps P-2A or P-2B will be used to re-circulate feed mix to tanks T-2A and T-2B and transfer feed mix to Feed Pump P-9. Re-circulation Pumps P-2A or P-2B will be local control only.

See Preparation section for procedure to transfer simulant from the Simulant Tank T-1 to the Feed/Mix Tanks T-2A and T-2B

Feed Pump P-9

The Feed pump P-9 will be used to transfer the feed mixture at an operator adjustable rate to the fluidized bed steam reformer. The re-circulation Pumps P-2A or P-2B will be used to transfer the feed mix from the Feed/Mix tanks T-2A and T-2B to Feed Pump P-9, and re-circulate the unused portion back to the tanks. An Operator will execute a manual valve line-up on the supply and return lines to select the feed path from either tank T-2A or T-2B. A LAL from L-T-2A or L-T-2B will alert the operator of a low level in the Feed/Mix Tank and the need to initiate the manual valve lineup to switch to the other Feed/Mix tank. The Feed pump will be controlled from the HMI (operator select on/off with variable speed on HMI). Manual valves located before the Feed Pump P-4 and outside the enclosure will provide isolation, water flush, and clean-out.

After the Feed Pump P-9, a combination of manual valves outside the enclosure, and solenoid valves HV-P-9-1 (Normally Open), HV-P-9-3 (Normally Open), and HV-P-9-2 (Normally Closed) inside the

enclosure will provide the same isolation, water flush, and clean-out function. The solenoids will be remotely operated (open/close) by the operator from the HMI as required.

Feed Line to Reformer Vessel

Nitrogen purge on the feed line through a solenoid valve will provide a purge if there is no flow in the feed line.

A Coriolis Mass Flow meter F-SR-1-1 will provide mass flow measurement of the feed to the reformer. Using the flow value from F-SR-1-1 and an adjustable Nitrogen Feed Nozzle ratio, the PLC will calculate and transmit a set-point to the mass flow controller FCVT-SR-1-1 on the atomizing Nitrogen line. The Mass flow controller FCVT-SR-1-1 will provide a flow signal to the PLC.

Steam

De-mineralized water will be provided for the steam generator.

A flow loop F-SG-1 will be installed in the water supply line to the Steam generator, and will provide input to the PLC, which will totalize the value. Utilizing a needle valve and the local indication from F-SG-1, the operator will manually set the maximum feed water rate at around twice the steam flow setting.

Steam Generator

The steam generator SG-1 will include a level signal or switch L-SG-1 which will be used by the PLC or internal controller to control the water supply to the steam generator SG-1 with a control or solenoid valve (Normally Closed) LV-SG-1. (This valve will have a manually controlled bypass loop).

The Steam generator will also include:

P-SG-1 – Steam generator pressure - This signal will be run to the PLC if possible, and used for remote indication and alarming.

T-SG-1 – Steam generator temperature - This signal will be run to the PLC if possible, and used for remote indication and alarming.

Solenoid valve HV-H-1-1 (Normally Closed) is the steam shut-off valve. This valve will be used for On/Off control of the steam to the SR-1 Steam Reformer (See the start-up and shutdown procedures). A steam vent will be required for pressure relief when the valve is closed and when the flow is restricted by the flow control valve located after Super Heater H-1.

Solenoid Valve HV-H-1-2 (Normally Open????) is the fluidizing Nitrogen shut-off valve. This valve will be used for On/Off control of the nitrogen used to fluidize the bed during start-up and shutdown. (See the start-up and shutdown procedures)

Solenoid Valves HV-ESD-1 and HV-ESD-2 (Normally Closed) are the redundant Emergency Nitrogen flush valves used to flush the system in the event of a emergency.

Super Heater H-1 is the first stage Super Heater for the steam system. The Heater will be controlled by Temperature loop T-H-1. This temperature loop will also include LAL at the HMI to indicate problems with the Super Heater.

Steam pressure P-H-1 will be taken after the first stage super heater H-1. This pressure will be indicated at the HMI and will be used by the PLC to calculate Steam Mass Flow.

An orifice plate will be used to measure flow F-H-1, and the PLC will use this reading as well as the pressure from P-H-1 and temperature from T-H-1 to calculate the mass flow rate of the steam. The operator will input a set point to the PLC for the required fluidizing flow for the Steam Reformer (This will be based on the temperature and pressure readings in the reformer as well as the Bed material. Note: this could be done automatically in the future if required). The PLC will control FV-H-1 based on the calculated mass flow and operator supplied fluidizing flow-rate set point.

Super Heater H-2 is the second stage Super Heater for the steam system. The Heater will be controlled by Temperature loop T-H-2. This temperature loop will also include LAL at the HMI to indicate problems with the Super Heater.

Additive Carbon

Additive carbon will be added to the reformer at a continuous rate between 1 and 10 lbs per hour. This will be accomplished using a Loss in Weight Feeder mounted approximately 12 feet above grade, and a storage hopper with a conveyer to refill the Loss in Weight Feeder as required. The vendor supplied controller for the Loss in weight Feeder will provide a weight to the PLC, and this will be indicated at the HMI. The operator will enter a set point for the feed rate at the HMI, and the PLC will send the vendor supplied controller the set point. The weight received from the controller will be used to determine when to turn on a conveyer (WSL) to fill the Loss in Weight Feeder. The conveyer will be turned off based on the weight signal (WSH) from the Loss in Weight Feeder or a timer.

Bed Material

Bed Material will be added to the reformer in batches. This will be accomplished using a Loss in Weight Feeder mounted approximately 12 feet above grade, and a storage hopper with a conveyer to refill the Loss in Weight Feeder as required. The vendor supplied controller for the Loss in weight Feeder will provide a weight to the PLC, and this will be indicated at the HMI. The operator will enter set points for batch size and feed rate at the HMI, and the PLC will send the vendor supplied controller the set points for Feed Rate and Batch size. The weight received from the controller will be used to determine when to turn on a conveyer (WSL) to fill the Loss in Weight Feeder. The conveyer will be turned off based on the weight signal (WSH) from the Loss in Weight Feeder or a timer.

Steam Reformer

Heaters

Temperature Loops T-SR-1 through 9 will be displayed and alarmed at the HMI, and will be used to control the bed heaters for the Reformer. An average of the temperature signals, or operator selection of one signal will be used as the input for the control.

Oxygen Feed

Oxygen mass flow controllers will be used for the control of oxygen to the Reformer. Solenoid Valve HV-SR-1-1 will provide On/Off control of the oxygen to the system. Solenoid Valve HV-SR-1-2 will provide On/Off control of the Nitrogen Clean-out for Oxygen feed. (See Start-up and shut-down procedures for sequence). FCVT-SR-1-2 will provide oxygen in the steam feed to the reformer. FCVT-SR-1-3 will provide oxygen to the lower disengaging section of the reformer vessel. FCVT SR-1-4 3 will provide oxygen to the upper disengaging section of the reformer vessel. The mass flow controllers will send the oxygen flow rate to the PLC, and it will be displayed and alarmed

at the HMI. The operator will enter flow rate set points for each of the mass flow controllers at the HMI, and the PLC will transmit the set points to the mass flow controllers.

Pressure Control

Three differential pressures from the reforming vessel will be measured and sent to the PLC. The Steam Reformer gas distributor differential pressure PD-SR-1-1, the Steam Reformer density differential pressure PD-SR-1-2, and the Steam reformer bed mass differential pressure PD-SR-1-3. The Steam reformer bottom pressure P-SR-1 will also be measured and sent to the PLC. All of these will be displayed at the HMI with some alarming. PD-SR-1-3 will also be used to control the pressure in the reforming vessel. An Air jet will be used on the off-gas system to create a negative pressure in the disengaging section of the reforming vessel. The amount of vacuum will be controlled so the differential pressure from the disengaging section above the fluidized bed solids column to the gas distributor below the fluidized bed solids column is approximately zero. To accomplish this, the operator will manually adjust the Operating Air Pressure regulator PCV-AJ-1 for Air Jet AJ-1 for the operating pressure (Set this to provide more suction and a lower pressure in the vessel than the desired value). The operator will then enter the operating set-point for control loop P-SR-1-3 at the HMI. Pressure in the reformer vessel is increased by opening the valve and decreasing the proportion of off-gas flow to the Air jet through dilution, and decreased by closing the valve thus increasing the proportion of off-gas flow through the Air Jet.

Cyclone C-1

Temperature of the off-gas line from Steam Reformer to Cyclone is T-C-1-1. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 500-750°C in the line.

Temperature of the off-gas line from the Cyclone to the Filter Vessel is T-C-1-3. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 350-500°C in the line.

Temperature inside Cyclone is T-C-1-2. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 500-750°C. in the Cyclone.

Cyclone differential pressure PD-C-1 will be displayed and alarmed at the HMI.

Level Switches LS-C-1-1 and LS-C-1-2 detect solids in the bottom section of the cyclone.

A diverter valve DV-C-1-1 is installed in the product solids line from the cyclone. This diverter will be used to select the path of the solids from the Cyclone to the Cyclone Weigh Bin and recycle, or to a sample port. If DV-C-1-1 is selected for the Cyclone Weigh bin, the following actions will occur:

A signal from LS-C-1-1 indicates the cyclone is full.

FV-C-1-1 will be opened.

A signal is received from LS-C-1-2 indicating the cyclone is empty of solids. (An alarm will sound if FV-C-1-1 opens and a signal is not received from LS-C-1-2).

FV-C-1-1 will be closed.

A weight W-C-1 will be recorded from the cyclone weigh bin. A timer will be used to determine when to take the reading after FV-C-1-1 has closed. (This will allow time for an accurate weight measurement).

FV-C-1-2 will be opened emptying contents to T-6 Bed solids Bin.

Weight W-C-1 will indicate the cyclone weigh bin is empty. (An alarm will sound if FV-C-1-2 opens and W-C-1 does not indicate cyclone weigh bin is empty).

FV-C-1-2 will be closed.

If DV-C-1-1 is selected for the Sample Port, the following actions will occur:

FV-C-1-1 will be opened.

A signal is received from LS-C-1-2 indicating the cyclone is empty of solids. (An alarm will sound if FV-C-1-1 opens and a signal is not received from LS-C-1-2).

FV-C-1-1 will be closed.

Temperature inside Cyclone Weigh Bin is T-C-1-4. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 350-500°C. in the Cyclone Weigh Bin.

Filter Vessel F-1

Temperature inside the Filter Vessel is T-F-1-1. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 350-500°C. in the Filter Vessel.

Temperature of the off-gas line from the Filter Vessel to the Scrubber is T-F-1-2. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 350-500°C in the line.

Filter Vessel differential pressure PD-F-1 will be displayed and alarmed at the HMI, and will be used by the PLC to control the nitrogen blow-back of the filters. The differential pressure across the filters will reach a value (PDSH) from particle build-up on the outside of the filters. When the signal from PD-F-1 reaches the PDSH, the PLC will send a sequenced pulse of nitrogen through each filter column to break up the particle build-up on the outside. The nitrogen pulses will be generated by briefly opening and closing solenoid valves (PV-F-1, PV-F-2) in individual lines from the pressurized nitrogen supply to each of the filter columns in a timed sequence. The sequencing will allow the remaining filter columns to continue operation as each filter is cleaned individually. The pressure of the nitrogen supply P-F-1 will be displayed and alarmed at the HMI.

Level Switches LS-F-1-1 and LS-F-1-2 detect solids in the bottom section of the Filter Vessel.

A diverter valve DV-F-1-1 is installed in the product solids line from the Filter Vessel. This diverter will be used to select the path of the solids from the Filter Vessel to the Filter Weigh Bin and recycle, or to a sample port. If DV-C-1-1 is selected for the Filter Weigh bin, the following actions will occur:

A signal from LS-F-1-1 indicates the Filter Vessel is full.

FV-F-1-1 will be opened.

A signal is received from LS-F-1-2 indicating the Filter Vessel is empty of solids. (An alarm will sound if FV-F-1-1 opens and a signal is not received from LS-F-1-2).

FV-F-1-1 will be closed.

A weight W-F-1 will be recorded from the Filter weigh bin. A timer will be used to determine when to take the reading after FV-F-1-1 has closed. (This will allow time for an accurate weight measurement).

FV-F-1-2 will be opened emptying contents to T-6 Bed solids Bin.

Weight W-F-1 will indicate the Filter weigh bin is empty. (An alarm will sound if FV-F-1-2 opens and W-F-1 does not indicate Filter weigh bin is empty).

FV-F-1-2 will be closed.

If DV-F-1-1 is selected for the Sample Port, the following actions will occur:

FV-F-1-1 will be opened.

A signal is received from LS-F-1-2 indicating the Filter Vessel is empty of solids. (An alarm will sound if FV-F-1-1 opens and a signal is not received from LS-F-1-2).

FV-F-1-1 will be closed.

Temperature inside Filter Weigh Bin is T-F-1-3. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 350-500°C. in the Filter Weigh Bin.

Product/Solids Handling

Bed Solids Bin T-6

The Bed solids bin T-6 will be used to collect the fines from the cyclone and filter vessel, as well as the material from the Product Separator S-1 that is screen sized for recycle to the reformer. The fines will be collected from a gravity feed from the cyclone and filter vessel, and the material from the Product Separator S-1 will be delivered via the Solids conveyer P-10. A level switch LS-T-6 will be displayed and alarmed at the HMI to provide an indication to the operator that the Bed solids bin T-6 is full. Temperature inside the Bed solids bin is T-T-6. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 350-500°C. in the Bed solids bin T-6. A diverter valve DV-T-6 will be installed at the outlet of the Bed solids bin. This diverter will be used to select the path of the solids from the Bed solids bin to the Steam Reformer via Bed Solids Conveyer P-6A (Normal Path), or to the Product Cooler HE-1 via Bed Solids Conveyer P-6B (Alternate Path). The Bed Solids Conveyers P-6A and P-6B will be remote controlled from the HMI (operator select on/off), and may be interlocked with the position of the diverter valve.

Product Separator S-1

The product separator will be used to separate the fine from the coarse products coming out the bottom of the Steam Reformer. A vibratory screen will be used to separate the product, and will be remote controlled from the HMI (operator select on/off). A gate valve FV-SR-1 will control the flow of product from the steam reformer to the product separator, and will be remote controlled from the HMI (operator select open/close). A diverter valve DV-S-1 will be installed at the outlet of the

product separator, and will be used to select a path for the fine particles from the separator. The Diverter valve will be remote controlled from the HMI, and will select to the Solids conveyer P-10 (Bed Solids Bin) or Solids conveyer P-11 (Product cooler). Temperature inside the product separator is T-S-1-1. This temperature will be displayed and alarmed at the HMI, and will be used by the PLC for heater control to maintain 350-500°C. in the product separator.

Off-gas

TBD

Preparation

Ensure all manual valves are in proper position per the valve lineup sheet for startup.

Feed

Feed/Mix

Mix one batch of simulant feed using the liquid feed line and/or the bottle chemical fill port located at the top of the vessel starting with water.

Turn on mixer M-1A (Local-Manual) after 80% (Local Indication) of the water has been added to the tank, add the chemicals in accordance with the simulant recipe, and then add the final 20% (Local Indication) of the water.

The mixer will be kept on until the first transfers to the feed/mix tanks are complete.

Use hand valves (Local-Manual control) on the Simulant SST Tank T-1 heat exchanger to maintain the temperature (T-T-1) below the boiling point with cooling water or to increase solubility of specific chemicals during the mixing phase by increasing solution temperature with steam.

Adjustable Temperature Alarms based on the Simulant Run.

Transfer the simulant to Feed/Mix tank T-2A or T-2B.

Line up manual valves for transfer to Feed/Mix tank T-2A or T-2B.

Turn on Transfer Pump P-1 (Local Manual)

Turn on mixer M-2A or M-2B (Local Manual).

Turn Off Transfer Pump P-1 (Local Manual) based on level in Feed/Mix tank T-2A or T-2B (Local Indication)

Ensure isolation valve to feed supply line is closed.

Turn on re-circulation pump P-2A or P-2B (Local Manual)

Mix into the simulant additional water and special additives in accordance with the parameters specified for the test.

Use hand valves (Local-Manual control) on the Feed/Mix vessel heat exchanger to maintain the temperature below the boiling point while mixing.

Adjustable Temperature Alarms based on the Simulant Run.

Mixers and re-circulation pumps to remain on for duration of the test. (LAL and LALL alarms at computer will be set to allow operator intervention to maintain level in tanks above impeller.

Scrub Solution Make Up

Mix scrub solution in Make Up Scrub Tank T-5 using the water feed line and the bottle chemical fill port located at the top of the vessel starting with water.

Add 80% of water to tank using local indication from L-T-5.

Position hand valves (Local-Manual) for re-circulation and use the Make Up Scrub Pump P-8 (Local-Manual) to mix the solution.

Add make up chemicals.

Top off water.

Steam

Ensure that the demineraizer tank, Steam Generator SG-1, Steam Superheater H-1, and final superheater are ready to operate in accordance with the manufacturers specifications.

The level switch will be used to actuate a solenoid valve in the water supply line. Based on past experience with this type of steam generator, undesirable fluctuation in steam pressure can occur if water is allowed to flow in too rapidly, so a turbine meter and needle valve will be installed in the water supply line, so that the operator may set the maximum feed water rate at around twice the steam flow setting. If the feed water flow is set below the steam flow, the steam generator will automatically shut down when the water level gets too low.

Additive Carbon

Load additive carbon into the Additive Bin T-3

Bed Material

Load bed material into the Bed Material Bin T-4

Nitrogen Purge

Fill Nitrogen Dewar with liquid nitrogen.

Steam Reformer

Heaters

Continuity checks?

Off-gas

Perform Integrity check of system (use helium or argon for a leak check)

Equipment

Make-up Scrub tank - Position hand valves (Local-Manual) for re-circulation and feed using the Make Up Scrub Pump P-5 (Local-Manual) to transfer scrub solution to the Scrub Tank T-7

Turn off Make Up Scrub Pump P-5 (Local-Manual) based on Local Level Indication from (L-T-7)

Granular Activated Carbon Bed

If the Activated Carbon Bed GAC-1 is used ensure that there is sufficient capacity for the run. If not empty and refill the bed with fresh activated carbon.

Analyzer

Perform analyzer maintenance and readiness check on the Mercury, Oxygen and Hydrogen analyzers.

Product/Solids Handling

Ensure that the product/solids handling equipment is free from plugs and ready to operate.

Start-up

1. Turn on nitrogen system and adjust rotameters to appropriate flows for feeds and purges.
2. Turn on system heaters (crossed hatched sections on P&ID).
3. Adjust Operating Air Pressure regulator PCV-AJ-1 for Air Jet AJ-1 for startup flow and enter the startup set-point for control loop P-SR-1.
4. Turn on cooling water to off-gas system condenser (Manual Control).
5. Turn on chiller and chiller water flow (Manual Control).
6. Turn on off-gas system equipment
Scrub Venturi Pump P-7 on.
Enter Start-up set-point for control loop F-P-7
7. Enable Sintered Metal Filter pulsed nitrogen blow-back.
8. Turn on off-gas system analyzers.
AE-O-1, AE-H-1, Mercury Monitoring System, and CEM
9. Adjust Operating Air Pressure regulator PCV-AJ-1 for Air Jet AJ-1 for operating pressure, and enter the operating set-point for control loop P-SR-1.
10. Turn on solids handling system.

DV-S-1 selected to Bed Solids Bin
DV-T-6 selected to Steam reformer
Product Separator S-1 on
Solids conveyer P-10 on
Solids conveyer P-6A on
11. After Steam Reformer Vessel reaches temperature of 125 degrees C, charge the vessel with Bed Material.
Batch Mode
The operator will enable the feeder in a batch mode by entering a feed-rate set-point and a time to deliver the desired volume as required by the process.
12. Turn on Fluidizing N2.
ZZ-H-1-1 Closed
ZZ-H-1-2 Open
Enter N2 Start-up set-point for control loop F-H-1.

13. Super-heaters H-1 and H-2 on.
Enter N2 Start-up set-point for control loops T-H-1 and T-H-2.
14. Turn on steam generator and support systems.

Start the steam generator with the desired operating parameters, and use needle valve and turbine meter installed in the water supply line to set the maximum feed water rate at around twice the steam flow setting. (At this point all steam generated will be vented)
15. After systems reach 150 degrees C and steam is at desired temperature and pressure, turn on steam (minimum fluidizing velocity) and turn off N2.
ZZ-H-1-1 Open
ZZ-H-1-2 Closed
Enter Steam Start-up set-point for control loop F-H-1.
16. Turn on reductant feed at 650 degrees C in the fluidized bed.
Loss in Weight Feeder on
Enter set point for feed-rate
17. Turn on the O2 feed (Start-up mode)
Start-up mode
Assumptions - FCVT-SR-1-2 Closed
 FCVT-SR-1-3 Closed
 FCVT-SR-1-4 Closed
 ZZ-SR-1-6 Closed
 ZZ-SR-1-5 Closed
All lines between ZZ-SR-1-5, ZZ-SR-1-6, FCVT-SR-1-2, FCVT-SR-1-3,
FCVT-SR-1-3 are purged.
N2 is flowing through check valves
Step 1 ZZ-SR-1-6 Open
Step 2 Enter Start-up Set-points to FCVT-SR-1-2, FCVT-SR-1-3, FCVT-SR-1-4.
18. Stabilize.
19. Select Feed/Mix tank T-2A or T-2B by lining up the manual valves for the supply and return lines.
20. Start feed/mix to the Fluidized Bed Steam Reformer SR-1 with feed pump P-4 on using HIC-P-4 to turn it on and adjust speed.
21. Switch to normal operations mode

Abnormal Operations

Feed

Feed/Mix

TBD

Steam

TBD

Additive Carbon

TBD

Bed Material
TBD

Steam Reformer

Heaters
TBD
Oxygen Feed
TBD
Pressure Control
TBD

Off-gas

Equipment
TBD
Mercury Analyzer
TBD
Oxygen Analyzer
TBD
Hydrogen Analyzer
TBD

Product/Solids Handling

TBD

Normal Shutdown

1. Stop feed/mix to the Fluidized Bed Steam Reformer SR-1.
2. Stop feed/mix recirculation pump.
3. Allow time for carbon additives to completely react.
4. Stop oxygen to the Fluidized Bed Steam Reformer SR-1.
5. Turn on nitrogen flush through oxygen lines to the Steam Reformer SR-1.
6. Turn off steam to Fluidized Bed Steam Reformer SR-1.
7. Turn on nitrogen purge through the bottom of the Steam Reformer SR-1.
8. Allow bed materials to cool down.
9. Remove bed materials from Fluidized Bed Steam Reformer SR-1.
10. Shut down solids handling system.
11. Turn off heat to heated vessels.
12. Turn off cooling water to off-gas system condensers and chillers.
13. Turn off off-gas system analyzers.
14. Turn off off-gas system equipment - Scrub Venturi Pump P-11.
15. Turn off off-gas system Air Jet AJ-1 and set pressure control for the Steam Reformer SR-1.
16. Turn off nitrogen purges.

Emergency Shutdown

1. Stop feed/mix to the Fluidized Bed Steam Reformer SR-1.
2. Stop feed/mix recirculation pump.
3. ~~Allow time for carbon additives to completely react.~~
4. Stop oxygen to the Fluidized Bed Steam Reformer SR-1.
5. Turn on nitrogen flush through oxygen lines to the Steam Reformer SR-1. **Note: nitrogen purge through the bottom of the Steam Reformer SR-1 must be on.**
6. **Turn off steam to Fluidized Bed Steam Reformer SR-1. (Need to ask Syl about this since steam can act as an additional diluent or a quench and may be desired for certain emergency situations.)**
7. ~~Allow bed materials to cool down.~~
8. ~~Remove bed materials from Fluidized Bed Steam Reformer SR-1.~~
9. **Shut down solids handling system.**
10. ~~Turn off heat to heated vessels.~~
11. ~~Turn off cooling water to off gas system condensers and chillers.~~
12. ~~Turn off off gas system analyzers.~~
13. ~~Turn off off gas system equipment — Scrub Venturi Pump P-11.~~
14. ~~Turn off off gas system Air Jet AJ-1 and set pressure control for the Steam Reformer SR-1.~~
15. ~~Turn off nitrogen purges.~~

Note: I used strikethrough for those steps of the normal shutdown sequence that I felt were not needed for an emergency situation. These are up for discussion.

