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PROGRESS REPORT ON THE MODEL SODIUM HEATED STEAM GENERATOR

AEC CONTRACT AT(11-1)-1280

RESEARCH REPORT NO. 5452

BY D. W. KOCH

MARCH 6, 1964

MASTER

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PROGRESS REPORT ON THE
MODEL SODIUM HEATED STEAM GENERATOR
by D. W. Koch

ABSTRACT

PURPOSE

A model sodium-heated steam generator has been designed to investigate the effects of carbon transfer on a system containing both ferritic and austenitic alloys. The model steam generator simulates the 1000 Mwe sodium-heated steam generator being developed by the Company under AEC Contract AT(11-1)-1280. This test program was developed to provide confidence in the selection of materials of construction for the 1000 Mwe unit.

PROJECT STATUS

The test apparatus has been designed and is described in detail. All loop components have been fabricated and the loop systems completed. Electrical connections and insulation of the loop piping remains to be finished. A summary of the expected test operation and examinations is presented.

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INTRODUCTION

A 1000 Mwe sodium-heated steam generator design is being developed by the Company under AEC Contract AT(11-1)-1280. The unit is a once-through type generator with the boiler bank consisting of Croloy 2-1/4 tubes and the superheater section of Type 316 stainless alloy. In liquid metal systems containing both ferritic and austenitic alloys, the decarburization-carburization problem is well known, but the parameters affecting this phenomenon are not clearly defined. In the absence of such fundamental data, this test program was developed to provide confidence in the selection of these alloys for the steam generator.

A model sodium-heated steam generator has been designed to simulate the 1000 Mwe steam generator and will be operated for 8000 hours to investigate the effects of decarburization and carburization as a function of time. This report presents the progress made in the design of the model unit.

DESCRIPTION OF APPARATUS

The test apparatus is illustrated schematically in Figure 1. The model steam generator consists of a separate boiler and superheater. The former is fabricated of Croloy 2-1/4 and the latter of Type 316 stainless steel. The sodium system consists of an electromagnetic pump, sodium heater, electromagnetic flowmeters, sodium preheater, sump, expansion tank, hot trap, cold trap and plugging indicator. The water side system includes a controlled volume pump, reservoir, subcooler, economizer, feedwater heater, boiler, super-

heater, condenser-cooler, cooler, and back pressure control valve. The sodium system and water side components shown in Figure 2 will now be discussed in detail.

Sodium System

1. Pump

The sodium pump is a Mine Safety Appliances Corporation Style VI AC electromagnetic pump with two Type 316 flow cells. This pump is capable of continuous operation at 1400 F and will develop a head of 30 psi at a flow of 25 gpm. A 375 watt, 115 volt heater unit, capable of raising the flow cell sections to 300 F in two hours, is built into the pump unit. A chromel-alumel sheath thermocouple is inserted along the outside of the pump piping to provide over-heating protection for the unit.

The sodium flow in the loop is controlled from the panel board by adjustment of a powerstat which is provided with a fixed stop to limit the output to 28 amps at 330 volts. A capacitor is connected across the pump electrical leads for power factor correction. Power to the pumps is interlocked with a low flow limit to protect the pump in the event that flow should cease while power is being supplied to the pump.

2. Heater

The sodium heater consists of 1-1/4-inch Sch 40 Type 316 pipe with three Type 304 lugs for electrical connections. The heater piping is connected with 1-1/4-inch Sch 40 tees in order that twelve 0.031-inch dia. Type 316 specimen wires could be installed in the

heater section. The over-all developed length of the heater is 16 feet, and the lugs are connected to a 140 KVA transformer and saturable reactor combination. The outer lugs are grounded with the center lug being electrically "hot". In this manner, the current is prevented from short circuiting through other loop components, and all current flows between the "hot" center lug and the outer grounded lugs. Solid copper bus bars, 1/2-inch thick x 12 inches wide, are used to connect the heater to the transformer. The power input to the heater is controlled by a proportional band temperature controller which adjusts the DC power to the saturable reactor which in turn governs the output of the transformer to the heater. The temperature rise of the sodium in the heater is 321 degrees, i.e., from 819 F to 1140 F. Over-temperature and low-flow limits are provided to prevent overheating of the heater piping.

3. Flowmeters

Flow is measured with two electromagnetic flowmeters in the system. The main loop flow is measured in the 1-1/4-inch Sch 40 pipe approximately 5 ft from the outlet of the pump. This is accomplished with a single 2700 gauss permanent magnet. Voltage tap leads are fused to the pipe 180 degrees apart and are connected to a millivoltmeter on the panel board. A second flowmeter is utilized to measure flow in the hot trap, cold trap and plugging indicator bypass system. A 7000 gauss magnet is used for this purpose.

4. Sodium Preheater

In order to minimize the electrical input required, a regenerative type heat exchanger, the preheater, is included in the sodium

system. The steam from the superheater outlet is cooled in the preheater from 1050 F to 680 F, thereby increasing the sodium temperature from 650 F to 820 F. The preheater consists of a 1/2-inch OD x 0.075-inch wall x 41-1/2 ft long Type 316 tube centered within a 1-1/4-inch Sch 40 x 40 ft long Type 316 pipe by spacers welded to the tube. The addition of the preheater to the test loop results in reducing the required electrical input by 50 KW.

5. Sump

The sump is rolled from 1/4-inch thick Type 316 plate into a cylindrical shape and seam welded. Each head is 1-inch thick Type 316 plate and welded in place. The resulting vessel has an OD of 2 ft and an over-all height of 3 ft. Inlet and outlet pipes are welded into opposite walls of the vessel and extend to within 3 inches from the bottom head internally in order that sodium may be circulated through the sump. For initial operation, eight 750 watt, 220 volt strip heaters are arranged on the periphery of the sump. In addition, a 1000 watt, 115 volt ring heater is attached to the bottom head and may be controlled manually by means of a Variac. A 1/2-inch drain valve is located in the wall of the vessel slightly above the bottom head.

On the top head are located a pressure gage, vent valve and a pressure relief device as well as a Conax electrode gland through which insertion or withdrawal of a probe makes the determination of the sodium level possible. A sampling device is also attached to the top head of the sump, consisting of an 8-inch long 1-1/4-inch

Sch 40 pipe nipple on which a 1-1/4-inch ball type shut-off valve is threaded and seal welded. A 1/4-inch tube cooling coil is wound tightly around the pipe below the ball valve to protect the valve seals from excessive deterioration at high temperature. Threaded into the top of the ball valve is a special fitting into which are threaded two 1/2-inch globe valves, one for admitting inert gas and the other for venting. Above the ball valve is a quick-disconnecting coupling for attaching the sample bomb to the sump. The sample bomb is a specially drilled 1-1/4-inch pipe nipple with a ball valve on each end. This bomb provides an inert gas filled chamber for transporting the sample to the chemical laboratory. On the top of the sample bomb is a threaded 1-1/4-inch pipe nipple and cap into which is threaded an adjustable packing gland. Through this gland, a 5'-9" long, 3/8-inch dia. rod extends and supports a sample boat which can be lowered through this series of valved chambers into the sump to collect a sodium sample. The sample boat is made of Type 316 stainless steel and will hold a sample of approximately 10 grams.

6. Expansion Tank

The expansion tank is located at the highest point of the sodium system and downstream from the heater. The vessel has sufficient capacity to accommodate expansion of the sodium from the melting point to 1200 F plus a space for an inert gas cover. The tank is fabricated from a 6-inch Sch 40 x 3-1/2 ft long Type 316 pipe, with a 1/2-inch thick Type 316 head welded into each end. Sodium enters on one side of the vessel at the bottom and leaves on the opposite side.

The tank is supplied with a probe for level detection identical to that for the sump. In addition, a pressure gage, vent valve, and pressure relief device are located on the top of the vessel. Four 500 watt, 240 volt strip heaters are attached at 90 degree intervals around the circumference of the tank in order to preheat the vessel prior to filling the system with sodium.

7. Hot Trap, Cold Trap & Plugging Indicator

A bypass system is connected across the EM pump for reducing and measuring the oxygen content of the sodium in the loop. Flow in this system is provided by the pressure differential across the pump. The system consists of a cold trap and a hot trap for control of oxide formation and a plugging indicator for determining the oxide content of the sodium.

As the sodium temperature is lowered in the cold trap, the solubility of sodium oxide is decreased, thereby causing the oxides to be precipitated, collected and retained on a Type 316 wire mesh inside the cold trap. It is possible to reduce and maintain an oxygen level at 30 ppm in sodium by this method. The cold trap is made from a 6 inch Sch 80 x 19 inch long Type 316 pipe. The ends are enclosed with 1/2-inch thick Type 316 plate. A flow distribution baffle is located 1-1/4 inches from the bottom of the vessel with the remaining space above the baffle filled with Type 316 wire mesh screen. The screen is 0.011-inch diameter wire woven into a blanket 16 inches wide x 1-inch thick. The blanket is rolled into a tight cylinder and packed into the vessel to serve as a filter for the oxides. The vessel is cooled externally by water flowing through

25 ft of oval-shaped stainless tubing wound around the outer surface of the trap. The water flow is regulated manually to control the cold trap temperature. The cold trap may be isolated from the system by means of two 1/2-inch bellows sealed globe valves. A thermocouple well is provided in the top head to determine the temperature of the sodium being discharged from the trap. For initial heating prior to filling with sodium, the cold trap is provided with a flexible heating unit rated at 1490 watts, 240 volts.

The hot trap supplements the function of the cold trap by making it possible to reduce the oxygen content to 10 ppm or lower. This is accomplished by heating the sodium to 1450 F while being circulated over a large surface of zirconium. The hot trap is constructed the same as the cold trap, except that the inside of the vessel is filled with zirconium foil and wire instead of stainless steel mesh screen, and heater elements are mounted on the vessel externally rather than water cooling coils. The zirconium foil, 9 inches wide x 0.004-inch thick, was crimped and then rolled to form a spirally wound cylinder to fit inside the hot trap vessel. The crimped offsets in the foil provide a 1/16-inch spacing for flow channels between adjacent layers of foil. Four quarter-circular heating units are installed on the periphery of the vessel. Each unit is rated at 2300 watts, 220 volts and are automatically controlled by an on-off temperature controller.

The plugging indicator is utilized to measure the oxygen content of the sodium flowing in the loop. This is accomplished by reducing the temperature of the sodium flowing through the plugging

indicator and noting the temperature at which the flow rate sharply decreases. The plugging indicator consists of a cooling system, plugging disc, temperature measuring device, and a flowmeter. The plugging indicator is constructed from a 2-inch Sch 40 x 3 ft long Type 316 pipe around which an oval-shaped water cooling coil is wrapped. In the downstream end of the pipe, a 1/4-inch thick Type 316 plugging disc is located through which thirteen 0.040-inch dia. holes are drilled. On the downstream side of the disc is a thermocouple well for measuring the temperature of the flowing sodium. A 7000 gauss electromagnetic flowmeter is utilized to measure the sodium flow.

Water System

1. Pump

Waterside circulation is provided by a controlled volume, positive displacement duplex pump manufactured by the Milton-Roy Company. The pump has a maximum capacity of 115 gph @ 2700 psig. The capacity is adjustable by changing the plunger stroke length from 0-100 per cent of full stroke. The liquid ends are Type 316 stainless steel and the plungers are Hastelloy D. Water is pumped from the reservoir at 20 psig through a cooler and discharged at 2450 psig with a rate of 514 lb/hr or approximately 62 gph.

2. Reservoir

The reservoir is rolled from 1/8-inch thick Type 304 stainless sheet into a cylindrical shape and seam welded. The resulting vessel has an ID of 12 inches and a height of 4 feet. Each head is 1/2-inch

thick and welded in place. The vessel is provided with a safety relief valve, vent pressure gage, inlet and outlet connections, fill line, and a 3 KW immersion heater to maintain the water at saturation temperature for 20 psig. In addition, stainless steel water level probes are installed in the top head to provide for automatic filling from the demineralized, deaerated water supply.

3. Subcooler

A subcooler is located between the reservoir and the suction side of the pump to eliminate the possibility of water flashing to steam in the pump. The subcooler consists of a Type 304 1/2-inch OD x 0.040-inch wall x 35 ft long tube inside of a 3/4-inch OD x 0.035-inch wall soft copper tube. The tubes form a helix having a diameter of 12 inches and length of 32 inches. Primary water passes through the stainless tube and secondary cooling water is circulated through the annulus formed by the two tubes.

4. Economizer

Water is discharged from the pump through the tube side of the economizer, a regenerative-type heat exchanger. The economizer consists of a 1/2-inch OD x 0.075-inch wall x 28 ft long Type 316 tube inside of a 3/4-inch Sch 80 Type 316 pipe. This unit is designed to raise the temperature of the water from 100 F to 480 F. Water is returned to the shell side of the economizer from the condenser-cooler and is cooled from 600 F to 300 F.

5. Feedwater Heater

Water is circulated from the tube inside of the economizer to the feedwater heater where the temperature of the water is raised from

480 F to 530 F before entering the boiler. The feedwater heater consists of a 440V, 10 KW immersion heater welded into one end of a 3-inch Sch 80 x 4 ft long Type 304 pipe. A pipe cap is welded on the opposite end of the pipe, and the unit is mounted vertically with water entering at the bottom and exiting at the top.

6. Boiler

The boiler is designed to simulate the boiler section of the 1000 Mwe unit. The following parameters have been duplicated as closely as possible: 1) tube wall outside surface temperature, 2) thermal gradient across the wall thickness, 3) sodium inlet and outlet temperature, and 4) water-steam inlet and outlet temperature. A comparison of the temperature distribution for the model boiler and the 1000 Mwe boiling section is shown in Figure 3.

The model boiler is a single tube, once-through, sodium-heated unit and is constructed entirely from a ferritic alloy, Croloy 2-1/4. The boiler consists of a 1/2-inch OD x 0.075-inch wall x 37 ft-4-inch long tube inside of a 1-1/4-inch Sch 40 pipe. Spacers are welded to the tube at 5 ft intervals to center the tube within the pipe and provide a uniform annular area. The water is heated in the tube from 530 F at 2450 psig to steam at 750 F. The sodium temperature differential across the unit is 370 F, entering the annular area at 1015 F and leaving at 645 F.

7. Superheater

The model superheater is designed to simulate the superheating section of the 1000 Mwe steam generating unit. A comparison of the

temperature distribution in the model and the large unit is shown in Figure 3. The superheater is a single-tube, once-through, sodium-heated unit, and is constructed entirely of Type 316 stainless steel. As in the model boiler, the tube metal temperature, thermal gradient and fluid temperatures have been duplicated as nearly as possible in order to closely simulate the actual conditions of the 1000 Mwe generator.

The model superheater is constructed with a 1/2-inch OD x 0.075-inch x 14 ft long tube centered in a 1-1/4-inch Sch 40 pipe by spacers at 120 degree intervals around the circumference of the tube and at intervals of 3 ft-6 inches along the length of the tube. The steam is heated in the tube from 750 to 1050 F in the superheater and the sodium in the annular area is cooled from 1140 F to 1015 F.

8. Condenser-Cooler

Steam is discharged from the sodium preheater at 680 F to the condenser-cooler where it is condensed and subcooled to 600 F. The condenser-cooler is a boiling water type heat exchanger, where water is boiled and evaporated on the shell side, thereby condensing and cooling the steam on the tube side of the exchanger. The condenser-cooler consists of a 1/2-inch OD x 0.075-inch wall x 28 ft long Type 316 tube that is wound into a helical coil with a diameter of 4-1/2 inches and an over-all length of 4 ft. The outer shell is a 6 inch Sch 40 carbon steel pipe that is supplied with Zeolite-treated water that, when evaporated, is vented to the atmosphere. The primary outlet temperature is controlled by the water level maintained on the shell side.

9. Cooler

Water from the shell side of the economizer is circulated to the cooler where the temperature is reduced from 300 F to approximately 210 F before passing through the back pressure control valve. The cooler, a double-pipe heat exchanger, consists of a 1/2-inch OD x 0.075-inch wall x 28 ft long Type 316 tube located inside of a 3/4-inch Sch 40 carbon steel pipe. The outlet temperature is regulated by a flow control valve in the secondary cooling water line.

10. Back Pressure Control Valve

A Fisher Type 530 Micro-Flo control valve is utilized to maintain the superheater outlet pressure at 2400 psig and to drop the pressure to 20 psig before the water is passed to the reservoir for recirculation. This valve is pneumatically operated and is designed for accurate control at low flows.

TEST PROGRAM

The test conditions for the model steam generator are as follows:

Sodium System

Superheater Inlet Temperature	- 1140 F
Boiler Outlet Temperature	- 644 F
Mass Flow	- 3280 lb/hr
O ₂ Content	- <30 ppm

Water System

Boiler Inlet Temperature	- 530 F
Superheater Outlet Temperature	- 1050 F

Superheater Outlet Pressure	- 2400 psig
Mass Flow	- 514 lb/hr
pH (adjusted with hydrazine)	- 8.5 - 9.2
O ₂ Content	- 0.005 ppm
Copper Content	- 0.002 ppm
Chloride Content (as Cl ⁻)	- 0.01 ppm
Iron Content	- 0.01 ppm
Silica Content	- 0.02 ppm
Total Dissolved Solids	- 0.05 ppm
Suspended Solids	- 0.01 ppm

To investigate the effects of decarburization and carburization as a function of time, short sections of loop piping of each alloy will be removed after 1000, 2000, 4000, and 8000 hours exposure to sodium. A complete metallographic examination, as well as microprobe analyses, will be performed on the removed sections of piping. Three 0.031-inch dia. Type 316 wires from the sodium heater will be removed at each inspection period and examined for evidence of carburization.

At the conclusion of 8000 hours of operation, the model boiler and superheater components will be destructively examined to determine the extent of carburization and decarburization of Type 316 material and Croloy 2-1/4 material, respectively, at several temperature levels. Chemical analysis of waterside deposits and microscopic examination of the components exposed to the water-steam environment will be made, with particular emphasis on the boiling or transition zone phenomena.

PRESENT STATUS

All loop components have been fabricated and the loop systems have been completed. Leak testing of the sodium system and pressure checking of the water system has been finished. Electrical connections have been made to the sodium heater and installation of contactors and switches has begun. Installation of thermocouples and auxiliary heaters is approximately 85 per cent complete and insulation of loop piping has begun.

The design, fabrication and erection of the test facility is being monitored on a Critical Path Schedule. The test operation is scheduled to begin April 1, 1964.

Submitted by *Dale W. Koch*
D. W. Koch

Approved by *T. M. Campbell Jr.*
T. M. Campbell, Jr.

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SCHEMATIC OF MODEL SODIUM-HEATED STEAM GENERATOR

ARRANGEMENT OF SODIUM HEATED MODEL STEAM GENERATOR

COMPARISON OF TEMPERATURE DISTRIBUTION
FOR MODEL & FULL SIZE GENERATOR