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SUBJECT: Plugging of the High Pressure Heat Exchanger
in the Slurry Blanket Mock-up

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Summary

This report describes the two occasions in which the high pressure heat exchanger loop plugged during the initial slurry run of the slurry blanket mock-up. The run extended from July 21 to July 27, and the plugging occurred on July 22 and July 26.

Operating conditions during the run were a slurry concentration of 500 g Th/kg H_2O , a system pressure of 1800 psig, a slurry temperature of 200°C prior to the first plugging incident, and a slurry temperature of 300°C prior to the second plugging incident. These conditions are consistent with those proposed for the homogeneous reactor test.

The initial concentration of 500 g Th/kg H_2O was maintained in the main loop during the run. This slurry was prepared from thorium oxide which was fired at 800°C and was contained in batch numbers LO-12 and LO-13. No additives were charged before or during the run to the slurry, which initially contained 8 ppm of iron, less than 5 ppm chromium, less than 5 ppm nickel, and less than 100 ppm sulfate. The pH of this slurry was 9.2. The concentration of the material which was discharged from the heat exchanger loop after the first plugging incident was 1650 g Th/kg H_2O .

An analysis of data obtained during an early period of the run indicates that the slurry was in laminar flow in the heat exchanger tubes and connecting lines and that plugging must have occurred in the 1/2-inch connecting lines in the heat exchanger loop. It is not clear whether or not the heat exchanger tubes plugged at the same time that the connecting lines plugged.

Because of the limited data available, the nature of this plugging in the 1/2-inch connecting lines cannot be explained satisfactorily.

Description of the System

A schematic diagram of the high pressure system including the heat exchanger is shown in Fig. 1. The heat exchanger loop by-passes the main flow element. Thus, the head loss in the heat exchanger loop is the same as that across the main flow nozzle. The heat exchanger loop consists of a tube bundle which is

Figure 1

SCHMATIC DIAGRAM OF HIGH PRESSURE
LOOP AND HEAT EXCHANGER LOOP

Fig. 1

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connected to the main loop through 1/2-inch lines. The tube bundle has three 3/8-inch U-tubes (0.245 I.D.) about 20 feet long in parallel. Flow in the heat exchanger loop can be varied by a control valve in the 1/2-inch line and pressure taps for measuring the pressure drop across the tube bundle are located in the 1/2-inch lines close to the tube header box. Thermocouples for measuring slurry temperatures at the inlet and outlet of the tube bundle are similarly located. A venturi located in one of the 1/2-inch lines measures heat exchanger flow, and a sample point is provided near the outlet of the heat exchanger loop. Water covers the tube bundle in the heat exchanger shell, and above the water level in the same shell a condenser loop is located to remove heat.

Operating Conditions

The operating conditions during this slurry run were a slurry concentration of 500 g Th/kg water, a system pressure of 1800 psig including 200 psi of oxygen, loop temperatures of 200°C and 300°C, and a slurry velocity through the heat exchanger tubes of about 6 ft/sec (calculated from the pressure drop across the venturi flow meter in the 1/2-inch lines). These conditions are comparable to those proposed for the homogeneous reactor test.

Preliminary Operating Period

During a preliminary two hour period on July 21 heat exchanger flow measurements were made which could not be obtained after this period because of instrument failure. The loop was filled with about 90 liters of slurry which was made with thorium oxide fired at 800°C and contained in batch numbers LO-12 and LO-13 and which had a concentration of 500 g Th/kg water. No additives were charged before or during the run to the slurry, which initially contained 8 ppm of iron, less than 5 ppm chromium, less than 5 ppm nickel, and less than 100 ppm sulfate. The pH of this slurry was 9.2. The run was started on the morning of July 21 with a system pressure of 965 psig. Fig. 2 shows that after 1-1/4 hours of operation the velocity in the heat exchanger tubes was 5.7 ft/sec. This velocity decreased in the next half hour to 5.3 ft/sec. In the same half hour, the velocity in the 1/2-inch lines between exchanger tubes and main loop decreased

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from 3.5 to 3.2 ft/sec, the loop temperature increased from 165 to 205°C, and the head across the exchanger increased from 9.5 to 10.9 ft. of fluid. This increase in head caused the wall shear stress in the heat exchanger tubes to increase from 0.20 to about 0.22 lbs force/sq ft. After 1-3/4 hours of operation, the velocity in the heat exchanger tubes was increased from 5.3 to 6.5 ft/sec and in the 1/2-inch lines from 3.2 to 3.9 ft/sec by opening the control valve in the heat exchanger loop. As a result, the head across the exchanger increased to 15.6 ft of fluid and the wall shear stress in the heat exchanger tubes increased to about 0.31 lbs force/sq ft. In the next 1/4 hour, the velocity decreased in the tubes from 6.5 to 6.2 ft/sec and in the 1/2-inch lines from 3.9 to 3.7 ft/sec. In this 1/4 hour interval the loop temperature increased from 205°C to 224°C. After two hours of operating time, the run was stopped to repair a leaky valve.

First Plugging Incident

The run was resumed on the morning of July 22. The heat exchanger flow recorder went immediately off scale and remained in that condition throughout the run. Cooling water to the condenser loop was off, and the inlet and outlet temperatures of the heat exchanger followed the loop temperature closely for two hours and then fell away from the loop temperature, as shown in Fig. 3. The head across the heat exchanger decreased rapidly at first, slowly near the end of the two hour period, and rapidly again after this period. The wall shear stress in the heat exchanger tubes was initially at 0.34 lbs force/sq ft and dropped to 0.20 lbs force/ft² in two hours. Evidently the exchanger loop plugged in about 2 hours. When the exchanger plugged, the loop temperature was 210°C and the system pressure was 1860 psi. Slurry samples withdrawn from the main loop on July 25 and 26 were found to have the same concentration (500 g Th/kg H₂O) as the slurry originally charged to the loop.

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FIGURE 3. FIRST PLUGGING INCIDENT ON JULY 22, 1956

Fig. 3

The heat exchanger loop was unplugged on the afternoon of July 26 by freezing the exit end of this loop and using system pressure to displace material out of the sample point on this loop. Approximately two liters of very dense, pasty slurry were accumulated in unplugging. This material was about the consistency of calking compound and had a concentration of 1650 g Th/kg H₂O. The volume of this material was about equal to the volume of the entire heat exchanger loop, including the 1/2-inch connecting lines.

Second Plugging Incident

After the heat exchanger loop was unplugged on the afternoon of July 26, the run was resumed with the same slurry concentration of 500 g Th/kg H₂O in the loop. The heat exchanger loop plugged again in 3-1/2 hours. During this time, the circulating pump was stopped for 10 minutes to add water to the purge water condensate tank and for 15 minutes to vent the back of the pump. Fig. 4 shows that the inlet and outlet temperatures of the exchanger closely followed the loop temperature for 3-1/2 hours and then fell away from the loop temperature. Note that the head across the heat exchanger decreased more rapidly than the decreasing head noted in the first plugging incident. When the exchanger loop plugged, the main loop temperature was 310°C, the system pressure was 1800 psi and the wall shear stress in the heat exchanger tubes was 0.21 lbs force/sq ft.

Discussion

An analysis of the data obtained in the preliminary period indicates that flow in the heat exchanger tubes was laminar. This analysis is presented in Fig. 5 as a pseudo friction factor-Reynolds number plot of $\Delta H/V^2$ versus V , where ΔH is the head loss across the heat exchanger tubes, feet of fluid, and V is the velocity in the tubes, ft/sec. Two sets of data are shown. The lower values of $\Delta H/V^2$ are for a water run and the higher values are for the

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FIGURE 5 COMPARISON OF WATER AND SLURRY DATA
ON PSEUDO FRICTION FACTOR-REYNOLDS NUMBER PLOT

slurry run. The data for water follow a curve having the same slope as the curve on a conventional friction factor-Reynolds number plot for turbulent flow in smooth pipe. Since the slurry data are considerably above the water data, the slurry was probably in laminar flow in the tubes. This phenomenon can be seen on a Hedstrom plot.*

Since a constant head was observed across the main flow nozzle during each plugging incident, the observed decreasing head across the exchanger tubes could only be caused by plugging in either or both of the 1/2-inch connecting lines. It is not clear from the data whether plugging occurred in the heat exchanger tubes at the same time as in the 1/2-inch lines or just afterward; however plugging did occur in the heat exchanger tubes, because the volume of slurry plug removed from the heat exchanger loop was about equal to the entire volume of this loop. Because of the limited data available, the nature of this plugging in the 1/2-inch lines or in the heat exchanger tubes has not been fully explained.

The curves in Fig. 2, 3, 4 and 5 are based on the data in Tables I, II, III and IV.

*Hedstrom, B.O.A., Ind. and Eng. Chem., 44, 651-656 (1952)

TABLE I

HIGH PRESSURE HEAT EXCHANGER DATA OF JULY 21

<u>Time, Hours</u>	<u>Loop Temp., °C</u>	<u>Slurry Head Across Heat Exchanger, ft.</u>	<u>Wall Shear Stress in Heat Exchanger Tubes, lbs. f./ft.²</u>	<u>Velocity in Heat Exchange Tubes, ft./sec.</u>	<u>Velocity in 1/2- inch lines, ft./sec.</u>
0445	165	9.54	0.20	5.75	3.45
0515	205	10.90	0.22	5.30	3.18
0515	205	15.60	0.31	6.49	3.90
0530	224	--	--	6.19	3.71

TABLE II

HIGH PRESSURE HEAT EXCHANGER DATA OF JULY 22

<u>Time, Hours</u>	<u>Loop Temp., °C</u>	<u>Heat Exch. Inlet Temp., °C</u>	<u>Heat Exch. Outlet Temp., °C</u>	<u>Slurry Head Across Heat Exch., ft.</u>	<u>Wall Shear Stress in Exchanger Tubes lb. f./sq.ft.</u>
0655	110	110	109.2	15.2	0.34
0725	162	158.3	156.2	12.85	0.27
0755	185	179	176	10.75	0.22
0830	200	--	--	10.38	0.21
0900	210	199.9	192	10.00	0.20
0930	218	--	--	6.50	0.15
1000	226	--	--	3.03	0.07
1057	218	138.5	116	--	--
1110	216	--	--	0	0
1240	205	83.7	80	0	0

TABLE III
HIGH PRESSURE HEAT EXCHANGER DATA OF JULY 26

Time, Hours	Loop Temp., °C	Heat Exch. Inlet Temp., °C	Heat Exch. Outlet Temp., °C	Slurry Head Across Heat Exch., ft.	Wall Stress Stress in Exchanger Tubes, lbs force/sq.ft.
1319	221	219	217	offscale	---
1445	266	---	---	24.7	0.43
1501	272	268	266.5	22.0	0.40
1520	280	274	272	19.8	0.35
1630	312	299	292	12.5	0.21
1709	309	241	232	0	0
1730	306	221.2	214.9	0	0
1814	301	168.2	164.9	0	0

TABLE IV
COMPARISON OF SLURRY AND WATER DATA

SLURRY RUN			WATER RUN NO. 4		
ΔH , ft. of fluid	V, fluid vel. in tubes, ft./sec.	$\frac{\Delta H}{V^2}$	ΔH , ft. of fluid	V, fluid vel. in tubes, ft./sec.	$\frac{\Delta H}{V^2}$
9.54	5.75	0.289	2.86	6.96	0.059
10.90	5.30	0.388	6.51	10.76	0.056
15.60	6.49	0.370	0.97	3.62	0.074
			1.89	5.54	0.062
			5.21	9.91	0.053
			5.74	9.96	0.058

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