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SUBJECT: Solids Accumulation and Fission Heating in the
HRT Chemical Plant Underflow Pot (Co-op Report,
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1.0 ABSTRACT

The purpose of this study was to develop equations for calculating fission product heating in the HRT-CP underflow pot from measured temperatures and to attempt to correlate the rate of solids accumulation in the underflow pot with fission heating and reactor power. Using fission heating data calculated from the heat balances developed, several semi-empirical equations relating solids accumulation and heating have been tested. In one case an error of no greater than 26% was incurred in the calculation of the total weight of solids collected during chemical plant runs 17-4, 17-5, and 17-6. Further development work will be done on this correlation.

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2.0 INTRODUCTION

The HRT Chemical Plant was designed for continuous removal of solids fission and corrosion products from the reactor fuel solution. A 0.56-in. hydroclone was employed as the solids removal unit in the system.

Fig. 1 is a schematic flow diagram of the processing plant. A 1.4-gpm bypass stream of fuel solution is taken from the core of the reactor and circulated through the high-pressure system which consists of a heater to make up heat losses, a screen to remove the larger solid particles which may plug the hydroclone, the hydroclone itself, and a pump to make up pressure losses.

Operation is continued for about one week, after which the chemical plant is isolated from the reactor system. Contents of the underflow receiver are transferred to the low-pressure system where heavy water is evaporated and recovered. The solids are then dissolved in H_2SO_4 , and sampled, and the solution is transferred to one of two 100-gal. storage tanks. Following a decay period, this solution is transferred to existing solvent extraction facilities for uranium decontamination and recovery.

Presently, there is no way of estimating the quantity of solids in the underflow pot during operation of the hydroclone system. Only after the solids have been dissolved and analyzed can the total weight of solids be calculated. It is desirable to estimate the approximate weight of solids in the underflow pot at any time in order better to regulate chemical plant operation.

Solid fission and corrosion products have been found to be intimately associated. Fission product activity, which depends upon reactor power, can be seen as fission product heating in the underflow pot. Based upon these observations, several attempts have been made to relate the rate of solids accumulation to fission heat and reactor power by means of semi-empirical equations.

3.0 FISSION PRODUCT HEAT CALCULATIONS

A simplified diagram of the hydroclone and underflow pot showing thermocouples used in the heat balances described below is shown in Fig. 2.

There are five terms to be taken into account in the heat balance made around the underflow pot:

- Q_1 -- the heat loss from the underflow pot.
- Q_2 -- the heat loss to the fuel stream passing through the hydroclone.
- Q_3 -- heat transferred from the air to the underflow pot.
- Q_4 -- the heat loss from the air line between thermocouple TI-3-26 and the underflow pot.
- H -- the fission product heat.

Equating fission heat to heat losses minus heat input:

$$H = Q_1 + Q_2 - Q_3 + Q_4$$

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Fig.1. Schematic Flow Diagram of the Processing Plant.

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Fig. 2. Thermocouple Locations for Fission Heat Calculations.

3.1 HEAT LOSS FROM AIR LINE

Thermocouple TI-3-26 which records air inlet temperature is located 15.2 ft from the underflow pot.

Experiments were conducted to correlate the heat loss from this line with the difference between TI-3-26 temperature and cell temperature. Hot air was blown through this line until normal operating temperature was reached ($\sim 300^{\circ}\text{C}$). Then the air was suddenly shut off, and cooling curves were plotted. These functions were graphically differentiated, and the heat loss per foot of pipe was calculated at several temperatures.

$$Q \text{ (Btu/hr-ft)} = C_p \frac{dT}{dt}$$

In order to calculate the total heat loss from the air line, the heat loss per foot of pipe was approximated by a straight line between 160°C and 260°C which is the normal operating range. This resulted in an error no greater than 2%.

The equation of the line is:

$$Q = a + bT$$

$$\text{where } a = 108 \frac{\text{Btu}}{\text{hr-ft}}, \text{ and } b = 1.210 \frac{\text{Btu}}{\text{hr-ft } ^{\circ}\text{C}}$$

Air is blown through the pipe at a mass flow rate W , which is normally 216 lb/hr. A heat balance is taken around a length dx of the line and heat loss from the air is equated to heat loss from the pipe.

$$(a + bT) dx = -WC_p dT$$

$$\text{where } C_p \text{ is the mean heat capacity of air } = 0.434 \frac{\text{Btu}}{\text{lb } ^{\circ}\text{C}}$$

Upon integration with T_2 unknown and L the total length of pipe

$$\frac{1}{WC_p} \int_0^L dx = - \int_{T_1}^{T_2} \frac{dT}{a + bT}$$

$$\frac{L}{WC_p} = -\frac{1}{b} \ln \frac{a + bT_2}{a + bT_1}$$

Solving for T_2 :

$$T_2 = \frac{(a + bT_1) e^{\frac{-bL}{WCP}} - a}{b}$$

Values of T_2 were calculated from assumed values of T_1 (for $160^\circ\text{C} < T_1 < 260^\circ\text{C}$). Finally the total heat loss is calculated by:

$$Q_4 = C_p (T_1 - T_2)$$

and plotted in Fig. 3 as a function of T_1 temperature (which really is $T_{\text{pipe}} - T_{\text{cell}}$).

3.2 HEAT LOSS FROM UNDERFLOW POT

The underflow pot consists of a 21-in. section of 6-in. Schedule 160 stainless steel pipe capped at each end. End thickness is 0.718 in. The 6-in. pipe is enclosed by an aluminum casting 9-in. O.D., 21-in. long, and containing eighteen 3/8-in. tubes. There is a total of 50.9 ft of 3/8-in. tubing (0.035-in. wall) and 6.3 ft of 1-1/2-in. Schedule 40 stainless steel pipe surrounding the aluminum jacket. The aluminum casting weighs 55.7 lb and a total of 115.6 lb of stainless steel is contained in the assembly.

Two experimental methods have been used to determine the heat loss from the underflow pot as a function of underflow pot temperature minus cell temperature.

The first was to obtain cooling curves with the fuel stream off and the underflow pot full of D_2O . With no fission heat, the heat loss was calculated in the same way as the heat loss from the air line.

An alternate method was to raise the temperature of the underflow pot in steps by adjusting the air heater. After thermal equilibrium had been established the heat balance simplified to: $Q_1 = Q_3 - Q_4$. As in the first case the fuel stream was off and there was no fission heat.

Fig. 4 shows the heat losses determined in several early experiments by estimating cell temperature in each of the two above procedures. More data should be obtained on the heat loss from the underflow pot since cell temperature was not recorded, and it has not been established if the underflow pot was completely full of D_2O during these experiments.

3.3 HEAT LOSS TO PROCESS STREAM

Heat loss to the process stream was correlated with the difference between underflow pot temperature and process stream temperature.

While the process stream was flowing through the hydroclone at a constant rate, the underflow pot was heated and allowed to come to equilibrium thereby establishing a definite temperature difference between thermocouples TR-T-1 and TR-1-1. A heat balance was made:

$$Q_2 = Q_3 - Q_1 - Q_4$$

and the procedure was repeated for other temperature differences. Fig. 5 shows the results of this experiment.

Fig. 3. Heat Losses from Air Line to Underflow Pot.

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Fig. 4. Heat Losses From Hydroclone Underflow Pot.

Fig. 5. Heat Losses From Underflow Pot to Process Stream.

3.4 HEAT LOSS FROM AIR

Because of the inverse solubility exhibited by the solid fission products, it is desirable to maintain the underflow pot at elevated temperatures. The underflow pot is heated by means of hot air flowing around the jacket. When the fission heat is very high (~ 5000 Btu/hr), it becomes necessary to use the air stream to cool the underflow pot.

Air is delivered by blowers at 216 lb/hr, and the mean heat capacity of air is 0.0434 Btu/lb $^{\circ}\text{C}$. Heat loss from the air becomes:

$$Q_3 \text{ (Btu/hr)} = (216 \text{ lb/hr}) (0.0434 \text{ Btu/lb } ^{\circ}\text{C}) (T_{I-3-26} - T_{R-1-6})$$

4.0 CONCLUSION

Equations for calculating fission heating in the HRT-CP underflow pot by means of a heat balance have been developed from experimental data. Using this data, fission heat has been evaluated for chemical plant runs 17-4, 17-5, and 17-6. This is plotted in Fig. 6, 7, and 8, respectively along with reactor power for reference.

K. W. West of the HRT instrument group has designed an instrument which computes fission heat directly from emf signals generated by the thermocouples using the equations developed in this study. This computer can be adapted to any modified expression which may be developed for fission heat merely by changing resistance settings which correspond to constants in the fission heat equation.

Correlation of fission heating with solids accumulation was tested by equations of the form proposed by O. O. Yarbrow.

Using the expression:

$$R = 0.147 \left(\frac{dH}{dt} - 60 \frac{dP_E}{dt} \right) e^{(1.0 - 0.1 P_E)} + 2.3 \times 10^{-4} (H - 200 P_E),$$

where: R = rate of solids accumulation - g/hr
 H = fission heat - Btu/hr
 P_E = effective power - Mw

the total weight of solids was calculated for runs 17-4, 17-5, and 17-6. Results are tabulated in Table I.

Constants were evaluated on entirely empirical grounds, but it is hoped that they can be determined experimentally in future runs during constant power operation.

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Fig. 6. Fission Heating for Run 17-4.

Fig. 7. Fission Heating for Run 17-5.

Fig. 8. Fission Heating for Run 17-6.

Table 1. Solids Accumulated in Underflow Pot

Run	17-4	17-5	17-6
Length of run, hr	289	421.5	101.1
Calculated grams of solids	366	241	106
Found in dissolver	474	204	84
Error, %	-23	+18	+26

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