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SUBJECT: Design of Solids Feed Loop for Shakedown of the
HRT Chemical Plant

TO: S. E. Beall

FROM: B. H. Hamling

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To: S. E. Beall
From: B. H. Hamling
Subject: Design of a Solids Feed Loop for Shakedown of the
HRT Chemical Plant
Date: March 5, 1956

I. Summary

A 400 gpm pump loop will be used to supply the HRT Chemical Plant with water and simulated reactor corrosion and fission products in natural uranyl sulfate solution at 300°C and 2000 psi for shakedown purposes. The loop will have no hot metal surfaces on which the corrosion and fission products might adhere.

Heating of the soup will be entirely from the brake horsepower of the pump. It is uncertain whether the loop can be heated up to 300°C by this method without causing increased wear on the graphitar bearings in the pump. A large portion of the heat available for heating up the loop is normally lost in the pump cooling water stream. Reducing this heat loss by decreasing the cooling water flow causes higher temperatures in the motor and increases bearing wear.

It is recommended that the more efficient insulation, Santocel, be employed throughout to reduce heat losses and minimize the work input required from the 400A pump (this will permit running the pump bearings at lowest temperatures).

II. Introduction

Before the HRT Chemical Plant can be connected to the reactor core and put into "hot" operation, extensive shakedown tests on it are required. After water tests are made, natural uranyl sulfate solution with simulated corrosion and fission products will be fed into the chemical plant at reactor temperature (300°C) and pressure (2000 psi). In order to maintain reactor temperature and pressure in the chem plant, a pump loop will be used to heat up the feed stream to the chemical plant. Plating out of corrosion and fission products on the loop itself will be kept to a minimum by eliminating all hot walls in the loop and heating the soup entirely by the brake horsepower of a 400A Westinghouse canned rotor pump.

A schematic of the Solids Feed Loop and its connections to the chem plant are shown in Fig. I. The Solids Feed Loop will be in the north-east corner of cell B and the chemical plant in cell C. Two 1/4" schedule 80 pipes connect the two systems through sleeve CW-13-1. Solids are added to the feed stream going to the chemical plant, thus giving the heater, H-3, and the hydroclone, S-1, a chance to see the solids before the pump loop. The corrosion and fission products are in solution as the sulfates until they are added to the feed stream and heated up to operating temperature, where the rare earth sulfates precipitate and the zirconium hydrolyzes to the insoluble oxide. The level of the soup in the pressurizer will rise due to the feed addition and will be lowered periodically by withdrawing solution out through the chem plant sampling system.

Fig. I: Sketch of Connection of Solids Feed Loop to HRT Chem. Plant

Fig. I

III. Description of Solids Feed Loop

A drawing of the Solids Feed Loop is shown in Fig. II. The main flow, 400 gpm, circulates through about 7 ft of 3 in. schedule 80 pipe in which two flow restrictors are placed to give a total of 100 ft pressure drop across the pump. About a 5 ft pressure drop occurs in the 3 in. pipe. The pressurizer tank, 52 inches of 6 in. schedule 160 pipe plus schedule 160 end caps, (1) supplies the system with oxygen pressurization, (2) maintains oxygen concentration in the soup to hinder corrosion in the pump and pipes and to simulate reactor conditions, and (3) acts as a surge volume for the soup. An 1/8 in. schedule 80 line sprays liquid into the vapor space at a rate of about 2.2 gpm for pickup of oxygen. Pressure drops and flows in the pipe are listed in Table I.

Table I

Pressure Drops and Flows in Pipes

Fluid properties:

Density 45.5 lb/ft³
 Viscosity 0.235 lb/ft hr
 Reynolds No. 58,300 x (i.d. in inches) x (fps flow)

$$\text{Pressure drop, } \Delta H = f \frac{L}{D} \frac{u^2}{2g}$$

Description of pipe	Pipe Size (Sch. 80)	Flow Rate (gpm)	D (in)	U (fps)	Re	f	L (ft)	ΔH Loss (ft)
Main Loop	3"	400	2.90	19.3	3.25×10^6	.0177	12*	5.1
Lines to and from Chem Plant	1/4"	0.75	0.302	3.4	5.9×10^4	.0225	40	6.2
Lines to and from pressurizer	1/8"	2.2	0.215	19.0	2.5×10^5	.019	8	47.5

*Includes 3 elbows.

The Westinghouse 400A canned rotor pump used to circulate the soup and heat it up to reactor temperature is a spare for the HRT main circulating fuel pump. Welded to both the inlet and discharge nozzles are 4 or 5 inches of HRP specification 347 stainless steel pipe. (The remainder of the piping is not made to meet HRP specifications.) The pump delivers 400 gpm with a head of 100 feet.

Each flow restrictor is designed to give a pressure drop of 47.5 feet. A drawing of the flow restrictor is shown in Fig. III. It is necessary to fabricate the flow restrictor from titanium since the flow through it is 73 feet per second. Flow of soup past stainless steel at this speed would soon alter the shape of the restrictor and a drop in head loss would result. The restrictor is shrink-fitted in the 3 in. pipe and stationed by four 1/8-in.-dia. pins welded in place in the pipe. Calculations on the flow restrictor are in Appendix A. A similar flow

Fig. II: HRT Chem. Plant Solids Feed Loop

Notes:

- (1) All materials are 347 S.S.
- (2) Operation at 300°C and 2000psi
- (3) 47.5 ft head loss across each
flow restrictor

Legend:

- (P) - Pressure gauge
 (T) - Thermocouple
 —▶— - Reducer
 —||— - Flow Restrictor

Design Data :

Flow - 400 gpm

Pressure Drop - 47.5 ft.

Scale: Full Size

General Notes :

1. All dimensions are in inches

2. < Finish to microinches indicated

Fig. III: Flow Restrictor

Fig. III

9

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restrictor designed by W.F. Schaffer for 100 ft pressure drop at 100 gpm flow was recently tested in Unit Operations and gave 102 ft drop at 100 gpm flow.

IV. Addition of Solids Feed to System

Concentrated feed containing the simulated corrosion and fission products is added to the 0.75 gpm stream to the chem plant. Addition of the solution containing the various concentrations listed in Table II at a rate of 900 ml/hr duplicates the expected removal rate of solids from the reactor core system.

Table II

Composition of Solids Feeds Stream

Basis: 1 liter of H_2O at room temperature

5 gm $Fe_2(SO_4)_3 \cdot 9H_2O$

4 gm $Zr(SO_4)_2 \cdot 10H_2O$

0.5 gm mixed rare earth $SO_4 \cdot x H_2O$

10 gm $U^{238} O_2 SO_4$

50% excess H_2SO_4

This rate can be fed adequately into the system against a 2000 psi head with a Lapp Pulsafeeder Pump Model CPS-1 (special order for 2000 psi service).

It is desirable to keep the feed as concentrated in corrosion and fission products as is possible in order to minimize the volume of feed added to the system and, thus, reducing the heat requirements needed to heat this stream from room temperature up to $300^\circ C$. It may be possible to concentrate the feed somewhat and still keep the salts of iron and zirconium in solution at room temperature.

V. Heat Balance on 400A Pump

In an enclosed loop such as the Solids Feed Loop, the entire brake horsepower of the pump goes into heating up the pumping medium. However, in the canned-rotor pump, cooling water is circulated around the pump motor in order to keep insulation cool and to reduce wear on the graphitar bearings. Heat is lost from hot soup in the pump volute through the thermal barrier into the motor part of the pump. Control of the loop temperature will be done by regulation of the cooling water rate to the back of the pump. Successful heating of the loop to $300^\circ C$ will depend on being able to reduce the water flow rate sufficiently without appreciably increasing wear on the graphitar bearings. Some data on the 400A pump are listed in Table III.

Table III

400-A Pump Data (Obtained by Actual Test at Y-12)

Flow	400 gpm
Total head	100 ft
Rated input	17 kw
Fluid H.P. (Sp.Gr. = .723) = (flow)(total head) x (conv. factor)	7.25 H.P.
Pump efficiency	75%
Brake H.P. (Sp.Gr. = .723) = (fluid H.P.) ÷ (pump eff.)	9.9 HP or 7.4 kw
Brake H.P. (Sp.Gr. = 1.0)	13.7 HP
Motor efficiency	~ 65%
Electrical input (Sp.Gr. = .723) = $\frac{(\text{Brake H.P.})}{(\text{Motor eff.})}$	15.2 HP or 11.4 kw
Normal cooling rates (temp. of soup back of thermal barrier held to 100°C)	

<u>Temp. of Loop Volute</u>	<u>Cooling H₂O Rate</u>	<u>ΔT</u>	<u>Cooling Rate</u>
80°C	6.76 gpm	5.5°F	5.4 kw
160	6.76	7.5	7.4
295	6.9	11.5	11.5

A heat balance around the pump, electrical input = cooling water heating + soup heating, shows that normally at 300°C approximately an equal amount of heat goes to the cooling water as is put in as electrical load and none is left for heating the soup stream.

VI. Heat Loss from Loop Piping and Chemical PlantA. Sources of Heat Loss

The main heat losses and requirements for the Solids Feed Loop are

- (1) 48 ft of 1/4" Sch. 80 pipe for the feed lines to the chem plant, which includes 18 ft of pipe inside cell C.
- (2) 5-1/2 ft of 6" Sch. 160 pipe for the pressurizer. Actually the pressurizer is 4.3 ft long plus two end caps.
- (3) 7 ft of 3" Sch. 80 pipe for the main circulating loop.
- (4) 5 ft² area of the 400A pump scroll
- (5) Heating of the concentrated solids feed stream, 900 ml/hr, from room temperature to 300°C.

The main heat losses in the chemical plant are:

- (1) 20 ft of 1/4" Sch. 80 pipe in the high pressure loop and F-1.
- (2) 8 pairs of 1/2" 2500 psi flanges
- (3) H-3, 1/2" Sch. 80 pipe with calrods cast in 3" o.d. aluminum.
- (4) S-1 and T-1, hydroclone and underflow receiver, are combined since they will be insulated as a unit.
- (5) P-1, 5 gpm pump

B. Type of Insulation

Two types of insulation are considered here: 85% magnesia and Santocel AO Grade. The heat transfer coefficients for a mean temperature of $\frac{572 + 70}{2} = 321^{\circ}\text{F}$ are:

$$85\% \text{ magnesia} - k_m = 0.54 \frac{\text{Btu.in.}}{\text{hr ft}^2 ^{\circ}\text{F}}$$

$$\text{Santocel AO Grade} - k_m = 0.22 \frac{\text{Btu.in.}}{\text{hr ft}^2 ^{\circ}\text{F}}$$

The temperature of the open cells is taken as 70°F .

C. Heat Transfer Calculations

In all heat transfer calculations it is assumed that the heat resistance of the liquid surface film and metal walls is negligible compared to the insulation medium. Preliminary calculations have shown that the 1" thick aluminum casting on H-3 and T-1 of the chemical plant offer negligible resistance to heat transfer. Temperature of solution throughout the system is taken as 572°F and the ambient temperature, 70°F .

The equation used for heat loss calculations is

$$q = \frac{k_m A_m \Delta T}{t}$$

where

q = Btu/hr lost to environment per ft of pipe

k_m = mean transfer coefficient for insulation, $\frac{\text{Btu in.}}{\text{hr ft}^2 ^{\circ}\text{F}}$

A_m = log mean area per ft of pipe

$$= \frac{\pi}{12} \frac{(d_2 - d_1)}{\ln(d_2/d_1)} \quad \text{where } d_2 \text{ and } d_1 \text{ are o.d. of insulation and pipe, respectively.}$$

$$\Delta T = 572 - 70 = 502^{\circ}\text{F}$$

t = thickness of insulation, inches

D. Heating of Concentrated Solids Feed

An additional heat requirement of the pump other than heat losses is heating the solids feed from room temperature up to 300°C as it enters the feed stream to the chemical plant. Heat requirements for a feed rate of 900 ml/hr is 0.31 kw.

E. Heat Loss from Chemical Plant 5 gpm Pump, P-1

Heating of cooling water circulated around the motor windings has been estimated to be about 1 kw based on an ORNL 5 gpm model. This represents a large heat loss in the chemical plant and decreases the temperature of circulating soup by about 6-1/2 °F

F. Heat Losses and Requirements from Solids Feed Loop

- Basis: (1) 2" thickness of 85% magnesia insulation
(2) The 48' of 1/4" pipe includes 18' in cell C

<u>Component</u>	<u>Am</u> (ft ² /ft)	<u>Thick</u> (in.)	<u>Q</u> (Btu/hr/ft)	<u>Length</u> (ft)	<u>Heat Loss</u> (kw)
3" Sch. 80 pipe	1.38	2	163	7	0.38
6" Sch. 80 pipe	2.22	2	262	5.5	0.48
1/4" Sch. 80 pipe	0.49	2	58.2	48	0.94
400A pump scroll	5 ft ²	2	--	--	0.20
Concentrated feed (900 cc/hr heated from 70 to 572°F)					<u>0.31</u>
Total					2.31 kw
Total if 2" thick Santocel A0 Grade is used					0.94 kw

G. Heat Loss from Chemical Plant

<u>Component</u>	<u>Length</u>	<u>Type Insulation</u>	<u>Thickness</u>	<u>Heat Loss (kw)</u>
1/4" Sch. 80 pipe	20'	Santocel A0	3" o.d.	0.17
Flange pairs	8 pairs	85% Magnesia	2" thick	0.12
H-3	50"	Santocel A0	6" o.d.	0.10
			around 3" o.d.	
T-1 and S-1	2.6'	Santocel A0	1" thick	0.21
P-1 (heat loss to cooling water, estimated)				<u>1.00</u>
Total				1.60 kw

H. Temperature Drop of Circulating Soup

Temperature drop in the chemical plant high pressure loop is 6.6°F at 0.75 gpm flow. In the lines between the feed loop and the chemical plant with Santocel A0 Grade insulation, the temperature drop is 2.6°F. Temperature drop between the Feed Loop and hydroclone is approximately 4.5°F. This does not include the temperature drop of the stream caused by addition of the solids feed.

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B. H. Hamling
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Appendix A

Flow Restrictor Calculations

Ref: Perry's Handbook, p. 388, Equations 38 and 40

See Fig. IV for diagram where

S_1, S_2 = flow areas in small and large pipe

V_1, V_2 = feet per second flow in small and large pipe

Pressure head losses:

$$F_{in} = K \frac{V_1^2}{2gc}, \frac{\text{ft-lb force}}{\text{lb mass}} \quad \text{When } \frac{S_1}{S_2} < 0.715, K = 0.4(1.25 - \frac{S_1}{S_2})$$

or if entrance is conical like the upstream section of a venturi tube (i.e., vertex angle of 25-30°) K has a value of only 0.05 whatever may be ratio S_1/S_2 provided flow through S_1 is turbulent.

$$F_{out} = \frac{V_1^2}{2gc} (1 - \frac{S_1}{S_2})^2, \frac{\text{ft-lb force}}{\text{lb mass}}$$

$$F_T = .05 \frac{V_1^2}{2gc} + \frac{V_1^2}{2gc} (1 - \frac{S_1}{S_2})^2$$

$$V_1 S_1 = V_2 S_2 \quad \text{or} \quad V_1^2 = V_2^2 (\frac{S_2}{S_1})^2$$

$$F_T = \frac{V_2^2}{2gc} \left[1.05 (\frac{S_2}{S_1})^2 - 2 \frac{S_2}{S_1} + 1 \right]$$

For 3" Sch. 80 pipe and a flow of 400 gpm, $V_2 = 19.4$ fps and $S_2 = 6.605$. A plot of F_T vs. S_2/S_1 is shown in Fig. IV. For the design pressure drop, F_T , of 47.5 ft across the flow restrictor, $S_2/S_1 = 3.725$. Therefore,

$$S_1 = \frac{6.605}{3.725} \text{ in}^2 = 1.725 \text{ in}^2$$

$d_1 = 1.502$ in., throat diameter of flow restrictor

Fig. II : Plot of F_T vs S_2/s_1 for Flow Restrictor Calculations