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for HRT-CP Component & Mock-up Studies
TO: W. E. Unger
FROM: P. E. Novak

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To: W. E. Unger

From: P. E. Novak

Subject: UNOP "B" Loop Design Modification for HRT-CP Component & Mock-up Studies

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1.0 INTRODUCTION

It was decided to utilize Unit Operations' "B" test loop as a source of circulating uranyl sulfate solution at 2000 psi and 300°C for the simultaneous testing of HRT-CP high pressure flanges under thermal cycling and determination of operating and heat transfer characteristics of the HRT-CP hydroclone and underflow pot. However, there was doubt if the two ORNL canned rotor pumps available in the loop could provide sufficient head to satisfactorily sustain both experiments at once. The Design Section was asked to determine the feasibility of the plan and to furnish a suitable design for the accomplishment of the two tests.

The resulting flowsheet recognizes the fact of limited pumping head and omits all superfluous fittings and limits piping distances to a minimum. Freeze plugs are used wherever possible to replace valves and thus eliminate any added pressure drops that would tend to limit the desired flowrates.

An added feature of the design permits the "B" loop to be operated as a mock-up of the HRT-CP high pressure loop. This will depend on delivery of components now unavailable.

2.0 SUMMARY

From experiments conducted 2/8/56 on the B loop, approximately 20 psi was available to drive the two experiments. This pressure drop was insufficient to support the proposed tests on the existing loop but could produce satisfactory results on a modified loop design. The pressure drop available on a modified loop would produce a flow rate of 0.6 gpm through the 400 mil hydroclone test loop and 0.8 - 1.1 gpm through the flange test loop at operating temperature and pressure. A flow rate approaching 3 gpm would also be available for circulation of the underflow pot contents at room temperature. These flow rates and temperatures approach operating conditions in the HRT-CP and are acceptable to Unit Operation and Design personnel for the proposed tests.

The HRT-CP equipment being utilized for the initial test consists of the hydroclone and underflow pot assembly, the titanium filter screen, four electric heaters, and a 50 scfm blower. The final mock-up will also include the HRT-CP sampler and a stainless steel prototype of the canned rotor pump to be used in the chem plant.

3.0 EXPERIMENTAL WORK

The existing "B" loop had been extensively modified since its original construction. Therefore experimental data was required to determine the available pressure drop on the existing pieces of equipment.

Pressure gages were connected a) three feet from the discharge port of the sub-loop pump, b) three and one-half feet from the suction port of the sub-loop pump, and c) one and one-half feet from the proposed high pressure tap on the main circulating loop (Fig. 1). The system was then filled with water and slight oxygen overpressure was added to operate the pressure gages in the optimum range.⁽¹⁾ From this experiment it was concluded that approximately 45 feet of head was available to drive the proposed flange and hydroclone test.

Recent work done on "Autoclave" fittings⁽²⁾ showed the desired flowrates could not be achieved with the original orientation of equipment since the fittings alone "burned up" more than the available head at the required 1 gpm.

3.1 Variation of Reynold's Number with Temperatures

For a constant flow rate through a specified pipe size, the Reynold's number changes by more than a factor of 10 from 25°C to 300°C.⁽³⁾ This causes a decrease (at constant flowrate) in the friction factor of the wellknown Fanning equation. Thus, at operating temperature and pressure, the resistance to flow through pipes is less for a given flowrate than at room temperature.

Because of this condition, experimental flow rates were not determined for the cold test system since they would not be the same at operating conditions. Instead, differential pressures at pertinent points throughout the system were used as the basis for calculation since, for the flow rates considered, the pump discharge head was essentially constant. (i.e., 41 ft of head from 0-8 gpm.)

4.0 RESULTING FLOWSHEET

The 1 gpm flow rate required in the flange test loop could not be attained with the existing high ΔP fittings. Also the relatively high pressure drop required to operate the hydroclone even at the minimum efficiency flowrate of 0.5 gpm dictated extreme economy in the use of any energy consuming flow restrictors or valves. Therefore every effort was made to minimize the number of valves and Autoclave fittings in order to permit the desired flow rates with the available pump head.

Freeze plugs were substituted for valves wherever possible because of their inherent stream line properties. 1/4" and 1/2" Sch. 80 pipe was used instead of 9/16" Autoclave tubing wherever feasible to allow maximum throughput. Large radius bends also were utilized instead of high pressure Autoclave fittings.

The resulting flowsheet (Fig. 2 except for dotted lines) has only 3 Autoclave valves located in the main process lines. All other line closures are provided by freeze plugs. This is possible since it will not be necessary to make valve changes while pumping solution. Various piping combinations may be made by stopping the pumps and freezing or unfreezing the desired plugs. One and one-quarter tons of freeze plug refrigeration will be provided by two compressor units.

MAIN LOOP PUMP	SUB LOOP PUMP	DIFFERENTIAL PRESSURE (PSI)		
		1	2	3
ON	ON	12	0	20
ON	OFF	0	0	10
OFF	ON	14	0	12

"B" LOOP MODIFICATION
ORIGINAL LOOP ORIENTATION
ORNL BLDG. 4505
2/27/56 P. E. NOVAK

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The above flowsheet may be modified slightly in final experiments involving thermal cycling of HRT-CP flanges. Initially there will be high pressure Autoclave valves located on both the upstream and downstream side of the flange test unit. These valves will be used for the purpose of isolating the test unit from the rest of the system should any gross leakage occur under thermal cycling. One of these valves may be removed in the latter stages of testing to permit higher flow rates and thus greater heat transfer.

Provision has also been made to circulate the contents of the underflow pot at flowrates approaching 3 gpm. This has been accomplished by isolating the recirculation system from the rest of the loop by freeze plugs. The two ORNL pumps are then operated in series to provide the necessary pumping head. Underflow samples are obtained by removing a section of pipe from the circulating system after thorough mixing.

Only one high pressure venturi meter was available with the desired flow rate capacity. It was installed on the hydroclone outlet to measure flow rates of the order of 0.5 gpm. 1 gpm flow rates in the flange test loop are measured by the pressure drop across a 10 ft section of 1/4" schedule 80 pipe. Three gpm flow rates are measured in the recirculation system by the pressure drop across a 1.25 ft section of 1/4" schedule 80 pipe.

4.1 Chemical Plant Mock-up

Since there is no mock-up of the HRT-CP the hydroclone-underflow pot test loop was so designed to permit further minor modifications as additional HRT-CP components become available. The final flowsheet (including dotted lines in Fig. 2) approximates as closely as possible the actual orientation of high pressure and sampling equipment as will be installed in the HRT-CP.

The HRT prototype pump (100 ft of head at 60 cycles) can be operated on variable frequency supplied from a motor-generator unit. This operation is similar to that encountered in the chem plant. During normal processing of solution through the hydroclone, the pump can be operated at low frequencies to maintain the flowrate through the hydroclone at 0.75 gpm. When the "chem plant" is isolated from the "reactor" ("B" loop) the pump speed and head may be increased to provide the desired high circulation rates through the underflow pot and sampler.

4.2 Underflow Pot Loop Instrumentation

Since the objectives of the proposed initial tests are to determine the operating characteristics of the hydroclone and underflow pot and the heat transfer coefficient between the underflow pot and the aluminum jacket, adequate instrumentation is necessary to utilize the benefits of high pressure, high temperature, loop operation.

Figure 3 shows the proposed instrumentation and the data desired from it. Temperature control on the air heaters is provided by on-off control of one of the four units. Air to the heating jackets will be supplied by one of the HRT-CP 50 scfm blowers.

REQUIREMENTS

- 1) DETERMINE HEAT TRANSFER COEFF. BETWEEN AL. JACKET & UNDERFLOW POT
- 2) CHECK OPERABILITY OF HYDRULLONE
- 3) DETERMINE MIXING EFF. OF CIRCULATION
- 4) DETERMINE HEAT UP & COOL DOWN TIME
- 5) DETERMINE "FREEZABILITY" OF FREEZE PLUG

FIG. -3-

"B" LOOP MODIFICATION	
UNDERFLOW POT INSTRUMENTATION	
ORNL BLDG 4505	
2/22/56	P.E. NOYAK

The instruments are to be mounted on a portable cabinet located near the operating equipment. The panelboard will include a 12 point temperature recorder, on-off temperature control, and individual switches for each of the four electric heaters. Flow and pressure differential indicators may also be mounted on this panel.

4.3 Air Heating Wiring

The four HRT-CP electric furnaces used to heat the underflow pot air supply will be wired as shown in Fig. 4. This wiring scheme permits utilization of existing circuits on the third floor of Building 4505. A total of 13.6 kw will be drawn at maximum heating output. Circuit breakers are provided at the existing panel box. However, operating switches will be mounted on the instrument console. Air temperature control will be realized by on-off control of one of the heater units and any required combination of other heaters.

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"B" LOOP MODIFICATION
AIR HEATER WIRING

ORNL BLDG. 4505

2/27/56

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5.0 APPENDIX

5.1 Calculations

Calculations of this nature may be treated by the method of trial and error since two variables are present, and are related only by an empirical curve (friction factor vs. Reynold's number). Only those solutions representing final answers will be presented.

The Fanning equation for pressure drop through pipe was used in the form

$$\Delta F = 2f \frac{V^2}{g_c} \frac{\Delta L}{D} \quad \text{where } F = \text{ft-lb}_f/\text{lb}_m, L = \text{duct length (ft)}, D = \text{diameter (ft)},$$

$$\rho = \text{density (lb}_m/\text{ft}^3), V = \text{linear velocity (ft/sec)}, g_c = \text{conversion factor}$$

$$\left(\frac{\text{lb}_m \text{ ft}}{\text{lb}_f \text{ sec}^2} \right) \text{ and } f = \text{Fanning friction factor. The relation of } f \text{ to Reynold's}$$

number was obtained from Fig. 23, p. 382 of the 3rd Edition of Chemical Engineer's Handbook by Perry.

Calculations are based on a flat pump characteristic curve from 0-8 gpm at 41 ft of head. It is assumed that all flow rates will be in this range and also that pumps will be operated only on 60 cycles/sec current. For operation at frequencies other than 60 cycles/sec, head of the ORNL pump may be computed from the equation:

$$\text{Available head} = 41 \left[\frac{(\text{frequency})}{60} \right]^{1.6} \text{ ft-lb}_f/\text{lb}_m$$

5.1.1 Flow Rate Through Flange Test Loop (Final Design)

Available $\Delta P = 20$ psi. Equivalent length of pipe = 86'. Assume 1.1 gpm

$$1.1 \text{ gpm} = \frac{1.1}{60} (.134) \frac{1}{.0005} = 4.91 \text{ ft/sec in } 1/4" \text{ Sch. 80 pipe}$$

$$\frac{\rho}{\mu} (300^\circ\text{C}) = 13.2(10^5) \frac{\text{sec}}{\text{ft}^2} \quad \text{Re} = \frac{.302}{12} (4.91)(13.2)10^5 = 1.63(10^5)$$

$$f = 0.005$$

$$\Delta F = 2f \frac{V^2}{g_c} \frac{\Delta L}{D} = 2(.005) \frac{(4.91)^2 (86) 12}{32.2 \cdot .302} = 25.7' \text{ head} = 11 \text{ psi}$$

$$\Delta P \text{ thru one } 9/16" \text{ Autoclave valve at } 1.1 \text{ gpm} = 9 \text{ psi}$$

$$20 \text{ psi}$$

Flow rate = 1.1 gpm at 300°C

5.1.2 Flow Rate through Flange Test Loop (Initial Design)

Available $\Delta P = 20$ psi. Equivalent length of pipe = 86'

Assume 0.8 gpm

$$0.8 \text{ gpm} = 3.57 \text{ ft/sec in } 1/4" \text{ Sch. 80 pipe. } \frac{\rho}{\mu} (300^\circ\text{C}) = 13.2(10^5) \text{ sec/ft}^2$$

$$Re = \frac{.302}{12} (3.57)(13.2)(10^5) = 1.2(10^5) \quad f = 0.0055$$

$$\Delta F = 2(0.0055) \frac{(3.57)^2}{32.2} (86) \frac{12}{.302} = 15' \text{ head} = 6.5 \text{ psi}$$

$$\Delta P \text{ thru 2 Autoclave } 9/16" \text{ valves} = \frac{11}{18} \text{ psi}$$

Flow rate = 0.8 - 0.9 gpm at 300°C

5.1.3 Flow Rate through Clone Test Loop (Before Installation of Prototype Pump)

Available $\Delta P \sim 30$ psi - Equivalent length of pipe = 20' - Assume 0.6 gpm

$$0.6 \text{ gpm} = 2.67 \text{ ft/sec in } 1/4" \text{ Sch. 80 pipe. } \frac{\rho}{\mu} (300^\circ\text{C}) = 13.2(10^5) \frac{\text{sec}}{\text{ft}^2}$$

$$Re = \frac{.302}{12} (2.67)(13.2)10^5 = 8.9(10^4) \quad f = 0.006$$

$$\Delta F = 2(0.006) \frac{(2.67)^2}{32.2} \frac{12}{.302} (30) = 3.2' \text{ head} = 1 \text{ psi}$$

$$\Delta P \text{ through 400 mil clone at } 0.6 \text{ gpm} = 27 \text{ psi}$$

$$\Delta P \text{ through two Autoclave tubing unions} = 2 \text{ psi}$$

$$\sim 30 \text{ psi}$$

Flow rate = 0.6 gpm at 300°C

5.1.4 Flow Rate through Recirculation Loop (Before Installation of Prototype Pump)

Available $\Delta P \sim 30$ psi - equivalent length of pipe = 24' - assume 2.5 gpm

$$2.5 \text{ gpm} = 11.2 \text{ ft/sec in } 1/4" \text{ Sch. 80 pipe. } \frac{\rho}{\mu} (25^\circ\text{C}) = 1 \times 10^5 \frac{\text{sec}}{\text{ft}^2}$$

$$Re = \frac{.302}{12} (11.2)10^5 = 2.8(10^4) \quad f = 0.007$$

$$\Delta F = 2(.007) \frac{(11.2)^2}{32.2} \frac{12}{.302} (24) = 52' \text{ head} = 22 \text{ psi}$$

$$\Delta P \text{ of Autoclave tubing unions} \sim \frac{8}{30} \text{ psi}$$

Flow rate = 2.5 gpm at 25°C

5.1.5 Mock-up Flowrates

Flow rates in the mock-up will be essentially the same as in the initial experiments. However, a larger variety of flowrates may be investigated by varying the frequency of the electrical supply to the prototype pump.

5.2 Flow Meter Pipe Tap Separation

Venturi meters were not available to measure the flow in all of the loop streams. Therefore, pipe taps were used to indicate flow rates through the recirculation system and the flange test loop. Available recording devices have a maximum differential pressure range of 40 in. of water (3.3 ft). Pipe taps were located to indicate design flow rates at 80 - 90% of instrument scale.

5.2.1 Recirculation Loop

$$52 \frac{\text{ft} - \text{lb}_f}{\text{lb}_m} / 24 \text{ ft of } 1/4" \text{ Sch. 80 pipe} = 2.16 \frac{\text{ft} - \text{lb}_f}{\text{lb}_m} / \text{ft pipe}$$

$$80\% (3.33 \text{ ft}) = 2.67 \text{ ft} \frac{2.67 \text{ ft head (ft pipe)}}{2.16 \text{ ft head}} = 1.24 \text{ ft pipe}$$

Required separation for 80% linear instrument scale at 2.5 gpm = 1.25 ft

5.2.2 Flange Test Loop (Final Design)

$$25.7 \frac{\text{ft} - \text{lb}_f}{\text{lb}_m} / 86 \text{ ft of } 1/4" \text{ Sch. 80 pipe} = 0.30 \frac{\text{ft} - \text{lb}_f}{\text{lb}_m} / \text{ft pipe}$$

$$90\% (3.33 \text{ ft}) = 3.0 \text{ ft} \frac{3.0}{0.30} = 10.0 \text{ ft pipe}$$

Required separation for 90% linear instrument scale at 1.0 - 1.1 gpm = 10.0 ft

5.2.3 Flange Test Loop (Initial Design)

$$15 \frac{\text{ft} - \text{lb}_f}{\text{lb}_m} / 86 \text{ ft of } 1/4" \text{ Sch. 80 pipe} = 0.175 \frac{\text{ft} - \text{lb}_f}{\text{lb}_m} / \text{ft pipe}$$

$$\frac{0.175(10)}{3.33} = 52\% \text{ of instrument scale at } 0.8 - 0.9 \text{ gpm}$$

5.3 Bibliography

- (1) Experimental Notebook, C. C. Haws, Feb. 7-8, 1956.
- (2) Pressure Drops through Autoclave Fittings, personal communication with R. W. Horton, February, 1956.
- (3) May, 1955 Edition of the Reactor Handbook (Vol. 2, p. 575).