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Westinghouse Circulating Pump

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HRT-CP Engineering Test Procedure P-1
Westinghouse Circulating Pump

1.0 Purposes and Functions of HRT-CP Canned Rotor Pump

Approximately 16 psi differential exists between the HRT-CP takeoff and return lines in the reactor core system due to the pressure drop across the reactor heat exchanger. The remainder of the 40 psi required for efficient operation of the hydroclone is developed by the Westinghouse canned rotor circulating pump.

To permit operation of the hydroclone at different flow rates, the pump head can be varied by means of the variable frequency generator which supplies power to the pump. Present plans call for operation of the hydroclone with a constant pressure drop controlled by automatic regulation of the V.F.G. Excessive corrosion or plugging of the hydroclone will result in respectively higher or lower flow rates at constant pressure drop across the clone.

The pump is equipped with two discharge nozzles; thus proper valving permits pumping back to the main reactor loop, recirculation, or sampling the chemical plant high-pressure system contents.

Two temporary flowmeters will be inserted in the system during shakedown loop tests to evaluate pump and system performance. A 0-1-gpm venturi will be located in the feed line between the solids feed loop and the chemical plant. High recirculation flow rates will be read from pipe taps spaced 18 inches apart in line 1100 between H-3 and F-1.

A pump characteristic curve will be determined by installing a temporary recirculation system in cell C and operating the pump in place.

2.0 Pump Specifications

The Westinghouse canned rotor pump used in plant operation is designed to deliver 1 gpm with 100 ft of heat at 60 cps. The operating temperature and pressure is 572°F and 2000 psia, respectively. Pump cooling water is required at 3 gpm, 90°F maximum.

The pump curve supplied by Westinghouse is relatively flat from 0 to 5 gpm. From this curve, pump head varies from 25 ft to 184 ft for a corresponding frequency variation of 30 to 80 cps, and can be expressed as a function of pump frequency in this range by

$$\text{head (ft)} = 0.0227\ (\text{frequency})^{2.06} \qquad (1)$$

The net positive suction head is 30 ft.

3.0 Pump Cavitation

In normal operation the chemical plant will be connected directly to the reactor system. This direct connection insures that the chemical plant is pressurized to the reactor pressure of 2000 psi, thus providing an overpressure of

750 psi. No pump cavitation is expected under these operating conditions. However, in shutdown and startup procedures, the chemical system will be isolated from the reactor and no overpressure will be available from the reactor loop. It is recognized that pump cavitation may possibly be encountered under these conditions.

In normal chemical plant startup procedure, the high-pressure system will be filled to approximately 75% of volume. The gas space above the liquid will be compressed as the fluid is heated and expands until the system is 100% full at 300°C. The resulting pressure will probably not be greatly above the liquid saturation pressure. Thus for this operation and also for the cool-down operation where the plant is again isolated from the reactor system, it is uncertain if the pump can operate without cavitation.

The problem of cavitation should become more clearly defined during the pump tests and plant shakedown. A means of supplying overpressure will be supplied if required.

4.0 Chemical Plant Flow Rate Estimates

Pressure drop across the hydroclone is a definite function of flow rate as shown in Fig. 1. The pressure drop is shown in feet of liquid and is essentially independent of temperature from 30° to 300°C.

Since the system flow rate is, in turn, dependent upon the pump frequency, qualitative information about hydroclone plugging and corrosion can be gained from pump frequency observations.

The theoretical variation of the system flow rate with the pump frequency was calculated by assuming conditions varying from gross plugging to gross corrosion for the hydroclone with a constant pressure drop across it. Pressure drop through the rest of the chemical plant lines was evaluated for various flow rates and this drop added to the hydroclone ΔP. Figure 2 presents the calculated frequency-flow-rate relationship for various hydroclone pressure drops.

In the course of the chemical plant shakedown, it will be useful to determine the actual flow rate through the system at various pump frequencies. Flow through the hydroclone, recirculation, and underflow sampling should be investigated.

5.0 Test Purposes

1) The variable frequency generator requires calibration to relate instrument setting to generated frequency.

2) The temporary flow meters used in the shakedown tests must be calibrated and cold readings extrapolated to operating conditions.

3) Actual pump head must be determined as a function of frequency. Various flow rates will be investigated to ascertain the pump characteristic curves over the entire operating range.

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Fig. 1

PRESSURE DROP VS FLOWRATE THRU 0.400" HYDROCLONE

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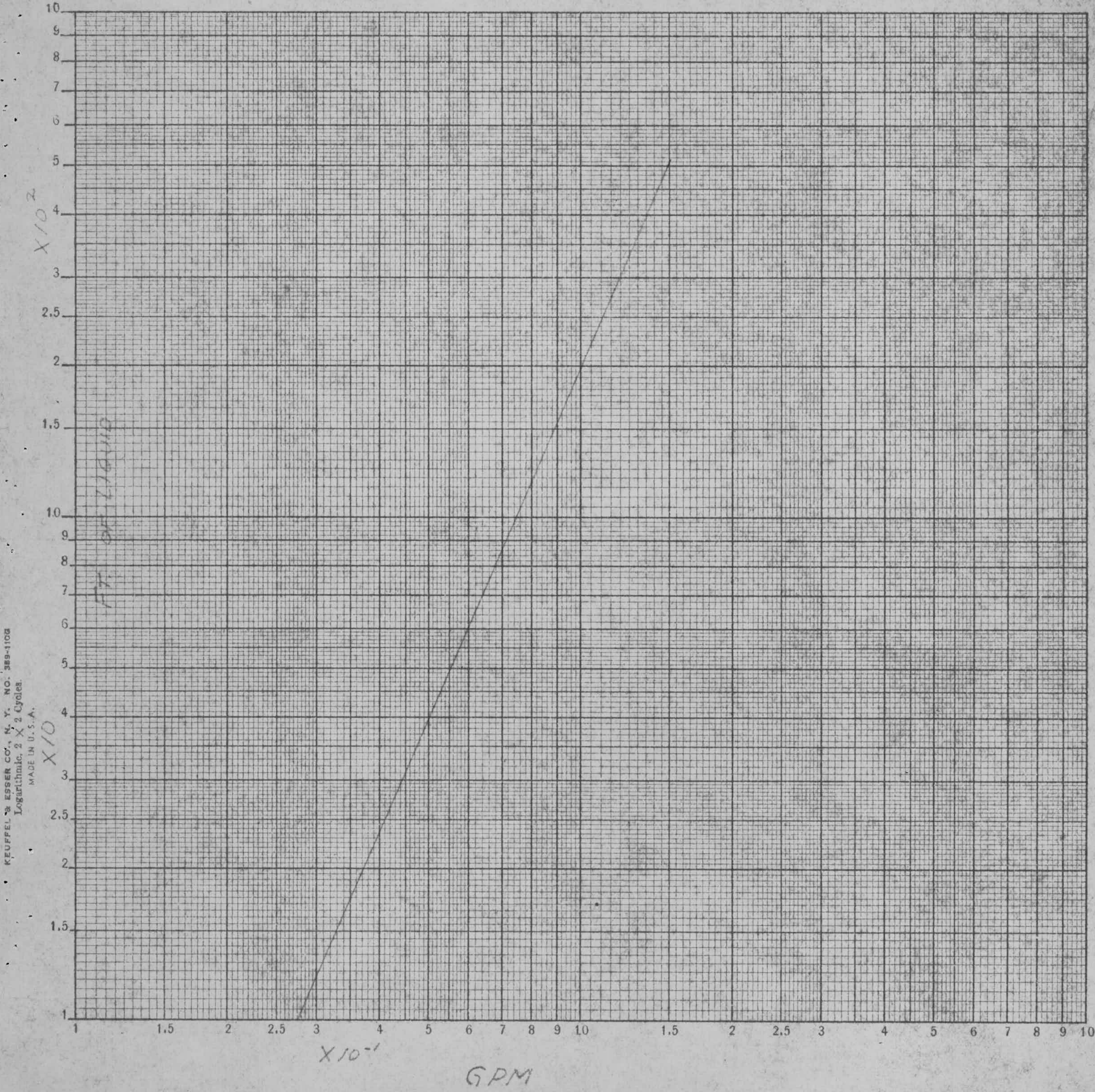

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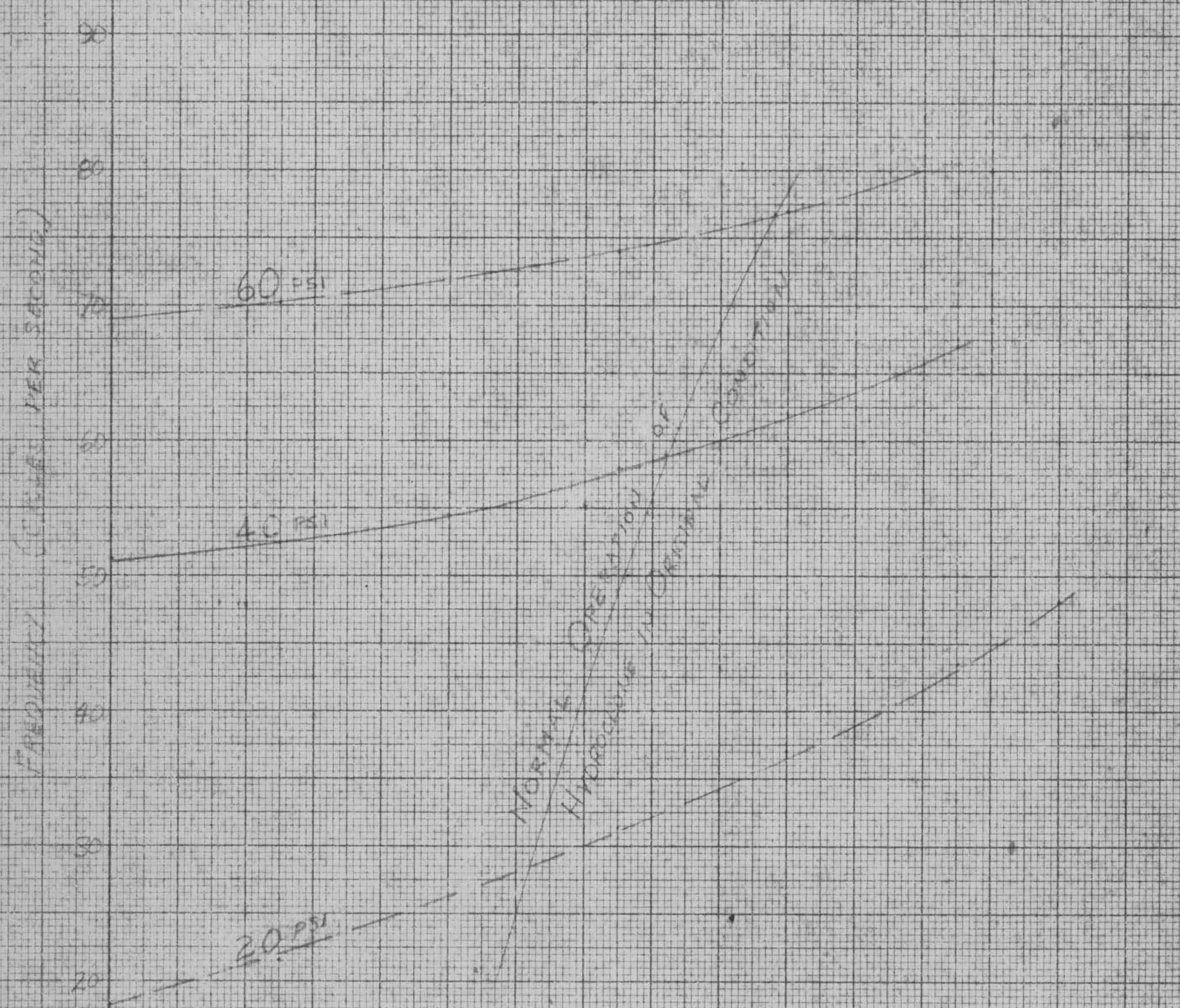
Fig. 2.

PLANT FLOWRATE VS PUMP FREQUENCY FOR THREE PRESSURE DROPS ACROSS HYDROCLONE



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4) Flow rates are to be estimated for the various chemical plant operations.

6.0 Test Procedures

6.1) Variable Frequency Generator Calibration.

Check plant supply air and adjust the supply air on the filter-regulator assembly to 30 psi. Set the cushion air regulator to 10 psi. Remove cover plate from varidrive unit to insure discs are closed on varibelt. Energize wall switch to start varidrive.

Vary signal from graphic panel board to "high" and then to "low" speed. If the varidrive does not follow promptly, adjust the supply and cushion air regulators. Refer to the "U.S. Variable Frequency and Varitrol Instruction Manual," (12/15/55), for correcting abnormal varidrive responses.

When the varidrive unit has been adjusted to proper signal sensitivity, determine the accuracy of the mounted electric tachometer with a "Strobotach" or other convenient tachometer. Equation 2 relates frequency generated in cps to the VFG rpm:

$$\text{frequency generated (cps)} = \frac{\text{rpm}}{30} \qquad (2)$$

After calibrating the electric tachometer (which reads directly in cps), determine the maximum and minimum frequencies available for the full range of signal pressures. Frequencies should be available from approximately 30 to approximately 80 cps.

With the panel board instrument on "manual" approach signal pressures of 5, 7, 9, 11, 13 psi from both higher and lower signal settings to determine reproducibility of the generated frequencies. Average the generated frequencies obtained at each signal pressure and determine maximum deviation.

If all of the above maximum deviations are less than 1/2 cps for a given signal pressure, set the manual control at 0% of scale and record the generated frequency. Increase in 5% increments recording corresponding frequencies. If maximum deviation is greater than 1/2 cps, record frequency at both increasing and decreasing signals of 5% of scale. (See Appendix for sample data sheet.)

6.2) Temporary Flow Meter Calibration.

Since positive flow meter calibration cannot be made conveniently at operating temperature and pressure, cold calibration is required and the result will then be extrapolated to operating conditions.

The 0-1-gpm venturi, located in the temporary feed line connecting the solids feed loop to the chem plant, will measure flow to the hydroclone. Pipe taps located in line 1100 will measure flow from 0-4.5 gpm during recirculation. The primary elements will be located as shown in Fig. 3.

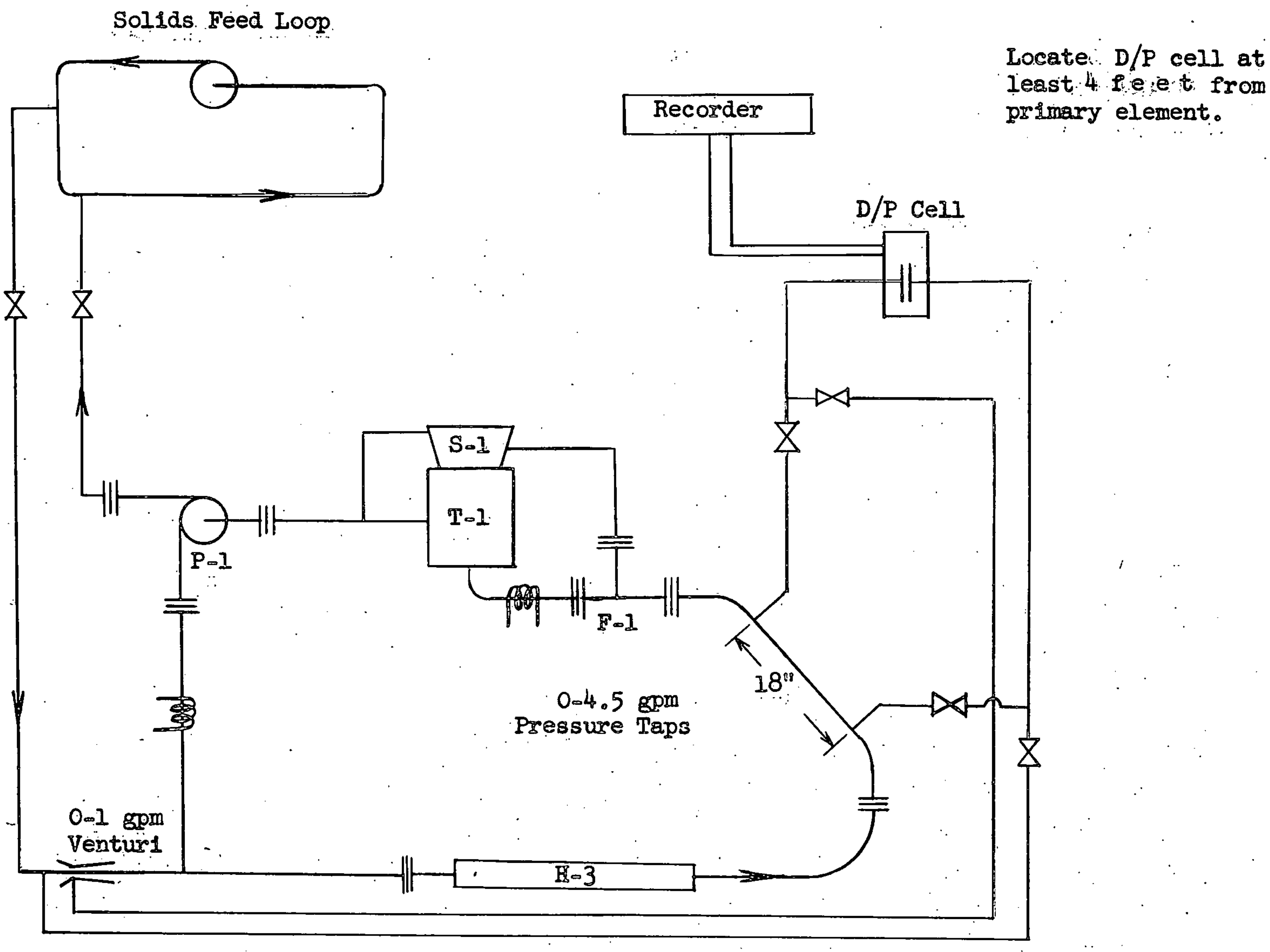


Fig. 3

Flow Meter Orientation in Chem. Plant

The two elements will be calibrated after they have been placed in the proper lines. The same D/P cell employed in the calibration will be used for actual operation. This cell has a range of 0-100 inches of water.

Break the pump (P-1) discharge flange in line 166 and connect a process water line to 166. Open the flange connecting line 1100 to F-1 and make suitable provision to collect and meter water discharging from 1100. Metering may be accomplished by collecting known volumes or weight of water for a given time interval or by use of a calibrated rotameter.

After purging air from the system, adjust the water flow rate to give a signal pressure of 15 psi (100% of scale) for the venturi meter. Determine this flow rate. Investigate at least ten other flow rates and tabulate the percent of scale reading at each flow rate. Repeat the above procedure for the pipe tap flow element (see Appendix for sample data sheet).

At constant volumetric flow rate, pressure drop through a venturi varies directly with the ratios of the densities of the fluid at flowing and meter temperatures.

$$V\rho = CA_2\rho\sqrt{\frac{2g\,\Delta H}{1-\beta^4}} \qquad (3)$$

$$\Delta H = \frac{\Delta P}{\rho}$$

Therefore, the correction to convert the indicated pressure drop at high temperature to the calibrated flow rate conditions is:

$$\frac{\text{Indicated chart reading (\%)}}{\rho_T} = \frac{\text{Corrected chart reading (\%)}}{\rho_b} \qquad (4)$$

Illustrative Example:

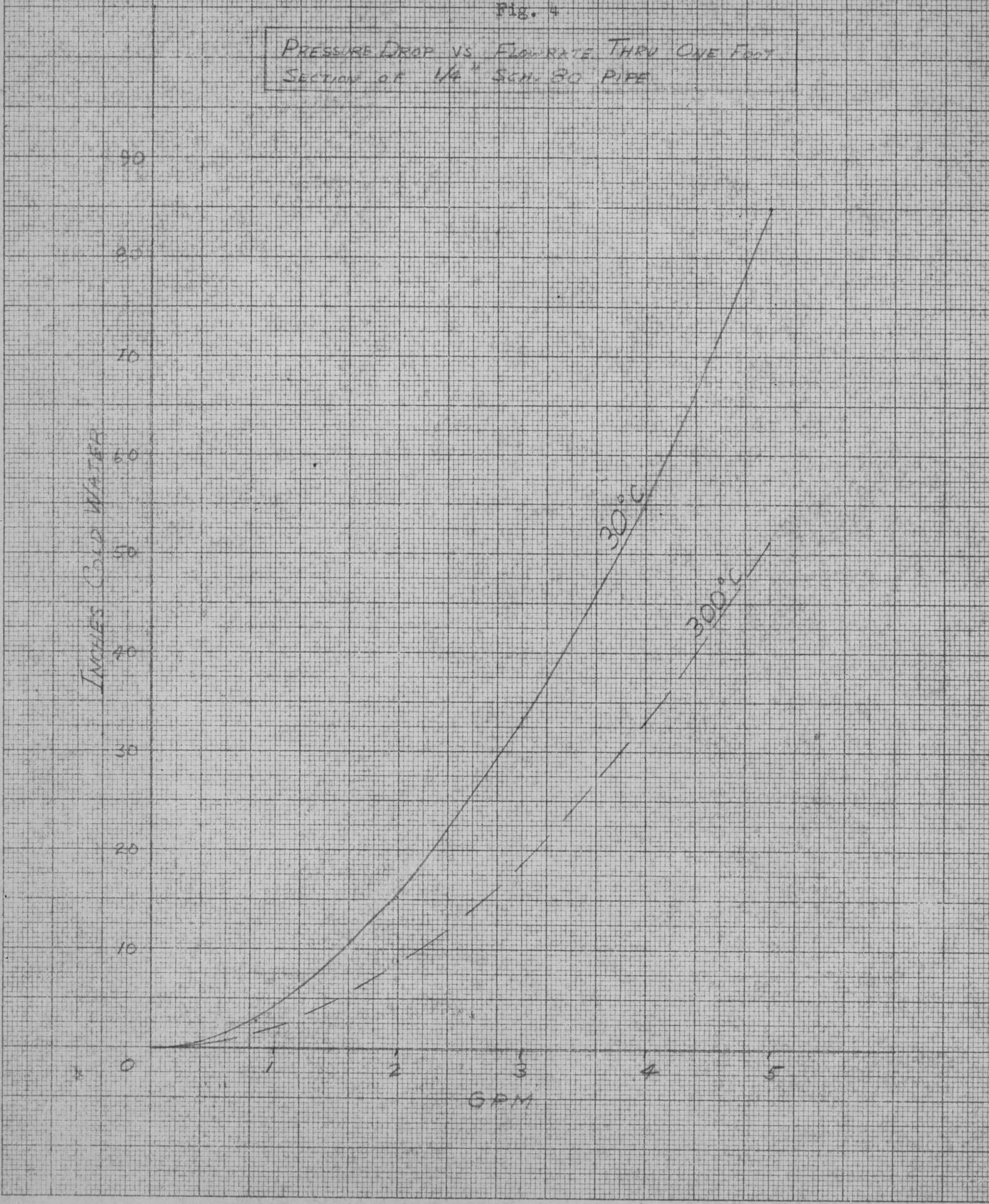
At 300°C, assume recorder reads 73% of full scale. Using Eq. 4:

$$\frac{73}{45.5} = \frac{\%}{62.4} \qquad \% = 100$$

Reading venturi calibration curve, 100% of scale = corrected volumetric flow rate.

Pressure drop through pipe is a function of the friction factor as well as velocity. Figure 4 shows the calculated variation of pressure drop with temperature through a 1-ft section of pipe from 30°C to 300°C.

Fig. 4


PRESSURE DROP VS FLOW-RATE THRU ONE FOOT SECTION OF 1/4" SCH. 80 PIPE
INCHES COLD WATER
GPM
30°C
300°C
0
1
2
3
4
5
10
20
30
40
50
60
70
80
90

6.3 Pump Head Characteristics

The Westinghouse canned rotor pump has not been operated at ORNL. It is, therefore, desirable to run the pump for preliminary testing and to measure the pump characteristic curve for operational calculations. These two objectives can be achieved simultaneously in a pump curve determination.

A temporary test loop can be set up as shown schematically in Fig. 5. This loop will operate with the pump mounted in place in Cell C. Use 1-in. natural rubber hose for the temporary lines. Thoroughly rinse all lines before using to remove dirt and halogen salts.

Connect the head tank drain line to the under-flow receiver drain line (1104). Remove F-1 to make this connection and suitably close off line 1101.

Connect the temporary discharge line to the head tank at the pump discharge nozzle flange in line 166. Suitably close off line 1103. Also freeze line 1700 at freeze plug 4, if possible, to facilitate the air bleed of the pump. Locate the head tank at least 12 feet above the pump to obtain proper suction head. Insure the proper flow of cooling water to the pump.

Using filtered water, investigate flows from 0 to 3.0 gpm in approximately 0.5 gpm intervals and at frequencies of 30, 45, 60, and 80 cps. Tabulate pressure developed at each condition. Determine flow by collecting water for timed intervals in suitable containers or by use of a calibrated rotameter. Also determine the flow required to produce cavitation of the pump (see Appendix for sample data sheet).

If the actual pump curve varies appreciably from the curve supplied by Westinghouse, check the electrical circuits to insure the pump is turning in the proper direction.

6.4 Chemical Plant Flow Rates

Pump frequency can be correlated to system flow rate to provide flow metering estimates. This relationship can be measured while the chemical plant is connected to the solids feed shakedown loop since the pressure drop across the chemical plant feed and return lines approximates that across the reactor heat exchanger.

Establish flow from the solids feed loop, through H-3, F-1, the hydroclone, P-1, and back to the loop at approximately reactor temperature and pressure and record these conditions. Operate P-1 at lowest obtainable frequency and record corresponding flow rate through venturi. Increase frequency and calibrate in 5 cps-increments for full range of V.F.G. (see Appendix for sample data sheet).

Recirculate chemical plant contents after isolation from the solids feed loop. The recirculation path is through P-1, H-3, F-1, the under-flow receiver, and back to P-1. Repeat the above calibration procedure using the pressure-tap flow meter located in line 1100.

Also calibrate the flow rate through the under flow sampler by the above procedure.

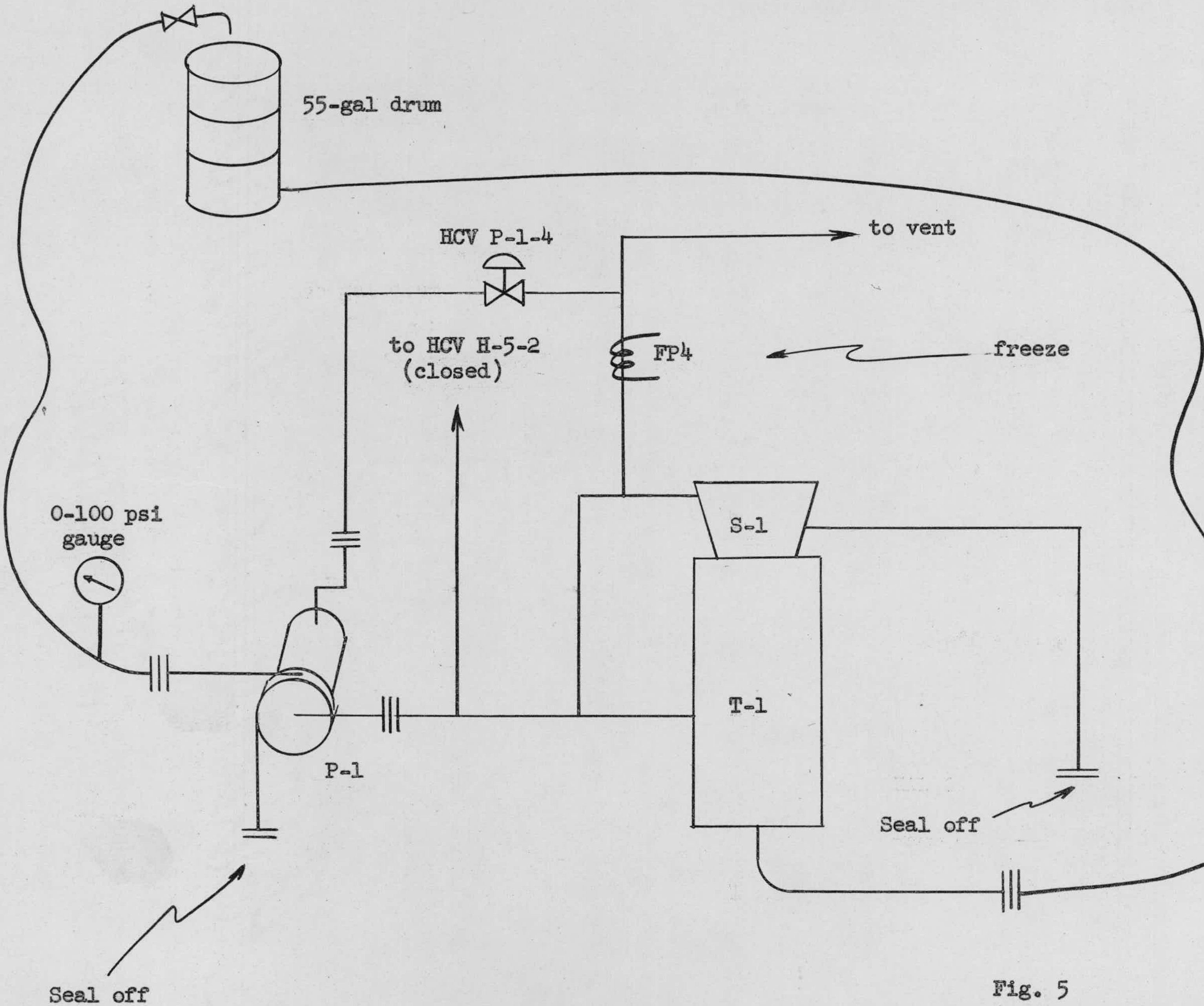


Fig. 5

<u>Pump Calibration Loop</u>

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Appendix

0-1-gpm Venturi

The venturi to be used for measuring low flow rates is available from the Unit Operations Section. Nominal range is 1 gpm at a Δ P of 100 inches H_2O: flow = 1 gpm; ρ = 62.4 lb/ft^3; D = 0.302; d = 0.133; β = 0.44; A_2 = 0.0000964 ft^2.

$$W = CA_2 \sqrt{\frac{2g_c\rho^2 \Delta H}{1 - \beta^4}} = V\rho$$

$$V = CA_2 \sqrt{\frac{2g_c \Delta H}{1 - \beta^4}}$$

$$\frac{1 \text{ gal ft}^3 \text{ min}}{7.481 \text{ gal min } 60 \text{ sec}} = .98\ (9.64)\ (10^{-5})\ \text{ft}^2 \sqrt{\frac{2\ (32.2)\ \text{ft} \Delta H \text{ ft}}{\text{sec}^2\ 1 - (.44)^4}}$$

$$.00223 \frac{\text{ft}^3}{\text{sec}} = 9.45\ (10^{-5})\ \text{ft}^2 \sqrt{66.9 \frac{\text{ft}}{\text{sec}^2} \Delta H \text{ ft}}$$

$$(2.89)^2 \text{ ft} = \Delta H \text{ ft} = 8.34 \text{ ft} = 100 \text{ inches}$$

100 inches of cold water = 3.62 psi.
100 inches of hot water = 73 inches cold water = 3.17 psi.

Pressure Drop Through 1/4-in. Schedule-80 Pipe

The calculation presented below is a sample of the procedure used to arrive at the theoretical curves of Fig. 2. Pressure taps are being used to determine 0-5 gpm recirculation flow rates. This method allows all available head to be used in equipment operation similar to actual plant operation. Figure 6 shows a detail of pipe tap installation.

$$\Delta H = f \frac{L}{D} \frac{v^2}{2g} \qquad Re = \frac{Dv\rho}{\mu}$$

Conditions: 3 gpm, 2000 psi, 300°C

μ = 0.235 lb/ft-hr; ρ = 45.5 lb/ft^3; D = 0.0252 ft; L = 1

v = 13.5 ft/sec

$$Re = \frac{(.0252)\ (13.5)\ (45.5)\ (3600)}{(0.235)} = 2.37\ (10^5)$$

f = 0.019

$$\Delta H = .019 \frac{1}{.0252} \frac{(13.5)^2}{64.4} = 2.13 \text{ ft} = 25.6 \text{ in.}_{hot} = 18.7 \text{ in.}_{cold}$$

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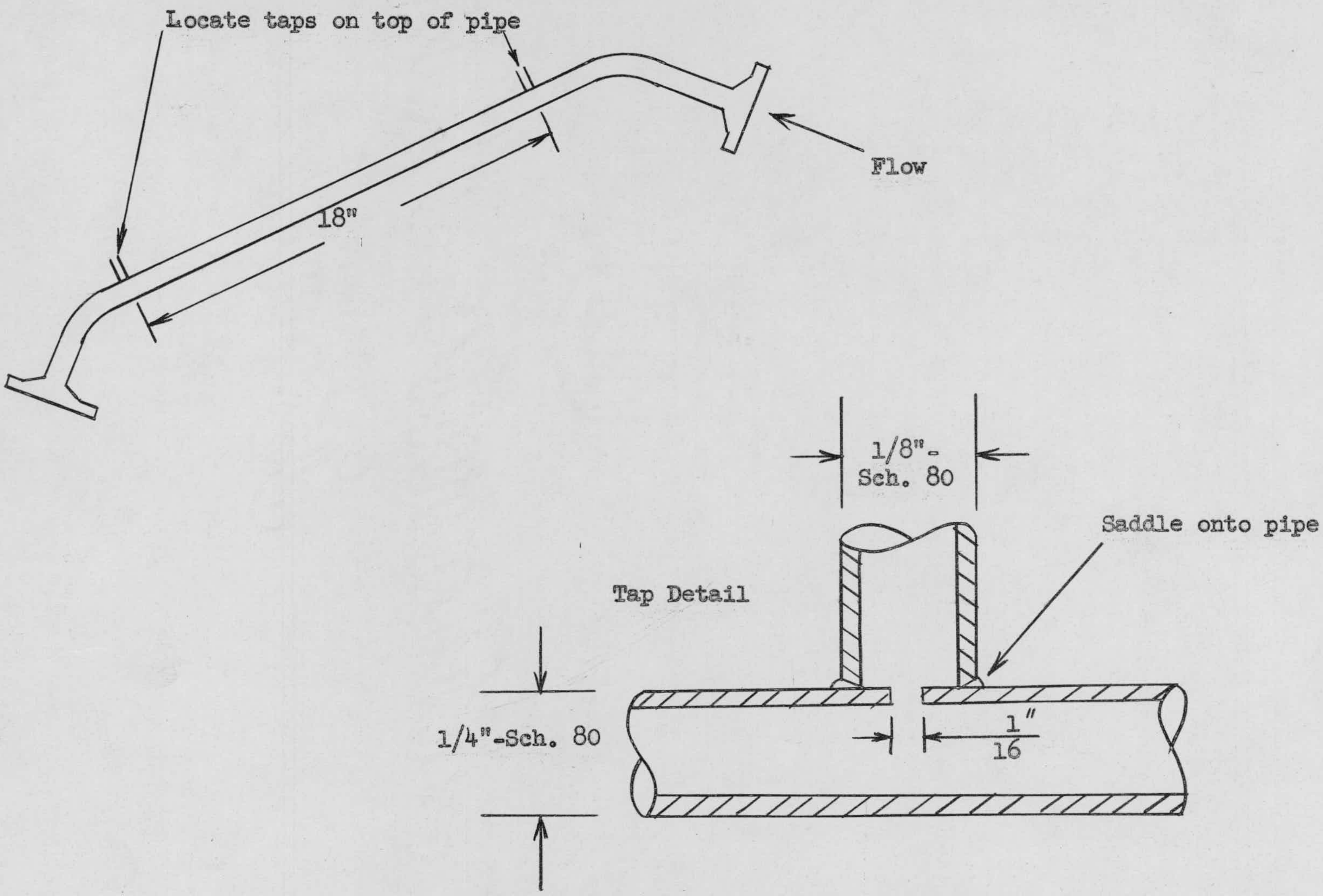

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Fig. 6

Pressure Tap Location and Detail

Conditions: 3 gpm, atm pressure, 30°C, $\rho = 62.4$ lb/ft^3

$\mu = 2.35$ lb/ft-hr; $v = 13.5$ ft/sec

$$Re = \frac{(0.0252)\,(13.5)\,(62.4)\,(3600)}{2.35} = 3.25\,(10^4)$$

$f = 0.025$

$$\triangle H = .025 \;\frac{1}{.0252}\;\frac{(13.5)^2}{64.4} = 2.8 \text{ ft} = 33.6 \text{ in.}_{cold}$$

Flow rate Relationship to Pump Frequency

An estimate of flow rate as a function of pump frequency is presented in Fig. 2. Presented below is a typical calculation.

The evaluated system includes two valves with a C_v of 0.3, 40-psi drop across the hydroclone, F-1, H-3, the Westinghouse pump, 40 ft of 1/4-in. Schedule-80 pipe, and 16 psi across the reactor heat exchanger.

Conditions: Frequency = 55 cps, feed line $\triangle P$ = 16 psi, hydroclone $\triangle P$ = 40 psi

pump head + 16 psi = hydroclone + pipe + 2 valves

Expressed in feet of head:

$$0.0227\,(fq)^{2.06} + 51 = 127 + 24.8\,f\,v^2 + (2)\,(11.1)\,\frac{v^2}{20.3}$$

Combining terms:

$$0.0227\,(fq)^{2.06} = 76 + 1.603\,v^2$$

$$123 = 76 + 1.603\,v^2$$

v = 5.41 ft/sec flow rate = 1.2 gpm .

P. E. Novak
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SAMPLE DATA SHEET

Variable Frequency Generator Calibration

RPM	Actual Frequency Generated	Indicated Frequency Generated	Increasing Signal Pressure			Decreasing Signal Pressure			Avg. Frequency	Max. Deviation	Increasing Signal Pressure		Decreasing Signal Pressure	
	cps	cps	psi	% of Scale	Freq. (Ind.)	psi	% of Scale	Freq. (Ind.)	cps	cps	% of Scale	Freq. (Ind.)	% of Scale	Freq. (Ind.)
			3			3					0		0	
			5			5					5		5	
			7			7					10		10	
			9			9					15		15	
			11			11					20		20	
			13			13					25		25	
			15			15					30		30	
											35		35	
											40		40	
											45		45	
											50		50	
											55		55	
											60		60	
											65		65	
											70		70	
											75		75	
											80		80	
											85		85	
											90		90	
											95		95	
											100		100	

SAMPLE DATA SHEET

Flow Meter Calibration

Venturi		Remarks	Pipe Taps		Remarks
Flowrate gpm	% of Scale	Water Temp. ________	Flowrate gpm	% of Scale	Water Temp. ________

SAMPLE DATA SHEET

Pump Calibration

Flowrate	Pressure Drop Through Pump (psi)				Remarks
gpm	30 cps	45 cps	60 cps	80 cps	

SAMPLE DATA SHEET

Chemical Plant Flow Rates

System: Solids Feed Loop, H-3, F-1, Hydroclone, P-1, Solids Feed Loop

Temperature

Pressure

Pump Frequency cps	Indicated Flow Rate gpm	Corrected Flow Rate gpm	Remarks

Nomemclature

A_2	Throat area of venturi
C	Venturi coefficient
D	Pipe inside diameter
d	Venturi throat diameter
f	Friction factor (Fanning Equation)
fq	Frequency, cycles per second
g_c	Conversion factor
ΔH	Head, feet of fluid at operating conditions
L	Length of pipe
ΔP	Pressure differential
Re	Reynold's number
V	Volumetric flow rate based on operating conditions
v	Velocity of fluid
W	Mass flow rate
β	Ratio of throat to pipe diameter for venturi
μ	Viscosity
ρ	Density
ρ_b	Density, base conditions
ρ_T	Density, at temperature of flowing stream

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