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**Prepared for the U.S. Department of Energy
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REACTOR PROCESS FLOW TECHNICAL DATA

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MASTER

Classification Change to

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4-74

By Loft 3/17/75

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I. INTRODUCTION

A computer program is being developed for the solution of general system flow problems. As a complement to this program, a summary of the process system has been prepared. This assembles information from a number of different reports, drawings and technical notebooks into one place for easy use and reference. It is expected that the information contained in this report will be of use in safety and design studies of these process systems.

II. SUMMARY

This report presents current values of the reactor flow characteristics and the primary pumping system characteristics. It also presents the process piping system and the basis for a computing program for calculating system pressure drops.

For purposes of convenience, all Hanford production reactors are included in one report, and considerable basic technical information is included as a background for accomplishing any desired system flow studies.

III. DISCUSSION

A. General

For a number of years, there has been a need for an over-all review of the process piping. A low-priority program to develop or summarize this information has been in progress for over a year. Although this information would probably have been more useful two years ago, it is believed that significant use of this information will still be made.

B. Computer Flow Program

1. General Equation

The basic equation for the flow-pressure relationships in a system having pressure continuity, i.e. no point of critical flow or free fall, is a modified form of the Bernoulli relationship:

$$\begin{array}{ccccccc}
 P_1 & + & \frac{P_1 H_1}{144} & + & \frac{P_1 V_1^2}{288 g_c} & + & \frac{P_p (\Delta H_p)}{144} & = \\
 \text{pressure} & + & \text{elevation} & + & \text{kinetic} & + & \text{pumping pressure} & = \\
 \text{at 1} & & \text{pressure at 1} & & \text{pressure at 1} & & \text{increase at pump} & \\
 \\
 P_2 & + & \frac{P_2 H_2}{144} & + & \frac{P_2 V_2^2}{288 g_c} & + & \sum \frac{\bar{V}^2 P (L + L_e) f_m}{288 g_c D_e} & (1) \\
 \text{pressure} & + & \text{elevation} & + & \text{kinetic} & + & \text{frictional pressure} & \\
 \text{at 2} & & \text{pressure at 2} & & \text{pressure at 2} & & \text{increase from 1 to 2} &
 \end{array}$$

Where p = static or stagnation pressure at a given piping location
- psig

f_m = Moody friction factor

g_c = gravitational constant - ft/sec²

De = equivalent flow diameter - ft = $4 \times \frac{\text{free cross-section}}{\text{wetted perimeter}}$

H = elevation of piping location above an arbitrary datum - ft

L = pipe length - ft

Le = equivalent length of the various pipe fittings - ft

V = average cross-sectional velocity - ft/sec

$\bar{V}$ = average velocity over the length L - ft/sec

ΔH_p = process pump total dynamic head, if there is one between the pressure points 1 and 2 - ft

ρ = fluid density - lbs/ft³

The $\sum$ in front of the frictional pressure drop allows for the possibility of various piping sizes, etc., between the chosen locations 1 and 2.

2. Frictional and Kinetic Pressure Losses

A computer program is being developed that will determine the pipe-line pressure losses according to the equation:

$$\Delta p_{f_L} + \Delta p_K = \sum \left(\frac{\rho \bar{V}^2 (L + Le) f_m}{288 g_c De} \right) + \sum \left(\frac{C (V_a^2 - V_b^2) \rho}{288 g_c} \right) \quad (2)$$

Where Δp_{f_L} = the sum of the frictional pressure losses - psi

Δp_K = the sum of the kinetic losses - psi

This program will give the frictional and kinetic losses for water flow through any piping system. If the pressure drop is known, the program can be used to determine the $\frac{(L + Le) f_m}{De}$ group in cases where pipe corrosion or complex piping components make it difficult to determine accurate theoretical values.

3. Frictional Effects

The friction factor, f_m , is a function of the pipe roughness, ϵ/D , and the fluid Reynold's number, N_{Re} . Values for the piping roughness are presented in the section on Process Piping.

The value of the Reynold's number determines whether the flow is laminar, critical, or turbulent. This is indicated by the following equations:

Laminar or Streamline Flow, $N_{Re} < 2000$

$$f_m = \frac{64}{N_{Re}} \quad (3)$$

$$\text{Where } N_{Re} = \frac{3600 \text{ De } V}{\mu} \quad (4)$$

μ = water viscosity - lbs/hr, ft

Critical Flow, $2000 < N_{Re} < 4000$

- a. Minimum pressure drop will occur when flow is gradually increasing from $N_{Re} < 2000$ to $N_{Re} < 4000$. The minimum friction factor would be:

$$f_m \approx \frac{64}{N_{Re}} \quad (5)$$

- b. Maximum pressure drop will occur when the flow is gradually decreasing from $N_{Re} > 4000$ to $N_{Re} > 2000$. Under these conditions, the Colebrook equation⁽¹⁾ applies:

$$\frac{1}{\sqrt{f_m}} \approx -2 \log \left[\frac{\epsilon}{D} + \frac{2.51}{N_{Re} \sqrt{f_m}} \right] \quad (6)$$

Where ϵ/D = pipe wall roughness factor

These two expressions represent the extreme rather than the actual conditions. It is quite difficult to predict where the actual case would be. Therefore, as an averaging approximation, the following relationship is applied to the critical region (see Figure 1):

$$f_m \approx 0.032 \left(\frac{N_{Re}}{2000} \right)^{0.322} \quad (7)$$

Turbulent Flow, $N_{Re} > 4000$

Here, equation (6) applies with no question concerning the nature of flow change.

4. Kinetic Effects

There are a number of locations in a piping system where kinetic energy effects occur. This happens at places of rapid changes in flow velocity such as orifices, venturi meters, free discharge, etc. The general equation for this effect is:

FIGURE 1

Moody Diagram for Pipeline Flow $10^3 < Re < 10^4$

$$\Delta p_K = \frac{C \rho (V_2^2 - V_1^2)}{288 g_c} \quad (8)$$

Where C is a flow loss coefficient to be obtained from various references^(2,3) for the particular piping configurations in use.

5. Computer Input and Output Information

In this program, the following input information is required:

- a. Water flow, W - lbs/sec.
- b. Pipe diameter (ID) or annulus (OD and ID) - ft.
- c. Pipe roughness, ϵ/D .
- d. Pipe length and summation of L_e values - ft.
- e. Average water temperature - °C.
- f. $\sum C$ values for kinetic energy changes.

From this information, the computer program is designed to provide the following output information:

- a. Reynold's Number, N_{Re} .
- b. Friction factor, f_m .
- c. Frictional pressure drop:

$$\Delta p_f = \frac{\bar{V}^2 (L + L_e) f_m}{288 g_c D_e} \quad (9)$$

- d. Total pressure drop, frictional plus kinetic, for given flow rate and geometry.

Thus, this program provides two of the basic terms in the general Bernoulli equation for the pressure change between two points in a system having flow and pressure continuity, i.e:

$$p_1 + \Delta p_p = p_2 + \Delta p_f + \Delta p_K + \Delta p_s \quad (10)$$

Where Δp_p = total dynamic pressure delivered by pump.

The remaining term unaccounted for is Δp_s , the net elevation pressure difference between points 1 and 2. Values of the elevation of the significant process points above mean sea level are presented in Table II. This effect is discussed further in Section III-D of this report.

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C. Process Piping

In the following tables and figures, the process piping conditions are presented for the various Hanford production reactors.

The K Reactors are in the middle of a project (CGI-844) designed to significantly improve their coolant backup system. Therefore, process piping figures showing the before and after piping conditions are presented.

From these tables, one can obtain the important variables of pipe diameter, D and De; pipe length, L; and pipe roughness, ϵ/D .

The equivalent length, L_e , of the various piping fittings may be obtained from a number of sources.^(4,5) The pipe roughness factors, ϵ/D , were obtained from tables of the Hydraulic Institute.⁽⁶⁾ In obtaining these values of ϵ/D , the Institute values were multiplied by a 1.2 factor to allow for piping corrosion effects. The importance of so doing was demonstrated by the tests of the reactor high-tank lines which showed a decrease in flow of over 20 percent because of line corrosion product buildup.

The reactor flow is generally expressed in terms of thousands of gallons of water per minute (G). However, this term changes with water density through the reactor and the flow velocity changes with both density and cross-section. Therefore, a term is recommended that is constant as long as there are no losses or additions of water to the system, i.e:

$$W = \frac{G \rho}{448,000}$$

Where W = mass flow rate in lbs/sec.

TABLE I-A

B, D, F Reactor Process Piping Dimensions

Bldg. No.	Pipe Section Description	Mat'l	Sched. No.	Wall Thckn. In.	O.D. In.	I.D. In.	Pipe Roughness ϵ/D^*	Transverse Internal Area Sq. Ft.	No. of Parallel Lines
190	Storage tank to distribution header	CS	--	--	30	--	---	---	4
190	Distribution header	CS	--	--	36	--	---	---	1
190 Annex	Suction header	CS	--	.375	42	41.25	0.0000523	9.28	2
190 Annex	Pump intake line	CS	30	.562	24	22.876	0.0000944	2.854	8
190 Annex	Pump discharge	CS	60	.750	18	16.5	0.000131	1.485	8
190 Tunnel	190 to 105 valve pit manifold	CS + SS lining	--	.480 CS .109 SS .589 total	12.75	11.572	0.000186	1.184	14
190 Tunnel	" " " "	CS	60	.750	18	16.5	0.000131	1.485	2
105	Valve pit manifold	CS	40	1.25	36	33.5	0.0000644	6.12	2
105	Valve pit manifold crosstie	CS	60	.656	16	14.688	0.000145	1.177	1
105	Riser	CS	40	1.25	36	33.5	0.0000644	6.12	2
105	Riser to crossheader	CS	80	.375	5.563	4.813	0.000449	0.126	78
105	Reactor crossheader	SS	40	.237	4.50	4.026	0.000536	0.0884	78
187	High tank to valve pit	CS	40	.406	12.75	11.938	0.000181	0.777	2

* ϵ/D = 1.2 (ϵ/D) for clean pipe, Hydraulic Institute.

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TABLE I-B

C Reactor Process Piping Dimensions

Bldg. No.	Pipe Section Description	Mat'l	Sched. No.	Wall	O.D. In.	I.D. In.	Pipe	Transverse	No. of Parallel Lines
				Thickn. In.			Roughness ϵ/D^*	Internal Area Sq. Ft.	
190	Suction header	CS	--	.500	48	47	0.0000458	12.05	4
190	Pump inlet line	CS	30	.562	24	22.876	0.0000944	2.854	10
190	Pump discharge line	CS	60	.75	18	16.5	0.000131	1.485	10
190	Pump discharge header	CS	60	.968	24	22.064	0.0000978	2.6552	4
190 Tunnel	Pump discharge header to 105 valve pit	CS	60	.968	24	22.064	0.0000978	2.6552	6
105	Valve pit to riser	CS	--	1.00	30	28	0.0000770	4.276	4
105	Riser	CS	--	1.00	30	28	0.0000770	4.276	4
105	Riser to crossheader	CS	80	.375	5.563	4.813	0.000449	0.126	92
105	Crossheader	SS	40	.237	4.5	4.026	0.000536	0.0884	92
187	High tank to valve pit	CS	40	.500	16	15.0	0.000144	1.227	2

* $\epsilon/D = 1.2 (\epsilon/D)$ for clean pipe, Hydraulic Institute.

TABLE I-C

DR Reactor Process Piping Dimensions

Bldg. No.	Pipe Section Description	Mat'l	Sched. No.	Wall	O.D. In.	I.D. In.	Pipe Roughness ϵ/D^*	Transverse	No. of Parallel Lines
				Thickn. In.				Internal Area Sq. Ft.	
190	Storage tanks to suction header loop	CS	--	--	36	--	---	---	4
190 Annex	Suction header	CS	--	0.375	42	41.25	0.0000523	9.28	2
190 Annex	Pump intake line	CS	30	0.562	24	22.876	0.0000944	2.854	8
190 Annex	Pump discharge	CS	60	0.750	18	16.5	0.0000131	1.485	8
190 Annex	Pump discharge header to tunnel valve pit	CS	60	0.562	12.75	11.626	0.000186	0.7372	16
190 Tunnel	Tunnel valve pit to 105 valve pit	CS	40	0.687	24	22.626	0.0000955	2.7921	4
105	Center connection valve pit crosstie	CS	60	0.968	24	22.064	0.0000978	2.6552	1
105	Valve pit crosstie to 105 reactor riser & riser proper	CS	40	1.25	36	33.5	0.0000644	6.12	2
105	Riser to crossheader	CS	80	0.432	6.625	5.761	0.000374	0.181	46
105	Crossheader	SS	40	0.237	4.5	4.026	0.000536	0.0884	46
187	High tank to riser	CS	40	0.500	16	15	0.000144	1.227	2

* $\epsilon/D = 1.2 (\epsilon/D)$ for clean pipe, Hydraulic Institute.

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TABLE I-D

H Reactor Process Piping Dimensions

Bldg. No.	Pipe Section Description	Mat'l	Sched. No.	Wall Thickn.	O.D. In.	I.D. In.	Pipe Roughness ϵ/D^*	Transverse Internal	No. of Parallel Lines
				In.				Area Sq. Ft.	
190	Storage tank to distribution header	CS	--	--	36	--	---	---	4
190	Distribution header	CS	--	--	36	--	---	---	1
190 Annex	Suction header	CS	--	0.375	42	41.25	0.0000523	9.28	2
190 Annex	Pump intake line	CS	30	0.562	24	22.876	0.0000944	2.854	8
190 Annex	Pump discharge	CS	60	0.750	18	16.5	0.0000131	1.485	8
190 Annex	Pump discharge header to crosstie lines	CS	60	0.968	24	22.064	0.0000978	2.6552	4
190 Annex	Crosstie lines	CS	60	0.968	24	22.064	0.0000978	2.6552	2
190 Annex	Tunnel to 105 valve pit	CS	40	0.687	24	22.626	0.000955	2.7921	4
105	Valve pit to riser	CS	40	1.25	36	33.5	0.0000644	6.12	2
105	Riser to crossheader	CS	80	0.432	6.625	5.761	0.000374	0.181	46
105	Front face crossheader	SS	40	0.237	4.5	4.026	0.000536	0.0884	46
187	High tank to riser	CS	40	0.500	16	15	0.000144	1.227	2

* ϵ/D = 1.2 x clean pipe value, Hydraulic Institute.

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TABLE I-E

K Reactor Process Piping Dimensions

Bldg. No.	Pipe Section Description	Mat'l	Sched. No.	Wall	O.D. In.	I.D. In.	Pipe Roughness ϵ/D^*	Transverse	No. of Parallel Lines
				Thickn. In.				Internal Area Sq. Ft.	
190	Low lift pump to high lift pump	CS	20	0.500	30	29	0.0000745	4.587	6
190	High lift discharge line	CS	60	0.968	24	22.064	0.0000978	2.6552	8
165 Tunnel	Tunnel piping to 105 risers	CS	40	1.25	36	33.5	0.0000644	6.12	4
105	Risers	CS	40	1.25	36	33.5	0.0000644	6.12	4
105	Riser to crossheaders	CS	80	0.375	5.563	4.813	0.000449	0.1263	116
105	Front face crossheaders	SS	40	0.237	4.50	4.026	0.000536	0.0884	116

* ϵ/D = 1.2 x clean pipe value, Hydraulic Institute.

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FIGURE 2

160'

24" Sch #60

24"

18" Sch #60

18"

18"

18"

18"

18"

PRIMARY & SECONDARY REACTOR PUMPS

8 24"

9 24"

10 24"

11 24"

12 24"

48"

48"

48"

48"

FROM STORAGE TANKS

1/2" WALL THICKNESS

24"

24" Sch #30

5 24"

4 24"

3 24"

2 24"

1 24"

18"

18"

18"

18"

18"

24"

24"

196'-0"

96'-2 3/4"

18'-0"

24'-2 3/4"

FIGURE 3

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DR PROCESS PIPING SCHEMATIC 190 BUILDING TO REACTOR BUILDING

Elevation Above Sea Level - FT.

	DR
190 Bldg. Zero Level Floor Elevation	443.50'
105 Bldg. Zero Level Floor Elevation	466.00'
187 High Tank W. S. Elevation - No. 1	620.44'
187 High Tank W. S. Elevation - No. 2	620.26'

FIGURE 4

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H PROCESS PIPING SCHEMATIC 190 BUILDING TO REACTOR BUILDING

Elevation Above Sea Level - FT.

	H
190 Bldg. Zero Level Floor Elevation	421.00'
105 Bldg. Zero Level Floor Elevation	423.00'
187 High Tank W. S. Elevation - No. 1	577.40'
187 High Tank W. S. Elevation - No. 2	577.44'

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K PROCESS
190 BUILDING TO

PIPING SCHEMATIC
REACTOR BUILDING

FIGURE 6

Before CGI-844

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K Process

FIGURE 6-A

Piping Schematic 190 Building to Reactor Building
After CGI-844

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D. Process Piping Elevations and Static Pressures

The elevation values (H) for different sections of reactor piping are summarized in Table II. From these elevations, the static pressure effect between the two points is:

$$\Delta p_s = \frac{\rho_2 H_2 - \rho_1 H_1}{144} \quad (11)$$

Where ρ = the water density at the point in question, lbs/ft³. In many cases, $\rho_1 = \rho_2$, and:

$$\Delta p_s = \frac{\rho \Delta H}{144} \quad (12)$$

However, when comparing front and rear face static pressures, there is often a significant density difference between water in the front and rear risers. The effect of this difference on the front and rear face static pressures is indicated in Figures 7 and 8.

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TABLE II - PROCESS PIPING ELEVATIONS

	Sea Level Elevations in Feet ⁽¹⁾						
	100-B	100-C	100-D	100-DR	100-F	100-H	100-K
River El: High	420	420	413	413	398	402	417.0
Low	383	383	375	375	360	369	375.0
181 Pump C.L. El.	375.5	375.5	367.5	367.5	347.5	361.5	424.5
Reservoir W.S. El.	461.5	479	470	(D-DR)	420.5	419	---
182 Pump C.L. El.	444.9	(B-C)	453.4	(D-DR)	403.9	402.53	---
Sedim. Basins W.S. El.	475	491.5	481	476.5	428.5	428	490
Clear Wells W.S. El.	462	517	468	463.5	415.5	415	470
183 Pump C.L. El.	442.88	432	448.88	---	403.38	398.75	---
190 Tank W.S. El.	513.5	---	513	---	458.5	470	---
190 Pump C.L. El:							
Secondary Steam Discharge	471.2	480.2	470.67	447.06	416.2	424.71	477 LL
Primary Electric Discharge	467.8	480.2	467.3	438.3	412.8	421.3	474 HL
105 Front Face Riser El:							
TORP	505.7	531.2	503.7	503.2	450.5	460.2	510.5
Ht. above 0'0"	37.2	37.2 495.5*	37.2	37.2	37.2	37.2	45.5 466*
187 High Tank W.S. El:							
No. 1	619.33	663	621.83	620.44	565.3	577.4	---
No. 2	627.33	663	622.83	620.26	569.3	577.4	---
190 Zero Level Fl. El.	467.5	479	467	443.5	412.5	421	474
105 Zero Level Fl. El.	468.5	494	466.5	466	413.3	423	465
Rear Cross Over ⁽²⁾ C.L.	520.6	546	518.6	518.1	465.4	475	521.5
Ht. Above 0'0" ⁽²⁾	52.1	52.1	52.1	52.1	52.1	52.1	56.5
Ht. Above TORP ⁽²⁾	14.9	15.6	14.9	14.9	14.9	15.1	11.0
Min. Ht. O-Flow ⁽²⁾	13.4	14.1	13.4	13.4	13.4	13.6	10.3

1) N. O. Strand. Physical Data of the 100 Areas' Process Water Systems, HW-25693. 9/26/58
(Reference 7)

2) S. S. Jones. Technical Notes.

* Riser pressure at C and K is read at bottom of riser (BORP).

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Tube Rows (Add 1/2 for Crossheaders)

REC-CT RICHLAND, WASH

Old React

FIGURE 7

Static Elevations B, C, D, DR, F, & H Reactors

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FIGURE 8

K-Reactors Static Elevations Above 0'-0"

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E. Process Pumps

Over the years, there have been a number of pump changes and improvements, such that a considerable difference may exist between the designed pump characteristics and its present operation. In the following charts, current performance characteristics of the main process pumps are summarized for the Hanford reactors. These may not be correct for each of the pumps at a given building, but do represent the current average conditions of these pumps. The curves are presented in terms of Total Dynamic Head (TDH) and pump discharge pressure (P_D). The pump discharge pressure may be obtained from the relationship:

$$P_D = \frac{\rho}{144} [(TDH) + \Delta H_s] + P_s + \frac{\rho}{288g_c} (V_s^2 - V_d^2) \quad (13)$$

Where P_s = pump suction pressure - psig.

ΔH_s = elevation of pump suction center-line above its discharge center-line - ft.

V_s = pump inlet velocity - ft/sec.

V_d = pump outlet velocity - ft/sec.

In many cases where the inlet and outlet lines to the pump are the same diameter and at essentially the same elevation, we have:

$$P_D = \frac{\rho}{144} (TDH) + P_s \quad (14)$$

Also, in most instances at Hanford, the primary process pumps have essentially a constant input head, except for frictional effects in the suction lines. This is because a water tower (190 tank) or reservoir (clearwell) provides a constant elevation head to the suction side of the process pump. This yields the equation:

$$P_D = \frac{\rho}{144} (TDH) + \frac{\rho}{144} (\Delta H_s) - \Delta p_{fp} - \frac{V_d^2}{288g_c} \quad (15)$$

Where Δp_{fp} = frictional pressure drop from tank or reservoir to process pump - psi

ΔH_s = elevation of water free surface in 190 tank or clearwell above pump discharge center-line - ft.

For the case of variable speed process pumps, performance characteristics at an arbitrary speed can be obtained from application of the affinity laws⁽⁹⁾ to established characteristic curves, i.e:

$$\frac{G_1}{G_2} = \frac{N_1}{N_2} ; \frac{H_1}{H_2} = \frac{N_1^2}{N_2^2} ; \frac{BHP_1}{BHP_2} = \frac{N_1^3}{N_2^3}$$

Where N = impeller speed - rpm.

BHP = brake horsepower.

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FIGURE 9
190 Process Water Pump Characteristics B, D, F, & H Reactors
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FIGURE 10

190-DR Process Water Pump Characteristics
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FIGURE 11
109-C Process Water Pump Characteristics
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Flow - 1000 GPM

FIGURE 13

190-K Steam-Turbine Pump Characteristics (Estimated)

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FIGURE 14

Frictional Pressure Losses From 190 Tanks or Clear Wells to Process Pump Discharge
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F. Pressure Drop, Pumps to Reactor

The important question is the pressure and flow that the process pumps can provide the reactor. This is determined by the pump discharge pressure, the number of pumps and lines in parallel, and the pressure drop from the pumps to the reactor. The reactor flow pressure is monitored at the top of the B, D, DR, F, and H Reactors, and at the bottom of the C and K Reactors. The pressure is read in the control room as top-of-riser pressure (TORP) in all cases, but still represents the static pressure at the point of measurement. Thus, we have:

1. B, D, DR, F, and H Reactors

$$p_T = p_D + \frac{\rho(v_D^2 - v_T^2)}{288g_c} + \frac{\rho}{144} \Delta H_{ST} - \Delta p_{fPR} \quad (16a)$$

Where p_T = top-of-riser pressure (TORP) - psig.

ΔH_{ST} = increase in pump elevation above TORP - ft.

Δp_{fPR} = frictional pressure drop from pump to reactor - psi

v_T = velocity at TORP = 0 since it is a stagnation point.

2. C, KE and KW Reactors

$$p_B = p_D + \frac{\rho(v_D^2 - v_B^2)}{288g_c} + \rho \Delta H_{SB} + \Delta p_{fPR} \quad (16b)$$

Where p_B = bottom-of-riser pressure (BORP) - psig.

ΔH_{SB} = increase in pump elevation above BORP - ft.

v_B = velocity at bottom of riser - ft/sec., and does not equal 0.

The frictional pressure drop along the pipe is:

$$\Delta p_{fPR} = \sum \left(\frac{\rho \bar{v}^2 (L + L_e) f_m}{288g_c De} \right) \quad (2)$$

Where for each parallel system with junction points, we must have the relationship:

$$G_T = \sum G_L \quad (17)$$

Approximate pressure drops from the pumps to the reactor front risers (TORP or BORP positions) are presented in Figure 15.

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FIGURE 15
Frictional Pressure Losses From Process Pumps to Reactor (TORP or BORP) Based on
Normal Operational Valving
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G. Reactor Pressure Characteristics

The actual reactor flow for any pumping situation depends upon the matching of the pump characteristic curve with the reactor resistance. This is indicated in Figure 16, which shows a current match point for B Reactor and the effects of various changes. This match point depends upon the pump characteristics in terms of delivered front riser pressure versus the reactor flow resistance. This resistance is made up of a frictional pressure drop plus the static elevation of the water level in the cross-over above the reactor TORP or BORP. This static head effect for various reactor flow is presented in Figures 17 and 18 for the old and the K Reactors. The frictional drop through the reactor is related to the reactor TORP or BORP by the expressions:

1. B, D, DR, F, and H Reactors

$$\Delta p_{fR} = p_T - \Delta p_s \quad \text{and } \Delta p_s \text{ is presented in Figure 17.} \quad (18a)$$

2. C Reactor

$$\Delta p_{fR} = p_T - \Delta p_s - \rho_B \frac{V_B^2}{2g} \quad (18b)$$

$$\text{Or } \Delta p_{fR} = p_B - 15.7 - \Delta p_s - \rho_B \frac{V_B^2}{2g} \quad (18c)$$

Where, again, Δp_s values are obtained from Figure 17.

3. KE and KW Reactors

$$\Delta p_{fR} = p_B - 19 - \Delta p_{sO} - \rho_B \frac{V_B^2}{2g} \quad (18d)$$

The expression, $19 + \Delta p_{sO}$, is combined in Figure 18 to give the total static head effect of water level in the downcomer approach section above the point of measurement of riser pressure, BORP. Therefore:

$$\Delta p_{fR} = p_B - \Delta p_{sO}' - \rho_B \frac{V_B^2}{2g} \quad (18e)$$

$$\text{Or } \Delta p_{fR} = p_T - \Delta p_{sO} - \rho_B \frac{V_B^2}{2g} \quad (18f)$$

Where $\Delta p_{sO}' = 19 + \Delta p_{sO}$

Δp_{sO} = net elevation difference between a theoretical TORP reference point and height of water in the downcomer approach section.

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The effect of outlet temperature on Δp_{fR} can be approximated by the empirical expression:

$$\frac{\Delta p_{fR} @ T_2}{\Delta p_{fR} @ T_1} \cong .50 + .50 \left(\frac{\rho_1}{\rho_2} \right) \left(\frac{\mu_2}{\mu_1} \right)^{0.2} \quad (19)$$

The following charts present TORP (BORP) and Δp_{fR} as a function of flow for all Hanford production reactors.

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FIGURE 16
B-Reactor Flow Match Point
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React

FIGURE 17

- B, C, D, DR, F, & H Reactors

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Reac

Estimated Static Head

r Flow - 1000 GPM

FIGURE 18
Above BORP K-Reactors

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B-

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FIGURE 19

Reactor Top of Riser Pressure vs. Flow
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FIGURE 20
B-Reactor Δp_{fr} vs. Flow
(February 1962)

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Reactor Flow - 1000 GPM

FIGURE 21

Reactor Top of Riser Pressure vs. Flow
(December 1961)

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FIGURE 22

C-Reactor ΔP_{fR} vs. Flow
(December 1961)

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FIGURE 23

Reactor Top of Riser Pressure vs. Flow
(February 1962)

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FIGURE 24

D-Reactor Δp_{fR} vs. Flow
(February 1962)

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FIGURE 25

Reactor Top of Riser Pressure vs. Flow
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FIGURE 26
DR-Reactor ΔP_{fR} vs. Flow
(February 1962)

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~~SECRET~~
~~CONFIDENTIAL~~
~~UNCLASSIFIED~~

FIGURE 27

-Reactor Top of Riser Pressure vs. Flow
(February 1962)

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FIGURE 28
F-Reactor Δp_{fR} vs. Flow
(February 1962)

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FIGURE 29

Reactor Top of Riser Pressure vs. Flow
(January 1962)

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FIGURE 30
H-Reactor Δp_R vs. Flow
(January 1962)

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K-1

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FIGURE 31

actors Bottom of Riser Pressure vs. Flow
(January 1962)

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FIGURE 32

K-Reactors ΔP_{fr} vs. Flow
(January 1962)

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IV. ACKNOWLEDGMENT

The authors have incorporated in this report material listed in many different documents. For the most part, these are included in the Bibliography. In case of oversight, the authors wish to express their thanks to the personnel of Process Engineering and Facilities Engineering Operation who have helped provide these data.

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ACKNOWLEDGMENT (Cont'd)

The authors are also indebted to F. H. Champagne for his work on the theoretical reactor flow resistance presented as the Δp_f curves in this report.

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ERRATA

The K-Area project noted on pages 4, 11, 21, and 22, was CGI-844, and not CGI-884, as noted.

Emergency Reservoir Water Pump - Bldg. 182

183 FILTER PLANT BACKWASH PUMPS

IMPELLER DIA.: 23 1/2
 PATT. NO. 16AFYBA
 CURVE NO. 15380
 DU PONT ORD. RPG 355 1/2
 PROJECT 9536
 EQ. PE. 183-804, 804A, 804B
 CHARACTERISTIC CURVE
 NO. 16 TYPE AFY 700 RPM
 PUMP NO. (SEE LIST)

DATE 6-14-44
 SERIAL NOS.
 01443043
 45
 46
 47) FILTER PLANT
 49) BACKWASH
 51)

TOTAL HEAD

G.P.M.

13000

12000

10000

8000

6000

4000

2000

0

EMERGENCY FILTERED WATER TO PROCESS, BLDG. 183

TEST CURVE NO. 36980-A

10x8 TYPE SH CENT. PUMP 37803

1000 G.P.M. 250 FE. HD 2250 R.P.M.

FOR

E. I. DUPONT de Nemours

ALLIS-CHAMBERS MFG. CO.

MILWAUKEE, WIS.

6/11/70 C.T.

C.O. R.P.G. 4213

DIA. 19"
 100 Max. Dia. 21"
 300
 200
 100
 0
 PSI

1265 RPM BHP
 1150 R.P.M.
 BHP SP. GR. = 1.0
 1150 RPM
 565 RPM BHP
 1150 RPM
 1150 RPM EFFICIENCY
 565 RPM EFFICIENCY

1000-GALLONS PER MINUTE
 0
 10
 20
 30
 40
 50
 60
 70
 80
 90
 100
 110
 120
 130
 140
 150
 160
 170
 180
 190
 200

0
 10
 20
 30
 40
 50
 60
 70
 80
 90
 100
 110
 120
 130
 140
 150
 160
 170
 180
 190
 200

CHARACTERISTIC CURVE
 NO. 16 TYPE A1Y PUMP
 1150 R.P.M.
 ORDER NO.
 PUMP TO.
 LINGERSOLL-RAND COMPANY
 CAMBROT PUMP DIVISION
 DATE 6-18-42
 CURVE 536PW-T

BLDG. 190 WATER REUSE PUMPS RFG 1052 1/2

MOTOR DRIVEN PROCESS PUMPS - RFG 419.1 1/2 BLDG. 190

DIA 16 3/4

INLET PATT. NO. 8GT-B

HANFORD ENGL. PROJECT

CHARACTERISTIC CURVE

NO. 8 TYPE GT-2 PUMP

1775 R.P.M.

PUMP NO. 034132 ORDER NO. 33-985

FINGERSOLL-RAND COMPANY

CAMERON PUMP DIVISION

DATE 3/29/44

CURVE 1505F

Gallons Per Minute

PER CENT EFFICIENCY

TOTAL HEAD IN FEET

BRAKE HORSE POWER

Curve No. 148 8
Date 8-11-44

STEAM PROCESS PUMP 190

E. I. DUPONT

PRIMARY PUMP

HANFORD ENG. PROJECT

CHARACTERISTIC CURVE

NO. 10 TYPE ALV PUMP

2100/2310 R.P.M.

PUMP NO. 02145080 ORDER NO. 33-985

INGERSOLL-RAND COMPANY

CAMERON PUMP DIVISION

DATE 22/11/44 CURVE

ASH SLUICE PUMPS

MOTOR DRIVEN FILTERED WATER TO POWER HOUSE PUMPS.

Turbine Driven River Water Pumps RFG 192 $\frac{1}{2}$ - 592 $\frac{1}{2}$

Steam Driven Reservoir Pumps RFG 209 $\frac{1}{2}$ and Steam Driven Pumps RFG 421 $\frac{1}{2}$

PROPOSAL CURVE NO. 8879-A

10x8 TYPE SH CENT. PUMP

1000 G.P.M. 250 FT. HD 2250 R.P.M.

FOR

E. I. DUPONT DE NEMOURS

ALLIS CHALMERS MFG. CO.

MILWAUKEE, WIS.

5-25-43 E.A.B.