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REPORT [redacted]

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MEASUREMENT OF PRESSURE DROPS ACROSS STANDARD PIPE AND FITTINGS

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FOREWORD

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[redacted] submits this report in compliance with Item 3.4 of the Development Objectives of [redacted] This report should be read in conjunction with Report [redacted] of which it forms part.

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ABSTRACT

Pressure drops were measured and recorded, tabularly and graphically, for various polyvinyl chloride fittings and straight pipe, both before and after reaming and fairing all internal protrusions. All mensuration equipment was described in detail and calibration data were included. Numerous tests and calculations were performed on the pump to check its operation. Recommendations for further research, in the light of present findings, are appended.

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SECTION 1

INTRODUCTION

1.1 DATA LIMITATIONS

When the liquid bearing concept was first considered, the state-of-the-art in processor design required only the movement of film through the various steps of developing and fixing by means of rollers or sprockets. Hydrodynamic and fluid mechanic complexities introduced by the new bearing, in which the film was supported on a liquid cushion, required STATOTHR [redacted] STATOTHR [redacted] engineers to depend heavily on available technical data - pump capacities, pipe and fitting losses, pressure drops through filters, and frictional coefficient buildup with photochemical deposits. Inadequacies in the published data parameters quickly became apparent when pump capacities had to be virtually doubled to compensate for line losses, even though supposedly ample design safety factors had been incorporated.

1.2 PURPOSE AND OBJECTIVES

One of the foremost objectives of the assignment was to satisfy the need for these missing parameters and provide, generally, a more complete technical documentation of fundamental engineering data germane to processor design. One important byproduct of the research program, then, was to eliminate rule-of-thumb calculations in which the pressure drop in a 45-degree elbow was assumed to be one-half of that for a 90-degree elbow, or that in a valve four times a 90-degree elbow, with a safety factor of 20 percent or better.

With the shortcomings of technical literature in mind, the objectives of the research project were formulated. The following list comprises the most important research objectives for this part of the program:

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1) Check as many different fittings (including straight pipe) as feasible in the light of time and budget.

2) Begin experimentation on 1-1/4-inch rigid polyvinyl chloride (PVC) pipe and threaded fittings. Measure Δp with unburred fittings and pipe. Repeat tests with burred fittings and internal taper.

3) Repeat tests outlined in objective (2) with socket-type fittings.

4) Repeat the series of tests with polished, sanitary stainless steel dairy pipe and fittings.

5) Determine the effect of pump inlet pipe size.

6) Determine the effect of restricted inlet pipe size.

7) Study input of pump, mechanical efficiency, losses, and the effect of a dropping head on pump output.

8) Make a long run breakdown test of pump, using actual photographic chemical solutions.

9) Check the interrelationship of pump outlet angle on delivered gpm.

10) Make effectivity comparisons among various types of flowmeters - rotameter, orifices, venturi, and newer types.

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SECTION 2

TECHNICAL DISCUSSION

2.1 EQUIPMENT AND INSTRUMENTATION

The pressure drop test apparatus is illustrated in Figures 2-1, 2-2, 2-3, and 2-4. All instrumentation and fittings are described in detail in Appendix F. A stainless-steel hold tank, on loan from [redacted] formed the core of the circulatory setup. From its center bottom outlet, a 2-inch ID PVC pipe fed a 2-horsepower centrifugal pump.

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On both the inlet and outlet sides of the pump, thermometer wells were provided for measuring T_1 and T_2 respectively. Unions were installed on both sides to enable easy removal of the unit without disturbing the rest of the apparatus. On the downstream side, a valved tee for drainage and a pressure gage to read P_1 were provided. The piping then led directly to a 1-1/4-inch ball throttling valve and the flowmeter, and from the latter to the remaining test apparatus. The test piping and fittings were all 1-1/4-inch PVC, with the exceptions noted (Appendix F). They were supported on two tiers by wooden racks.

The lower level was a straight run of pipe over 10 feet long; a riser led to the upper level and to a union leading to a tee. The left branch of the tee was arbitrarily designated Branch I and the right, Branch II. Each of these two branches returned to the hold tank. Branch I embodied three test fittings and Branch II, four. The wooden supporting racks were carefully leveled so that both the upper and lower stages were precisely horizontal. Each fitting was provided with an upstream and downstream pressure tap for Δp measurement. These consisted of holes drilled and tapped for 1/8-inch standard pipe thread. The tapping depth was controlled so that when the flanged brass tubing adapters were screwed in, their bottoms would be flush with the inside of the pipe in accordance with Hydraulic

Institute Standards (Ref: 11). The test apparatus was completely assembled from a scale drawing by two shop plumbers. The only specific instruction given them was to use standard shop practice in cutting, fitting, and threading pipe and to use "Proseal" (flexible two-component epoxy mixture) in making up the joints. The completed test rack closely approximated the assembly technique incorporated in any standard [redacted] gear.

All pressure drops were measured with either a vertical U-tube manometer or a sensitive inclined mercury manometer. The tank temperature, T_3, was measured with an accurate Centigrade thermometer.

2.2 PRESSURE DROP EXPERIMENTATION

The first step in the research project was the calibration of the flowmeter. This was done by accurately timing, with a stopwatch, the filling of a standard bucket whose exact capacity had been measured. Enough runs were made at each 2 gpm flow increment on the rotameter scale to assure an accurate mean average. The data are presented graphically in Figure 2-5 and tabularly in Table 2-1. Based on the same data, the Reynolds numbers were calculated and plotted against friction coefficients (both are dimensionless) for PVC pipe (Figure 2-6). The data for various commercial pipes and tubes were obtained from the literature (References 1 and 2). It is interesting to note how much less the coefficients of friction are for plastic than for glass, supposedly the epitome of smoothness.

The pressure drops and Reynolds numbers were measured on the horizontal 10.020-foot section of the 1-1/4-inch PVC pipe (lower level). So that the total pressure drop for the section could be measured simultaneously, a long 1/4-inch diameter copper tube was connected to the upstream pressure tap and brought to the downstream end. When all lines were bled free of air, the readings were taken on the inclined mercury manometer.

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Time, rate of flow, temperature, inlet pressure, and pressure drop were recorded in a typical series of tests. The flow was changed from maximum to minimum rotameter readings in 5 gpm increments. Enough rechecks were made to assure reproducibility of readings. As the tests progressed, it was found better practice to proceed from the lowest to the highest flow reading. Use of this technique resulted in less overall temperature variation (since the tank was nonadiabatic) for a series which might take as long as 26 minutes. Corrections for density, viscosity, etc., with temperature were made in the observed results (Appendix A).

Since the accurate calorimetric thermometers used were of the total immersion type, stem temperatures were recorded during the early runs. A sample calculation (Appendix B) showed the stem correction to be negligible in the 69° to 77°F ambient operating temperature range used, so it was neglected.

Pressure drops on the 1-1/4-inch tee were recorded across each leg independently, with the opposite leg blocked off, and again with both legs open. Data obtained for pressure drops with both legs of the tee open were omitted because their intervariation was slight and in all cases, the readings were less than those with one leg blocked off. Since design would be based on maximums, these data lost their significance. Note that the pressure drops across the leg leading to Branch II were higher than those leading to Branch I. Two explanations are possible: 1) An internal aberration in the plastic die not removed by the burring operation was responsible, or 2) The increased pressure drop in Branch II (in all cases higher than Branch I) was reflected back to the leg of the tee.

In only three instances could comparable data be found in published charts, those for straight pipe, a 90-degree elbow, and a tee. These are presented, together with our data, in Figures 2-7, 2-8, and 2-9. Some of the proprietary data seems overly optimistic. Note that the [redacted]

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data is not exactly comparable, since the closest size to our 1-1/4-inch ID pipe is their 1.402-inch stainless.

The remaining data are presented graphically in Figures 2-10 through 2-19 and tabularly in Tables 2-2 through 2-20. Each set of data presents a comparison between pressure drops in the fittings with unreamed pipe and with reamed pipe. The latter data were obtained in the following manner. After all tests were made on the original setup, the components were carefully identified and the apparatus completely disassembled. All fittings were internally deburred and each end of the connecting pipes faired with a special tool (Figure 2-20). The apparatus was then reassembled with Proseal in exactly the original order and orientation. With no other change, the flow was increased 6.7 percent. This result points to possible economies in reduced pump sizing on large production machines.

When the test apparatus was first assembled, a source of sweep fittings to check against the common, standard pipe thread, short-turn types could not be located. Continued market research uncovered a line of specialized electrical conduit fittings manufactured by [redacted] The tests were subsequently performed on two of these PVC Schedule 40 conduit turns (Figure 2-13) fitted with female adapters, slip to thread. The pressure drops in the 90-degree sweep elbow (Figure 2-12 and Table 2-14) were almost exactly equal to those of a straight pipe of equivalent length. In neither the case of the 45-degree sweep nor that of the short-turn elbow were the pressure drops half of those of the 90-degree elbow. They were more. This phenomenon cannot be explained by inaccuracies of mensuration (see discussion of errors, Appendix C). The appendix also includes calculations of pump heads and effect of discharge angle on delivery.

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TABLE 2-1
FLOWMETER CALIBRATION DATA AND REYNOLDS NUMBER CALCULATION

Flowmeter Reading gpm	Measured Flow gpm	T_2 °F	ρ gm/ml	ft^3/sec	V ft/sec	$1/V^2$ sec^2/ft^2	f	μ lb/ft sec	$1/\mu$ ft. sec./lb.	ρ lb./ft^3	R_ϵ
41.2	40.8	71.05	.99720	.0893	10.36	.00932	.00218	.000608	1645	62.25	1.11×10^5
39.6	40.8	72.55									
37.7	38.2	72.75	.99718	.0833	9.66	.01072	.00214	.000607	1649	62.25	1.04×10^5
35.8	38.2	72.85									
33.9	33.8	72.95	.99716	.0724	8.40	.01417	.00215	.000606	1651	62.25	9.05×10^4
32.1	31.2	72.45									
30.2	29.6	72.55									
28.3	26.9	72.65	.99716	.0618	7.17	.01945	.00228	.000605	1652	62.25	7.73×10^4
26.3	26.3	72.70									
24.4	23.7	72.85									
22.5	21.5	72.90	.99714	.0509	5.90	.02873	.00349	.000605	1654	62.25	6.37×10^4
20.6	19.7	73.00									
18.7	18.2	73.10	.99713	.0400	4.64	.04645	.00259	.000604	1655	62.25	5.01×10^4
16.7	15.8	73.20									
14.7	13.9	73.30	.99712	.0291	3.38	.08754	.00315	.000603	1657	62.25	3.65×10^4
12.8	11.1	73.45									
10.9	10.3	73.50									
9.0	7.9	73.55	.99710	.0182	2.11	.2246	.00332	.000603	1660	62.25	2.29×10^4
6.9	7.2	73.65									
4.9	4.5	73.75									
-	2.6	74.05	.99706	.0071	.823	1.476	.00417	.000600	1667	62.25	8.95×10^3

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Table 2-2

Head Loss In Feet Of Water/100 Feet Of 1-1/4-Inch PVC Pipe

(Unreamed)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	Δø				Total	Total/2	Ft. Water $\times \frac{13.56}{12} - 1$	Ft. Loss/ 100' $\times \frac{100}{10.02}$		
				Zero	High	Zero	Low						
40.6	41.1	76.08	13.9	.03	2.95	.54	4.25	6.63	3.32	3.48	34.73		
37.7	37.7	76.21	14.4		2.46		3.78	5.67	2.84	2.97	29.64		
33.0	32.6	76.32	15.1		1.86		3.00	4.29	2.15	2.25	22.46		
28.3	27.8	76.39	15.7		1.45		2.44	3.32	1.66	1.74	17.37		
23.5	22.9	26.45	16.2		1.07		1.95	2.45	1.23	1.29	12.87		
18.7	18.0	76.56	16.7		.68		1.47	1.58	.79	.83	8.28		
13.8	13.0	76.62	17.3		.40		1.19	1.02	.51	.53	55.29		
9.0	8.2	76.76	17.8		.17		.81	.41	.21	.22	2.19		
4.1	4.1	77.06	18.3		.03		.61	.07	.04	.04	.40		
40.7	41.2	76.65	13.9		2.88		4.28	6.59	3.30	3.46	34.53		

Table 2-3

Head Loss In Feet Of Water/100 Feet Of 1-1/4-Inch PVC Pipe

(Reamed)

43.2	44.3	70.30	13.6	.53	4.63	.03	3.57	7.64	3.82	4.00	39.92		
40.0	40.4	70.25	14.1		4.07		3.12	6.63	3.32	3.48	34.73		
35.0	34.7	70.22	14.9		3.29		2.43	5.16	2.58	2.70	26.95		
30.0	29.5	70.16	15.6		2.57		1.86	3.87	1.94	2.03	20.26		
25.0	24.4	70.15	16.0		2.00		1.43	2.87	1.44	1.51	15.07		
20.0	19.3	70.13	16.5		1.48		.96	1.88	.94	.98	9.78		
15.0	14.2	70.15	16.9		1.04		.59	1.07	.54	.57	5.69		
10.0	9.2	70.15	17.8		.74		.32	.50	.25	.26	2.59		
5.0	4.8	70.27	18.2		.56		.13	.13	.07	.07	.70		

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Table 2-4

Head Loss In Feet Of Water For 1-1/4" Rigid PVC Union

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	$\Delta\phi$				Total	Total/2	Ft. Water x $\frac{13.56-1}{12}$	Correction Factor Ft. Loss/Inch	Tap Distance x 14.4 In.	Corrected Reading Hd Loss in Ft.
				Zero	High	Zero	Low						
40.5	41.0	70.33	13.8	.25	1.14	.09	.57	1.37	.69	.72	.0297	-.43	.29
35.0	34.7	70.35	14.6		.90		.50	1.06	.53	.55	.0211	-.30	.25
30.0	29.5	70.42	15.4		.77		.43	.86	.43	.45	.0158	-.23	.22
25.0	24.4	70.47	15.9		.67		.37	.70	.35	.37	.0117	-.17	.20
20.0	19.3	70.55	16.6		.57		.32	.55	.28	.29	.0082	-.12	.17
15.0	14.2	70.62	17.1		.47		.27	.40	.20	.21	.0051	-.07	.14
10.0	9.2	70.67	17.6		.40		.23	.29	.15	.16	.0024	-.03	.13
5.0	4.8	70.69	18.1		.33		.23	.22	.11	.11	.0009	-.01	.10

Table 2-5

Head Loss In Feet Of Water For 1-1/2" Rigid PVC Union

(Reamed Pipe)

43.2	44.3	70.61	13.6	.50	1.48	.08	.52	1.42	.71	.74	.0333	-.48	.26
40.0	40.4	70.56	14.2		1.37		.43	1.22	.61	.64	.0289	-.42	.24
35.0	34.7	70.55	15.0		1.17		.36	.95	.48	.50	.0225	-.32	.18
30.0	29.5	70.50	15.6		.98		.28	.68	.34	.36	.0169	-.24	.12
25.0	24.4	70.42	16.0		.85		.25	.52	.26	.27	.0126	-.18	.09
20.0	19.3	70.40	16.7		.72		.19	.33	.17	.18	.00816	-.12	.06
15.0	14.2	70.40	17.1		.62		.16	.20	.10	.11	.00475	-.07	.04
10.0	9.2	70.40	17.7		.55		.12	.09	.05	.05	.00217	-.03	.02

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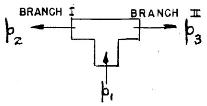

Table 2-6

Head Loss In Feet Of Water For 1-1/4" Rigid PVC Tee

($\Delta \phi_1 \phi_2$ For Unreamed Pipe) Branch I Open - Branch II Closed

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	$\Delta \phi_1 \phi_2$				Total	Total/2	Ft. Water x $\frac{13.56}{12}$ -1	Correction Factor Ft. Loss/In.	Tab Distance x14.45	Corrected Reading Hd Loss in Ft.
				Zero	High	Zero	Low						
40.5	41.0	70.52	13.9	.25	2.90	.09	2.44	5.00	2.50	2.62	.0297	-.43	2.19
35.0	34.7	70.56	14.7		2.26		1.97	3.89	1.95	2.04	.0211	-.31	1.73
30.0	39.5	70.58	15.6		1.77		1.48	2.91	1.46	1.53	.0158	-.23	1.30
25.0	24.4	70.62	15.8		1.36		1.12	2.14	1.07	1.12	.0117	-.17	.95
20.0	19.3	70.66	16.6		1.00		.80	1.46	.73	.76	.0082	-.12	.64
15.0	14.2	70.73	17.1		.72		.54	.92	.46	.48	.0051	-.07	.41
10.0	9.2	70.82	17.5		.51		.36	.53	.27	.28	.0024	-.03	.25
5.0	4.8	70.94	18.2		.35		.21	.22	.11	.12	.0009	-.01	.11

Table 2-7

Head Loss In Feet Of Water For 1-1/4 Rigid PVC Tee

($\Delta \phi_1 \phi_3$ For Unreamed) Branch I Closed - Branch II Open

				$\Delta \phi_1 \phi_3$								x14.55	
				Zero	High	Zero	Low						
40.0	40.4	71.33	13.8	.26	3.30	.10	2.64	5.58	2.79	2.92	.0289	-.42	2.50
35.0	34.7	71.42	14.8		2.66		2.34	4.64	2.32	2.43	.0211	-.31	2.01
30.0	29.5	71.45	15.5		2.13		1.74	3.51	1.76	1.84	.0158	-.23	1.61
25.0	24.4	71.47	16.1		1.62		1.39	2.65	1.33	1.39	.0117	-.17	1.22
20.0	19.3	71.52	16.7		1.20		1.02	1.86	.93	.97	.0082	-.12	.85
15.0	14.2	71.58	17.2		.89		.69	1.22	.61	.64	.0051	-.07	.57
10.0	9.2	71.62	17.6		.60		.42	.66	.33	.35	.0024	-.03	..32
5.0	4.8	71.75	18.0		.42		.26	.32	.16	.17	.0009	-.01	.16

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Table 2-8

Head Loss In Feet Of Water For 1-1/4" Rigid PVC Tee

($\Delta p'_1 p'_2$ For Reamed) Branch I Open - Branch II Closed

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	$\Delta p'_1 p'_2$				Total	Total/2	Ft. Water x $\frac{13.56}{12} - 1$	Correction Factor Ft. Loss/In.	Tab Distance x 14.45	Corrected Reading Hd Loss in Ft.
				Zero	High	Zero	Low						
43.2	44.3	70.82	13.8	.51	3.28	.08	2.63	5.32	2.66	2.78	.0333	-.48	2.30
40.0	40.4	70.80	14.3		2.85		2.24	4.50	2.25	2.35	.0289	-.42	1.93
35.0	34.7	70.73	15.0		2.33		1.76	3.50	1.75	1.83	.0225	-.33	1.50
30.0	29.5	70.70	15.6		1.83		1.32	2.56	1.28	1.34	.0169	-.24	1.10'
25.0	24.4	70.67	16.0		1.47		1.00	1.88	.94	.98	.0126	-.18	.80
20.0	19.3	70.66	16.6		1.09		.68	1.18	.59	.62	.00816	-.12	.50
15.0	14.2	70.71	17.1		.87		.44	.72	.36	.38	.00475	-.07	.31
10.0	9.2	70.70	17.7		.66		.27	.34	.17	.18	.00217	-.03	.15
5.0	4.8	70.90	18.1		.53		.13	.07	.04	.04	.00058	-.01	.03

Table 2-9

Head Loss In Feet Of Water For 1-1/4" Rigid PVC Tee

($\Delta p_1 p_2$ For Reamed) Branch I Closed - Branch II Open

42.7	43.7	69.38	13.8	.51	3.38	.08	2.71	5.50	2.75	2.88	.0327	-.48	2.40
40.0	40.4	69.38	14.2		3.02		2.41	4.84	2.42	2.58	.0289	-.42	2.11
35.0	34.7	69.37	14.9		2.46		1.89	3.76	1.88	1.97	.0225	-.33	1.64
30.0	29.5	69.37	15.5		1.97		1.46	2.84	1.42	1.49	.0164	-.25	1.24
25.0	24.4	69.38	16.0		1.54		1.07	2.02	1.01	1.06	.0126	-.18	.88
20.00	19.3	69.40	16.6		1.20		.73	1.34	.67	.70	.00816	-.12	.58
15.0	14.2	69.40	17.1		.97		.51	.89	.45	.47	.00475	-.07	.40
10.0	9.2	69.55	17.6		.72		.30	.43	.22	.23	.00217	-.03	.20
5.0	4.8	69.60	18.2		.55		.13	.09	.05	.05	.00058	-.01	.04

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Table 2-10

Head Loss In Feet Of Water For 1-1/4" Rigid PVC 90° Elbow

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	Δφ Zero	High	Zero	Low	Total	Total/2	Ft. Water $\times \frac{13.56}{12} - 1$	Correction Factor Ft. Loss/In.	Tab Distance x14.45	Corrected Reading Hd Loss in Ft.
40.5	41.0	69.97	13.8	.50	2.76	.05	2.12	4.33	2.17	2.27	.0297	-.46	1.81
35.0	34.7	70.06	14.7		2.19		1.62	3.26	1.63	1.71	.0211	-.33	1.38
30.0	39.5	70.12	15.3		1.73		1.21	2.39	1.20	1.26	.0158	-.24	1.02
25.0	24.4	70.17	15.9		1.38		.89	1.72	.86	.90	.0117	-.18	.72
20.0	19.3	70.22	16.6		1.05		.62	1.12	.56	.59	.0082	-.13	.46
15.0	14.2	70.31	16.9		.83		.40	.68	.34	.36	.0051	-.08	.28
10.0	9.2	70.36	17.6		.63		.23	.31	.16	.17	.0024	-.04	.13
5.0	4.8	70.52	18.1		.52		.13	.10	.05	.05	.0009	-.01	.04

Table 2-11

Head Loss In Feet of Water For 1-1/4" Rigid PVC 90° Elbow

(Reamed Pipe)

43.2	44.3	71.66	13.8	.37	2.38	.20	1.98	3.79	1.90	1.99	.0333	-.51	1.48
40.0	40.4	71.65	14.3		2.05		1.72	3.20	1.60	1.68	.0289	-.45	1.28
35.0	34.7	71.65	14.9		1.64		1.33	2.40	1.20	1.25	.0225	-.35	.90
30.0	29.5	71.63	15.6		1.35		1.09	1.87	.94	.99	.0169	-.26	.73
25.0	24.4	71.64	15.9		1.12		.77	1.32	.66	.69	.0126	-.19	.50
20.0	19.3	71.65	16.5		.81		.62	.86	.43	.45	.00816	-.13	.32
15.0	14.2	71.65	16.9		.65		.47	.55	.28	.29	.00475	-.07	.22
10.0	9.2	71.67	17.4		.47		.32	.22	.11	.12	.00217	-.03	.09
5.0	4.8	71.80	18.3		.40		.23	.06	.03	.03	.00058	-.01	.02

STAT

Table 2-12

Head Loss In Feet Of Water For 1-1/4" Flanged 90° Elbow

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	Δø				Total	Total/2	Ft. Water $\times \frac{13.65}{12} - 1$	Correction Factor Ft. Loss/In.	Tab Distance x14.45	Corrected Reading Hd Loss in Ft.
				Zero	High	Zero	Low						
40.2	40.6	69.44	14.1	.52	2.38	.08	1.72	3.50	1.75	1.83	.0291	-.43	1.40
35.0	34.7	69.48	14.7		1.96		1.29	2.65	1.33	1.39	.0211	-.31	1.08
30.0	29.5	69.53	15.5		1.53		.97	1.90	.95	.99	.0158	-.23	.76
25.0	24.4	69.56	15.8		1.26		.71	1.37	.69	.72	.0117	-.17	.55
20.0	19.3	69.63	16.6		.96		.49	.85	.43	.45	.0082	-.12	.33
15.0	14.2	69.67	17.0		.79		.35	.54	.27	.28	.0051	-.07	.21
10.0	9.2	69.74	17.6		.63		.22	.25	.13	.14	.0024	-.04	.10
5.0	4.8	69.88	18.1		.52		.15	.07	.04	.04	.0009	-.01	.03

Table 2-13

Head Loss In Feet Of Water For 1-1/4" Flanged 90° Elbow

(Reamed Pipe)

42.7	43.7	68.45	13.8	.39	2.37	.22	2.00	3.76	1.88	1.97	.0326	-.48	1.49
40.0	40.4	68.42	14.2		2.12		1.73	3.24	1.62	1.70	.0289	-.42	1.28
35.0	34.7	68.40	14.8		1.71		1.38	2.48	1.24	1.30	.0225	-.33	.97
30.0	29.5	68.40	15.6		1.35		1.08	1.82	.91	.95	.0169	-.25	.70
25.0	24.4	68.36	16.1		1.07		.83	1.29	.65	.68	.9126	-.18	.50
20.0	19.3	68.36	16.6		.82		.62	.83	.42	.44	.00816	-.12	.32
15.0	14.2	68.40	17.1		.63		.44	.46	.23	.24	.00475	-.07	.17
10.0	9.2	68.43	17.7		.49		.32	.20	.10	.10	.00217	-.03	.07
5.0	4.8	68.50	18.2		.42		.25	.06	.03	.03	.00058	-.01	.02

Table 2-14

Head Loss In Feet Of Water For 1-1/4" Rigid 90° Swéep Elbow

(Reamed Pipe)

Meter Flow gpm	Corrected gpm	T_3 °C	P_1 psi	ΔØ				Total	Total/2	Ft. Water x $\frac{13.56}{12}-1$	Correction Factor Ft. Loss/In.	Tab Distance x14.45	Corrected Reading Hd Loss in Ft.
				Zero	High	Zero	Low						
45.0	46.9	14.50	24.9	.38	1.32	.18	1.22	2.54	1.27	1.33	.0458	-.67	.66
40.0	40.4	14.42	25.6		1.18		1.10	1.72	.86	.90	.0225	-.43	.47
35.0	34.7	14.34	26.4		.92		.90	1.26	.63	.66	.0225	-.33	.33
30.0	29.5	14.31	27.1		.81		.70	.95	.48	.50	.0169	-.25	.25
25.0	24.4	14.17	27.5		.67		.57	.68	.34	.36	.0126	-.18	.18
20.0	19.3	14.10	28.0		.57		.45	.46	.23	.24	.00816	-.12	.12
15.0	14.2	14.02	28.5		.49		.34	.27	.14	.15	.00475	-.07	.08
10.0	9.2	13.93	29.1		.43		.26	.13	.07	.07	.00217	-.03	.04
5.0	4.8	13.85	30.0		.38		.21	.03	.02	.02	.00058	-.01	.01
5.0	4.8												

Table 2-15

Head Loss In Feet Of Water For 1-1/4" Rigid 45° Sweep Elbow

(Reamed Pipe)

												x 14.67	
45.0	46.9	15.46	24.8	.32	2.30	.18	2.10	3.90	1.95	2.04	.0458	-.67	1.37
40.0	40.4	15.42	25.5		1.73		1.57	2.80	1.40	1.47	.0289	-.42	1.05
35.0	34.7	15.34	26.4		1.43		1.22	2.15	1.08	1.13	.0225	-.33	.80
30.0	29.5	15.30	27.1		1.13		.96	1.59	.80	.84	.0169	-.25	.59
25.0	24.4	15.21	27.6		.93		.73	1.16	.58	.61	.0126	-.18	.43
20.0	19.3	15.18	28.1		.74		.55	.79	.40	.42	.00816	-.12	.30
15.0	14.2	15.15	28.5		.58		.38	.46	.23	.24	.00475	-.07	.17
10.0	9.2	15.08	29.0		.46		.26	.22	.11	.12	.00217	-.03	.09
5.0	4.8	15.00	30.1		.40		.18	.08	.04	.04	.00058	-.01	.03

STAT

Table 2-16

Head Loss In Feet Of Water For 1-1/4" Rigid 45° Elbow

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	Δ∅ Zero	High	Zero	Low	Total	Total/2	Ft. Water x $\frac{13.56}{12}-1$	Correction Factor Ft. Loss/In.	Tab Distance x14.45	Corrected Reading Hd Loss in Ft.
40.2	40.6	70.27	13.9	.52	2.74	.08	2.30	4.46	2.23	2.33	.0291	-.43	1.90
35.0	34.7	70.37	14.7		2.22		1.76	3.40	1.70	1.78	.0211	-.31	1.47
30.0	39.5	70.41	15.3		1.78		1.32	2.52	1.26	1.32	.9158	-.23	1.09
25.0	24.4	70.42	15.8		1.38		.92	1.72	.86	.90	.0117	-.17	.73
20.0	19.3	70.51	16.6		1.06		.61	1.09	.55	.58	.0082	-.12	.46
15.0	14.2	70.66	17.1		.82		.39	.63	.32	.34	.0051	-.07	.27
10.0	9.2	70.66	17.5		.64		.22	.28	.14	.15	.0024	-.04	.11
5.0	4.8	70.77	18.1		.53		.10	.05	.03	.03	.0009	-.01	.02

Table 2-17

Head Loss In Feet Of Water For 1-1/4 Rigid 45° Elbow

(Reamed Pipe)

42.5	43.4	69.17	13.6	.37	2.34	.20	2.18	3.95	1.98	2.08	.0324	-.48	1.60
40.0	40.4	69.15	14.2		2.08		1.93	3.44	1.72	1.80	.0289	-.42	1.38
35.0	34.7	69.13	14.9		1.76		1.58	2.77	1.39	1.45	.0225	-.33	1.12
30.0	29.5	69.08	15.6		1.38		1.22	2.03	1.02	1.07	.0169	-.25	.82
25.0	24.4	69.07	16.2		1.05		.91	1.39	.70	.73	.0126	-.18	.55
20.0	19.3	69.07	16.6		.81		.67	.91	.46	.48	.00816	-.12	.36
15.0	14.2	69.10	17.1		.62		.48	.53	.27	.28	.00475	-.07	.21
10.0	9.2	69.15	17.6		.47		.32	.22	.11	.12	.00217	-.03	.09
5.0	4.8	69.20	18.2		.38		.23	.04	.02	.02	.00058	-.01	.01

Table 2-18

Head Loss In Feet Of Water For 1-1/4" Rigid PVC Ball Valve

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	Δφ Zero	High	Zero	Low	Total	Total/2	Ft. Water x $\frac{13.56}{12}-1$	Correction Factor Ft. Loss/In.	Tab Distance x 16.50	Corrected Reading Hd Loss in Ft.
40.5	41.0	69.67	13.8	.50	1.89	.05	1.26	2.60	1.30	1.36	.0297	-.49	.87
35.0	34.7	69.75	14.7		1.54		.98	1.97	.99	1.04	.0211	-.35	.69
30.0	29.5	69.81	15.4		1.25		.73	1.43	..72	.75	.0158	-.26	.49
25.0	24.4	69.87	15.9		1.02		.65	1.12	.56	.59	.0117	-.19	.40
20.0	19.3	69.93	16.6		.83		.38	.66	.33	.35	.0082	-.14	.21
15.0	14.2	69.96	17.1		.68		.28	.41	.21	.22	.0051	-.08	.14
10.0	9.2	70.03	17.4		.57		.18	.20	.10	.10	.0024	-.04	.06
5.0	4.8	70.21	17.9		.50		.13	.08	.04	.04	.0009	-.01	.03

Table 2-19

Head Loss In Feet Of Water For 1-1/4" Rigid PVC Ball Valve

(Reamed Pipe)

43.2	44.3	67.86	13.6	.37	1.27	.19	.88	1.59	.80	.84	.0333	-.55	.29
40.0	40.4	67.82	14.2		1.12		.78	1.34	.67	.70	.0289	-.48	.22
35.0	34.7	67.80	14.9		.94		.65	1.03	.52	.54	.0225	-.37	.17
30.0	29.5	67.80	15.5		.77		.52	.73	.37	.39	.0169	-.28	.11
25.0	24.4	67.76	16.1		.65		.42	.51	.26	.27	.0126	-.21	.06
20.0	19.3	67.75	16.6		.54		.36	.34	.17	.18	.00816	-.13	.05
15.0	14.2	67.77	17.1		.47		.28	.19	.10	.10	.00475	-.08	.02
10.0	9.2	67.75	17.6		.42		.23	.09	.05	.05	.00217	-.04	.01
5.0	4.8	67.90	18.3		.37		.20	.01	.01	..01	.00058	-.01	-

Table 2-20

Head Loss In Feet Of Water For 1-1/4" Rigid PVC "Y" Valve

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	Δφ Zero	High	Zero	High	Total	Total/2	Ft. Water x $\frac{13.56}{12}$ -1	Correction Factor Ft. Loss/In.	Tab Distance x 16.50	Corrected Reading Hd Loss in Ft.
40.5	41.0	69.31	13.9	.45	3.24	.06	2.92	5.65	2.83	2.97	.0297	-.49	2.48
35.0	34.7	69.39	14.7		2.57		2.16	4.22	2.11	2.21	.0211	-.35	1.86
30.0	29.5	69.45	15.4		1.98		1.59	3.06	1.53	1.60	.0158	-.26	1.34
25.0	24.4	69.51	15.9		1.50		1.12	2.11	1.06	1.11	.0117	-.19	.92
20.0	19.3	69.56	16.6		1.13		.77	1.39	.70	.73	.0082	-.14	.59
15.0	14.2	69.62	17.1		.82		.43	.74	.37	.39	.0051	-.08	.31
10.0	9.2	69.72	17.6		.60		.25	.34	.17	.18	.0024	-.04	.14
5.0	4.8	69.85	18.1		.48		.11	.08	.04	.04	.0009	-.01	.03

Table 2-21

Head Loss In Feet Of Water For 1-1/4" Rigid PVC "Y" Valve

(Reamed Pipe)

43.2	44.3	68.20	13.6	.37	2.19	.19	2.02	3.65	1.83	1.92	.0333	-.55	1.37
40.0	40.4	68.16	14.1		1.97		1.74	3.15	1.58	1.66	.0289	-.48	1.18
35.0	34.7	68.12	14.8		1.59		1.47	2.50	1.25	1.31	.0225	-.37	.94
30.0	29.5	68.10	15.6		1.25		1.08	1.77	.89	.93	.0169	-.28	.65
25.0	24.4	68.10	16.2		.98		.82	1.24	.62	.65	.0126	-.21	.44
20.0	19.3	68.07	16.6		.75		.62	.81	.41	.43	.00816	-.13	.30
15.0	14.2	68.11	17.1		.58		.43	.45	.28	.29	.00475	-.08	.21
10.0	9.2	68.15	17.8		.43		.28	.15	.08	.08	.00217	-.04	.04
5.0	4.8	68.25	18.2		.37		.23	.04	.02	.02	.00058	-.01	.01

Table 2-22

Head Loss In Feet Of Water For 1-1/2" Rigid PVC Plug Valve

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	Δφ				Total	Total/2	Ft. Water x $\frac{13.65}{12}$ - 1	Correction Factor Ft. Loss/In.	Tab Distance x 14.50	Corrected Reading Hd Loss in Ft.
				Zero	High	Zero	Low						
40.0	40.4	69.90	13.8	.52	1.77	.08	1.13	2.30	1.15	1.20	.0289	-.42	.78
35.0	34.7	70.03	14.6		1.47		.98	1.85	.93	.97	.0211	-.31	.66
30.0	29.5	70.10	15.4		1.19		.67	1.28	.64	.67	.0158	-.23	.44
25.0	24.4	70.16	15.9		.98		.49	.89	.45	.47	.0117	-.17	.30
20.0	19.3	70.21	16.6		.81		.33	.56	.28	.29	.0082	-.12	.17
15.0	14.2	70.26	16.9		.68		.23	.33	.17	.18	.0051	-.07	.11
10.0	9.2	70.32	17.4		.57		.15	.14	.07	.07	.0024	-.03	.04
5.0	4.8	70.47	18.0		.51		.10	.03	.02	.02	.0009	-.01	.01

Table 2-23

Head Loss In Feet Of Water For 1-1/2" Rigid PVC Plug Valve

(Reamed Pipe)

42.7	43.7	68.95	13.8	.38	1.48	.19	1.17	2.08	1.04	1.09	.0326	-.47	.62
40.0	40.4	68.90	14.3		1.33		1.06	1.82	.91	.95	.0289	-.42	.53
35.0	34.7	68.90	14.9		1.13		.87	1.43	.72	.75	.0225	-.33	.42
30.0	29.5	68.90	15.7		.91		.68	1.02	.51	.53	.0169	-.25	.28
25.0	24.4	68.87	16.1		.74		.53	.70	.35	.37	.9126	-.18	.19
20.0	19.3	68.87	16.6		.59		.43	.45	.23	.24	.00816	-.12	.12
15.0	14.2	68.90	17.1		.49		.32	.24	.12	.13	.00475	-.07	.06
10.0	9.2	68.95	17.7		.40		.27	.10	.05	.05	.00217	-.03	.02
5.0	4.8	69.00	18.1		.39		.23	.05	.03	.03	.00058	-.01	.01

STAT

Table 2-24

Head Loss In Feet Of Water For 1-1/4" Rigid PVC Coupling

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	$\Delta\phi$ Zero	High	Zero	Low	Total	Total/2	Ft. Water $\times \frac{13.56}{12} - 1$	Correction Factor Ft. Loss/In.	Tab Distance x 14.50	Corrected Reading Hd Loss in Ft.
40.2	40.6	69.68	13.8	.52	1.48	.08	.82	1.70	.85	.89	.0291	-.42	.47
35.0	34.7	69.73	14.6		1.25		.63	1.28	.64	.67	.0211	-.31	.36
30.0	29.5	69.81	15.3		1.08		.51	.99	.50	.52	.0158	-.23	.29
25.0	24.4	69.85	16.0		.92		.38	.70	.35	.37	.0117	-.17	.20
20.0	19.3	69.85	16.5		.77		.29	.46	.23	.24	.0082	-.12	.12
15.0	14.2	69.91	69.9		.67		.22	.29	.15	.16	.0051	-.07	.09
10.0	9.2	69.95	17.4		.58		.17	.15	.08	.08	.0024	-.03	.05
5.0	4.8	70.14	18.1		.52		.12	.04	.02	.02	.0009	-.01	.01

Table 2-25

Head Loss In Feet Of Water For 1-1/4" Rigid PVC Coupling

(Reamed Pipe)

42.7	43.7	68.80	13.8	.39	1.22	.22	.79	1.40	.70	.73	.0326	-.47	.26
40.0	40.4	68.80	14.3		1.12		.73	1.24	.62	.65	.0289	-.42	.23
35.0	34.7	68.77	14.9		.96		.65	1.00	.50	.52	.0225	-.33	.19
30.0	29.5	68.75	15.6		.82		.53	.74	.37	.39	.0169	-.25	.14
25.0	24.4	68.73	16.1		.68		.45	.52	.26	.27	.0126	-.18	.09
20.0	19.3	68.75	16.6		.57		.39	.35	.18	.19	.00816	-.12	.07
15.0	14.2	68.75	17.1		.50		.32	.21	.11	.12	.00475	-.07	.05
10.0	9.2	68.80	17.7		.44		.27	.10	.05	.05	.00217	-.03	.02
5.0	4.8	68.88	18.2		.41		.23	.03	.02	.02	.00058	-.01	.01

Table 2-26

Head Loss In Feet Of Water For 1-1/4" PVC Pipe And Fittings - Branch I

(Unreamed Pipe)

Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	High		Low		$\Delta \phi$ av.	Corrected $\Delta \phi$ Head Loss in Ft.		
				Max.	Min.	Max.	Min.				
40.8	41.3	70.84	13.8	10.65	10.45	10.65	10.62	21.19	22.19		
35.0	34.7	70.91	14.7	8.01	7.85	8.03	7.80	15.85	16.59		
30.0	29.5	70.99	15.5	6.04	5.84	6.15	5.87	11.95	12.51		
25.0	24.4	71.20	15.9	4.19	3.95	4.20	4.04	8.19	8.57		
20.0	19.3	71.17	16.3	2.72	2.63	2.85	2.67	5.44	5.70		
15.0	14.2	71.21	17.0	1.69	1.54	1.78	1.70	3.36	3.52		
10.0	9.2	71.18	17.3	.83	.75	.96	.88	1.71	1.79		
5.0	4.8	71.37	18.1	.54	.50	.61	.57	1.11	1.16		

Table 2-27

Head Loss In Feet Of Water For 1-1/4" PVC Pipe and Fittings - Branch II

(Unreamed Pipe)

40.0	40.4	70.77	13.9	11.02	10.80	11.05	17.75	21.81	22.84		
35.0	34.7	70.81	14.6	8.47	8.19	8.47	8.25	16.69	17.47		
30.0	29.5	70.86	15.4	6.36	6.20	6.47	6.17	12.74	13.34		
25.0	24.4	70.95	15.9	4.60	4.50	4.65	4.58	9.17	9.60		
20.0	19.3	70.97	16.5	3.30	3.10	3.35	3.15	6.45	6.75		
15.0	14.2	71.02	16.9	2.20	2.10	2.25	2.10	4.33	4.53		
10.0	9.2	71.10	17.6	1.28	1.24	1.35	1.30	2.59	2.71		
5.0	4.8	71.27	18.2	.77	.70	.82	.78	1.54	1.61		

STAT

Table 2-28

Head Loss In Feet Of Water For 1-1/4" PVC Pipe And Fittings - Branch I

(Reamed)

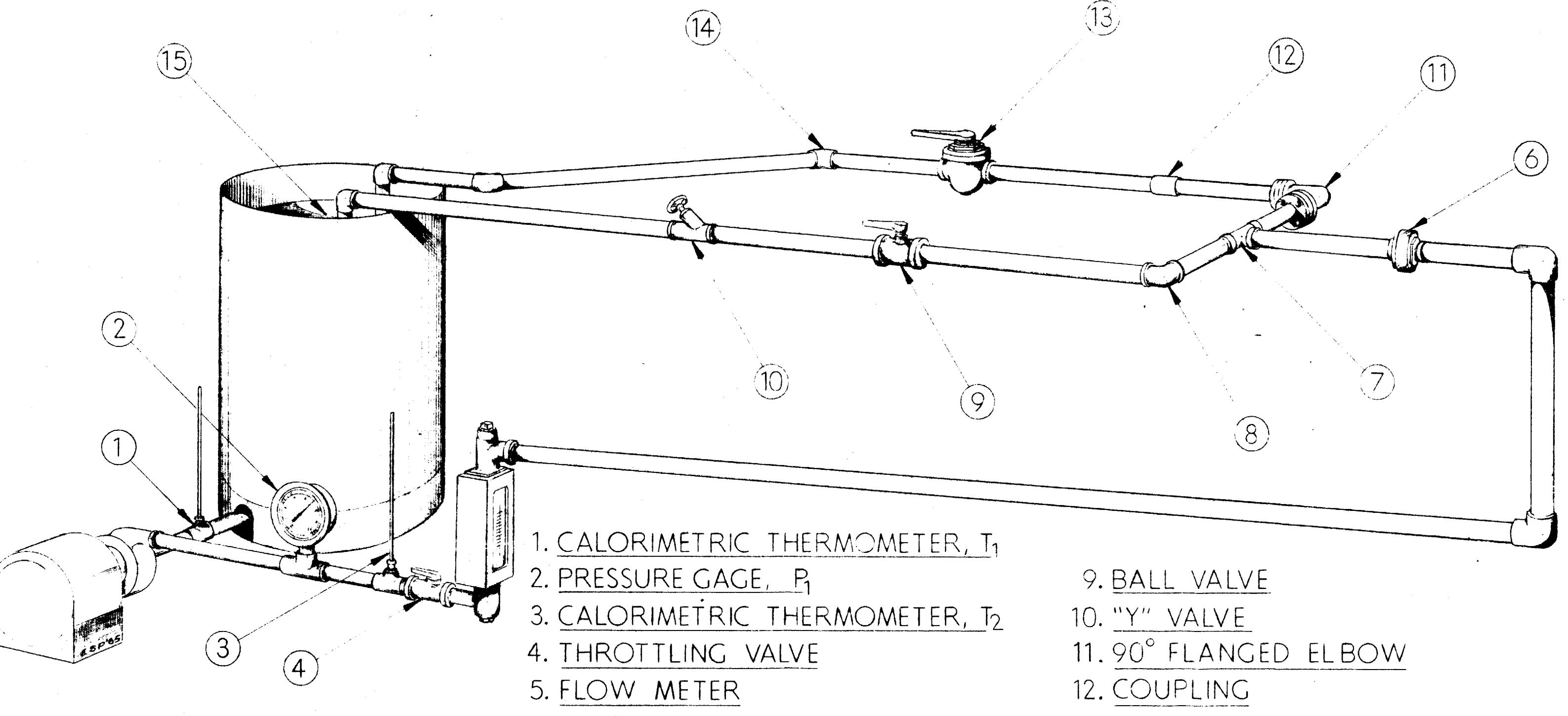
Meter Flow gpm	Corrected gpm	T_2 °F	P_1 psi	High Max.	High Min.	Low Max.	Low Min.	Δø av.	Corrected Δø Head Loss in Ft.		
43.2	44.3	69.86	13.5	10.50	10.18	10.50	10.18	20.68	21.65		
40.0	40.4	69.86	14.0	9.08	8.78	9.03	8.80	17.85	18.69		
35.0	34.7	69.80	14.9	7.29	6.97	7.29	7.01	14.28	14.95		
30.0	29.5	69.80	15.6	5.29	5.18	5.37	5.18	10.51	11.00		
25.0	24.4	69.75	15.9	3.92	3.77	3.98	3.72	7.70	8.06		
20.0	19.3	69.75	16.6	2.65	2.43	2.67	2.53	5.14	5.38		
15.0	14.2	69.76	17.0	1.63	1.48	1.66	1.49	3.13	3.28		
10.0	9.2	69.80	17.6	.85	.77	.92	.80	1.67	1.75		
5.0	4.8	69.86	18.1	.35	.30	.35	.28	.64	.67		

Table 2-29

Head Loss In Feet Of Water For 1-1/4" PVC Pipe And Fittings - Branch II

(Reamed)

42.5	43.4	69.40	13.8	10.32		10.27		20.59	21.56		
40.0	40.4	69.35	14.2	8.95		9.00		17.95	18.79		
35.0	34.7	69.35	14.8	7.22		7.30		14.52	15.20		
30.0	29.5	69.35	15.6	5.33		5.40		10.73	11.23		
25.0	24.4	69.35	16.0	3.78		3.90		7.68	8.04		
20.0	19.3	69.35	16.6	2.52		2.64		5.16	5.40		
15.0	14.2	69.35	17.2	1.64	1.50	1.65	1.48	3.14	3.29		
10.0	9.2	69.35	17.6	.85	.79	.92	.87	1.77	1.85		
5.0	4.8	69.55	18.2	.52	.48	.61	.56	1.09	1.14		



1. CALORIMETRIC THERMOMETER, T_1
2. PRESSURE GAGE, P_1
3. CALORIMETRIC THERMOMETER, T_2
4. THROTTLING VALVE
5. FLOW METER
6. UNION
7. TEE
8. 90° ELBOW
9. BALL VALVE
10. "Y" VALVE
11. 90° FLANGED ELBOW
12. COUPLING
13. PLUG VALVE
14. 45° ELBOW
15. TANK TEMPERATURE, T_3

Figure 2-1. Pressure Drop Test Apparatus

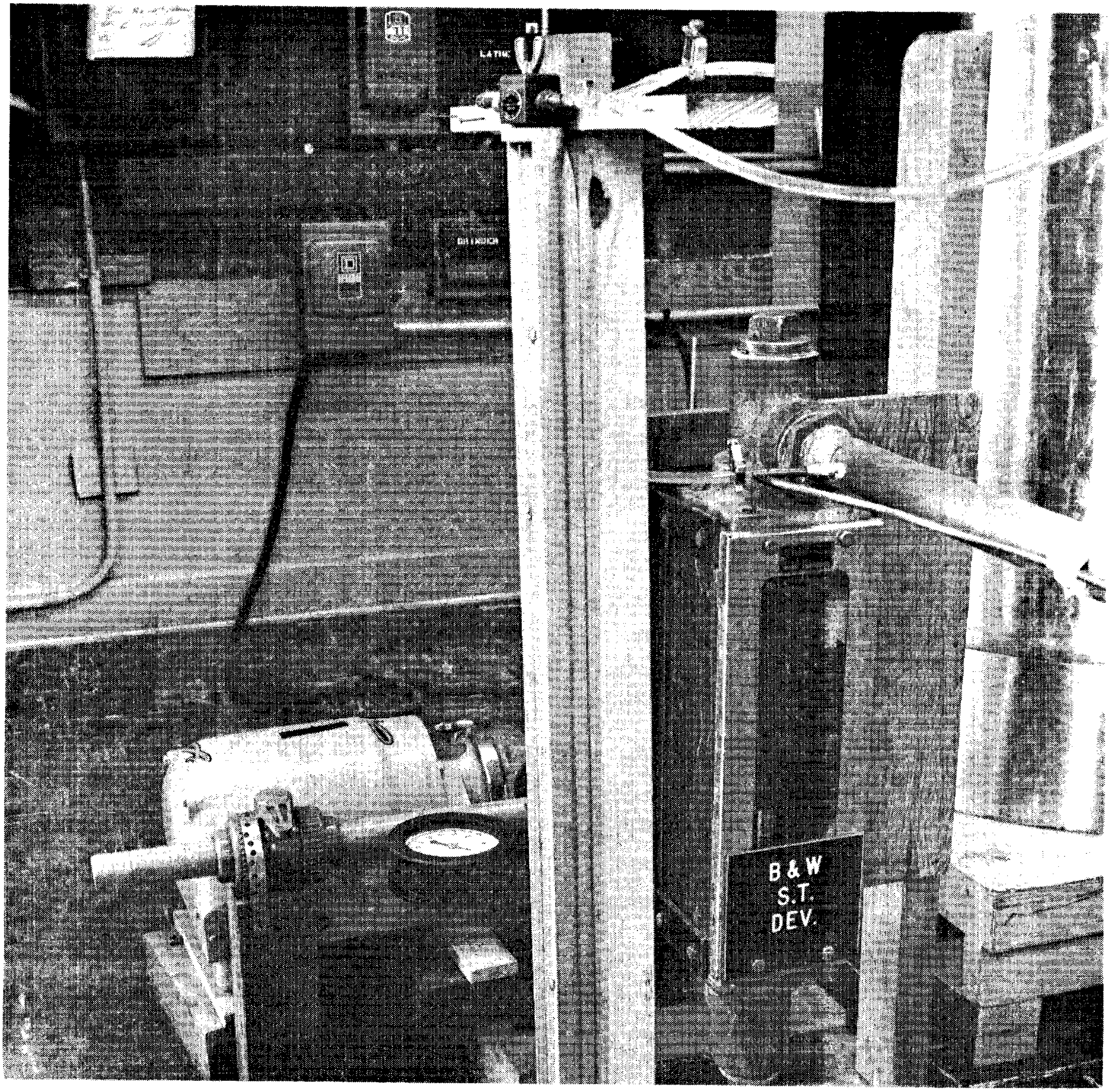


Figure 2-2. Test Rack - Pump, Gage, Manometer, and Flowmeter

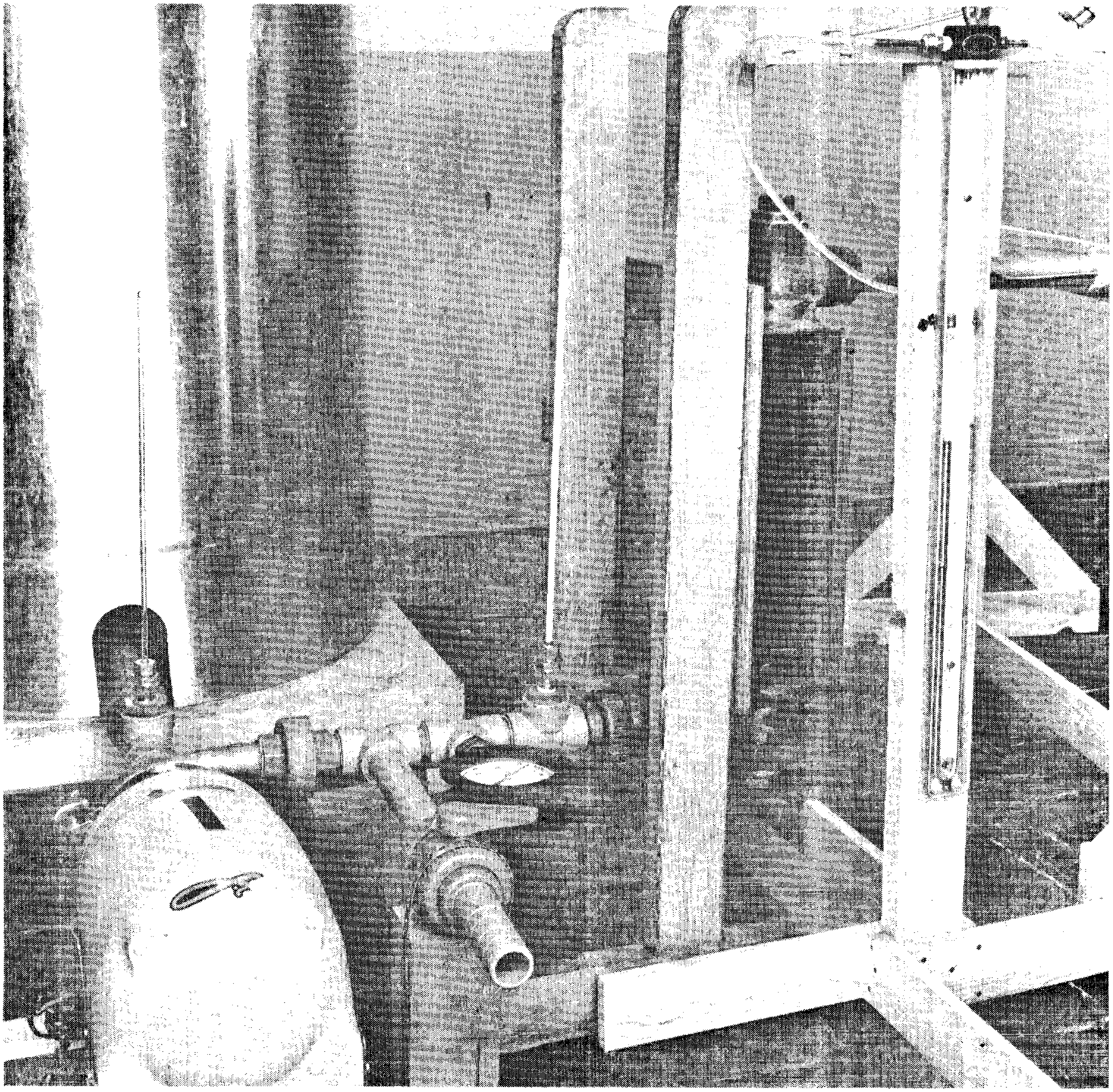


Figure 2-3. Test Rack - Pump, Gage, Manometer, and Thermometers

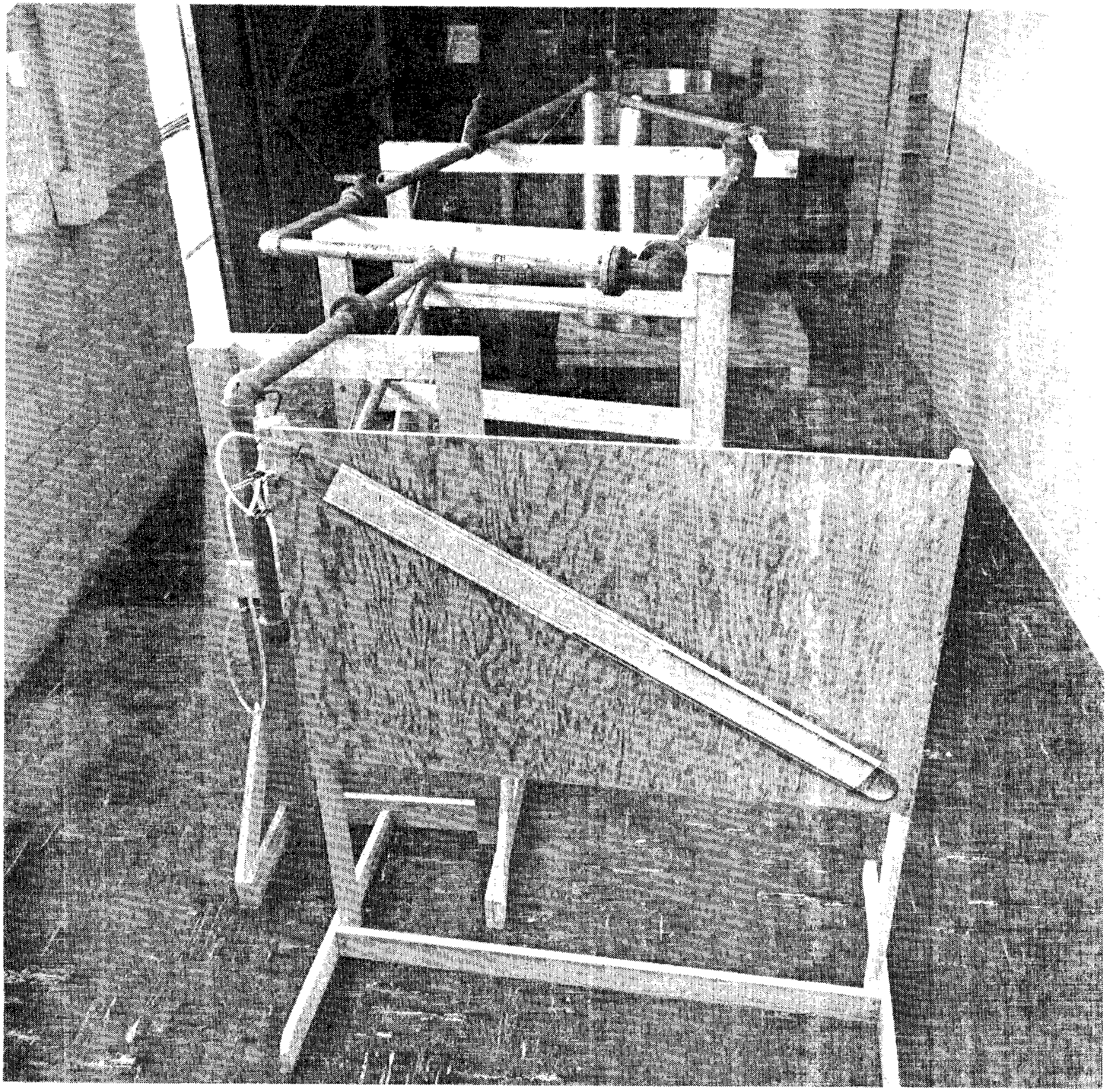


Figure 2-4. Test Rack Apparatus and Inclined Manometer

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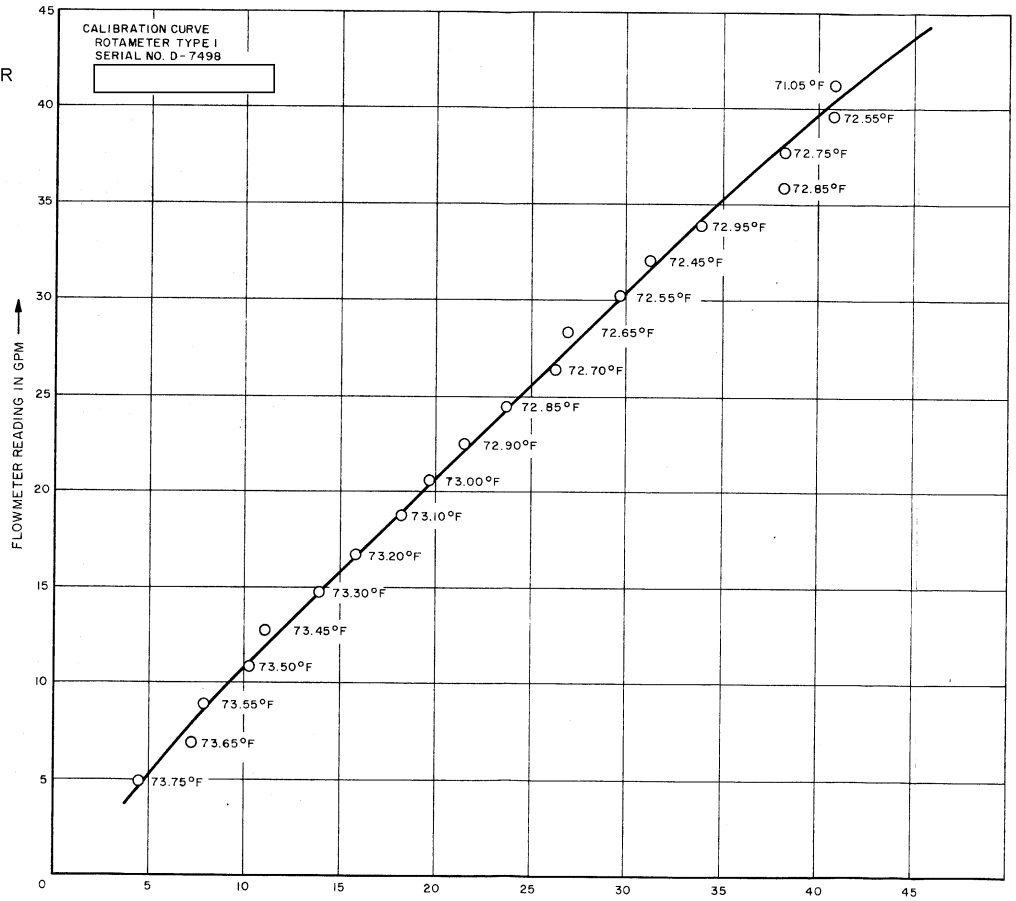

Figure 2-5. Flowmeter Calibration Chart

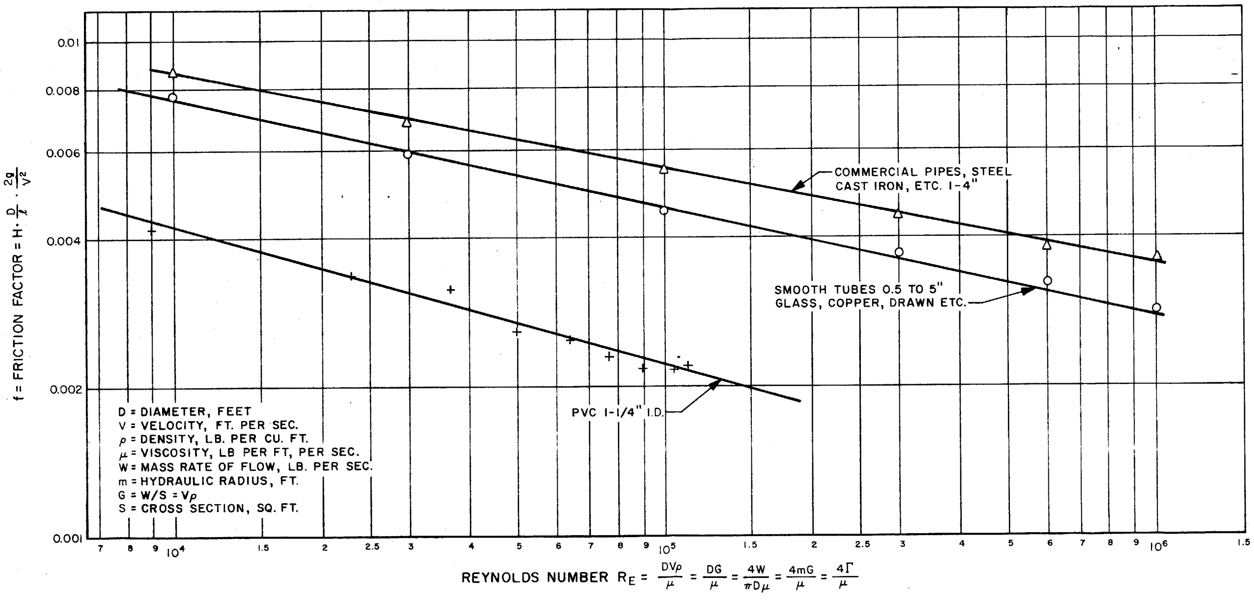

Figure 2-6. Reynolds Numbers vs. Friction Coefficients

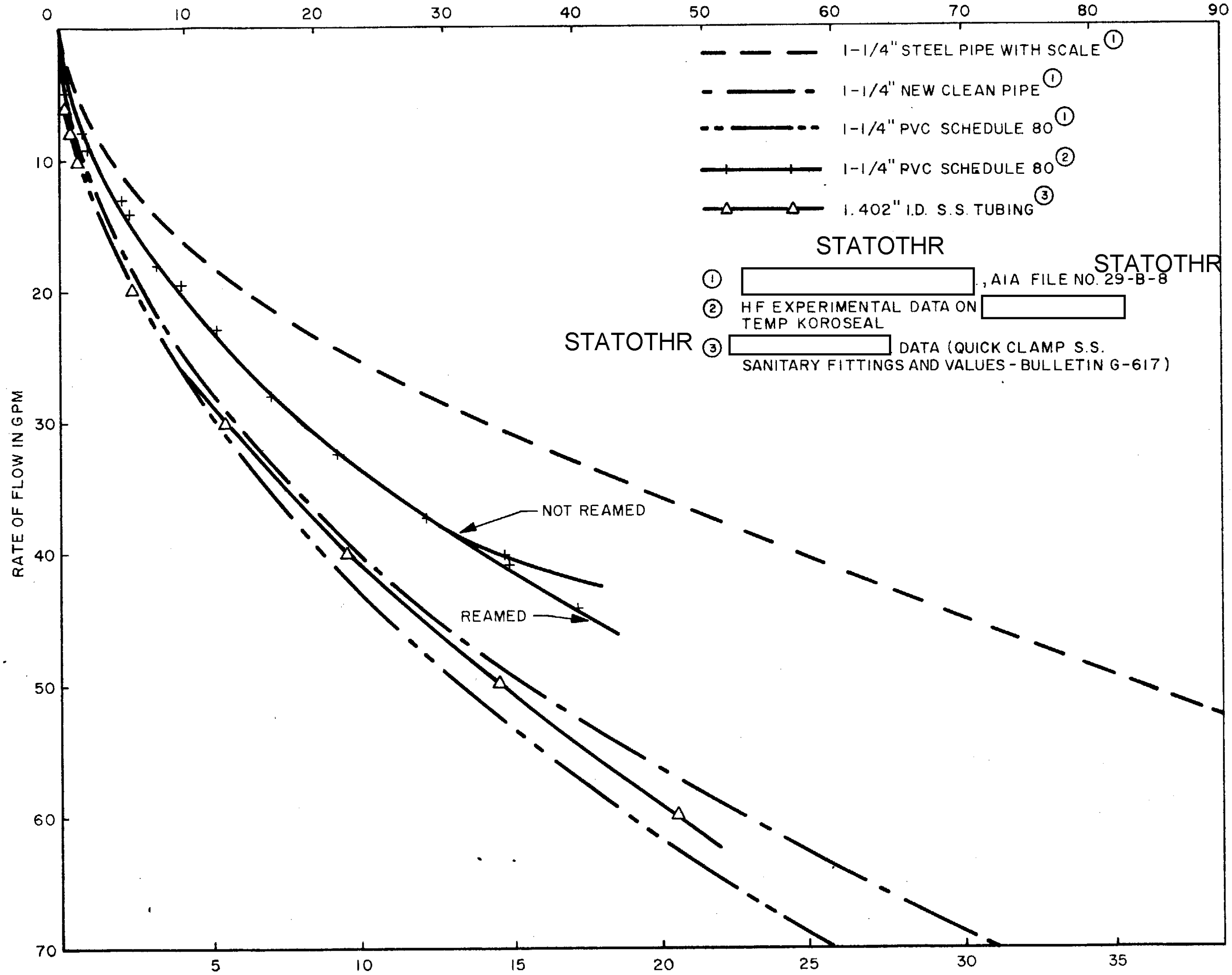

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Figure 2-7. ΔΦ For Straight Pipes

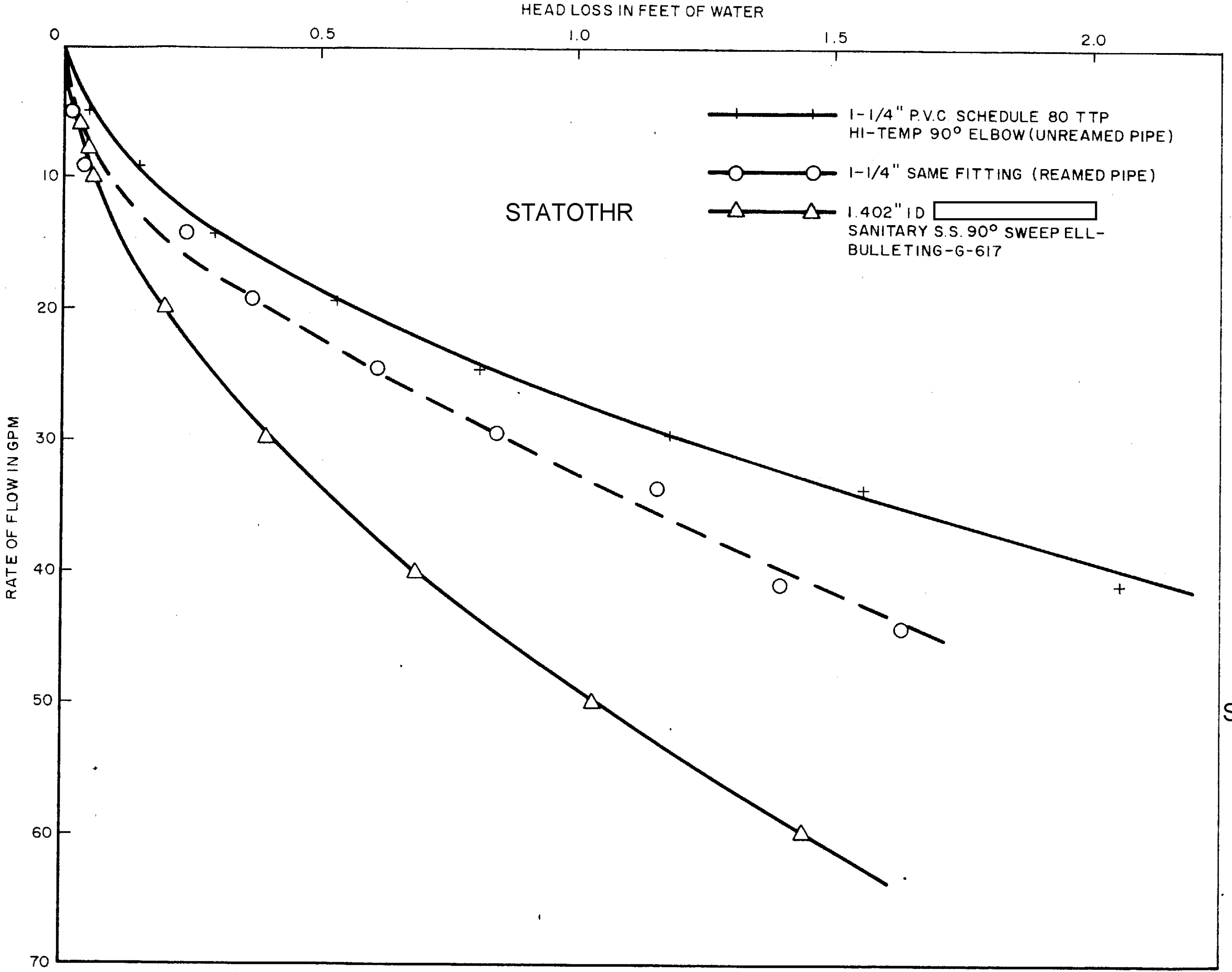

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Figure 2-8. Δp's for 90° Elbows

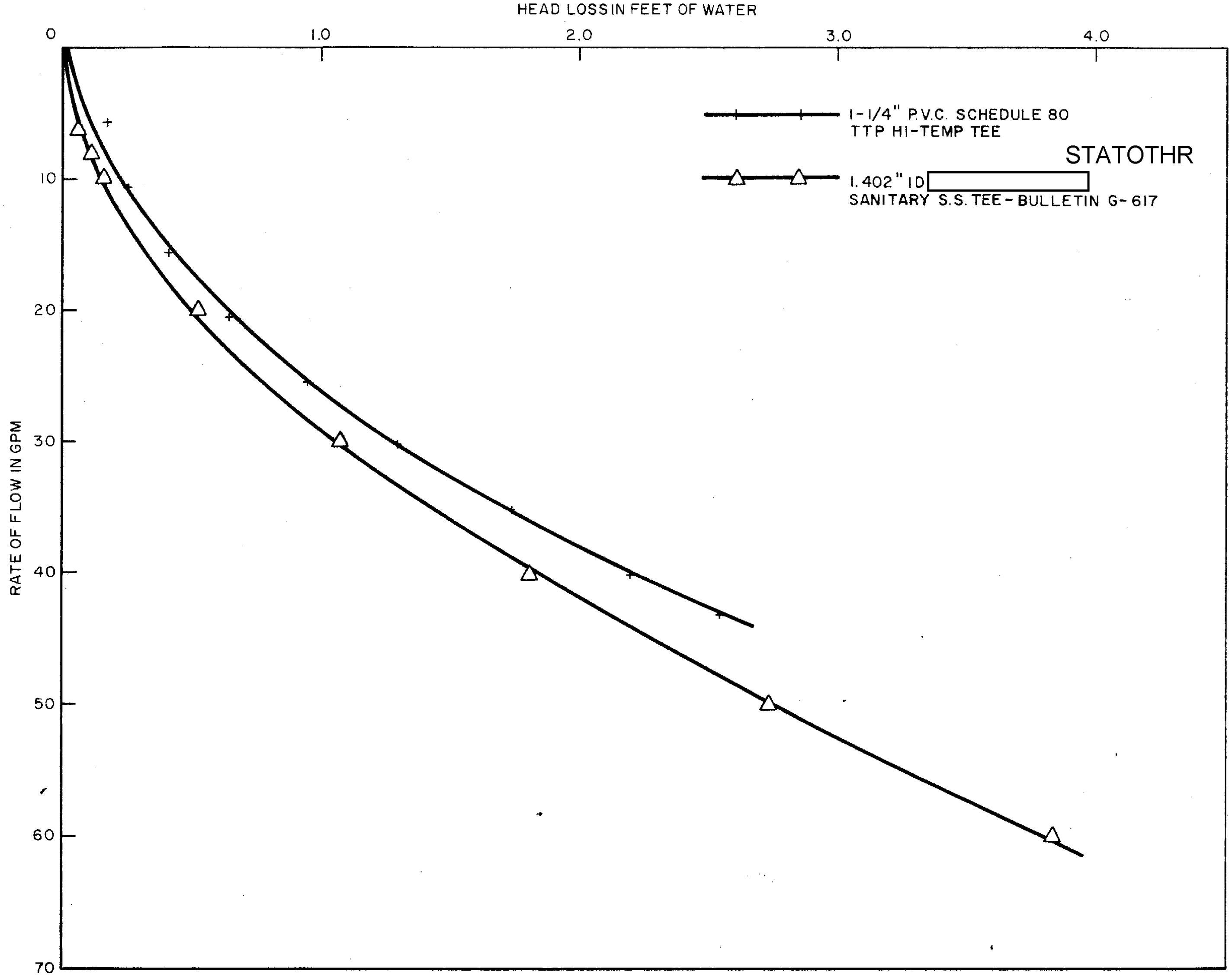

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Figure 2-9. Δ p's for Tees

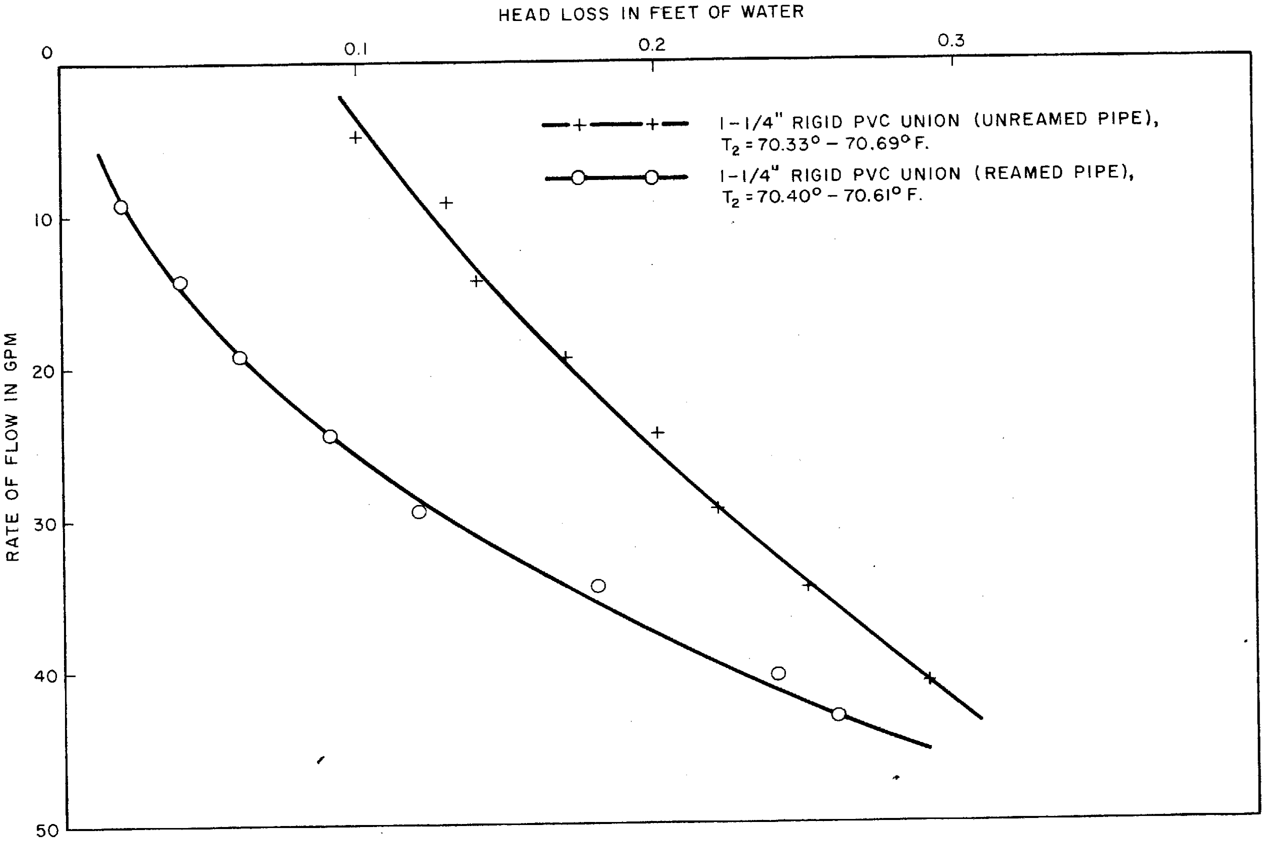

Figure 2-10. Δ p for PVC Union

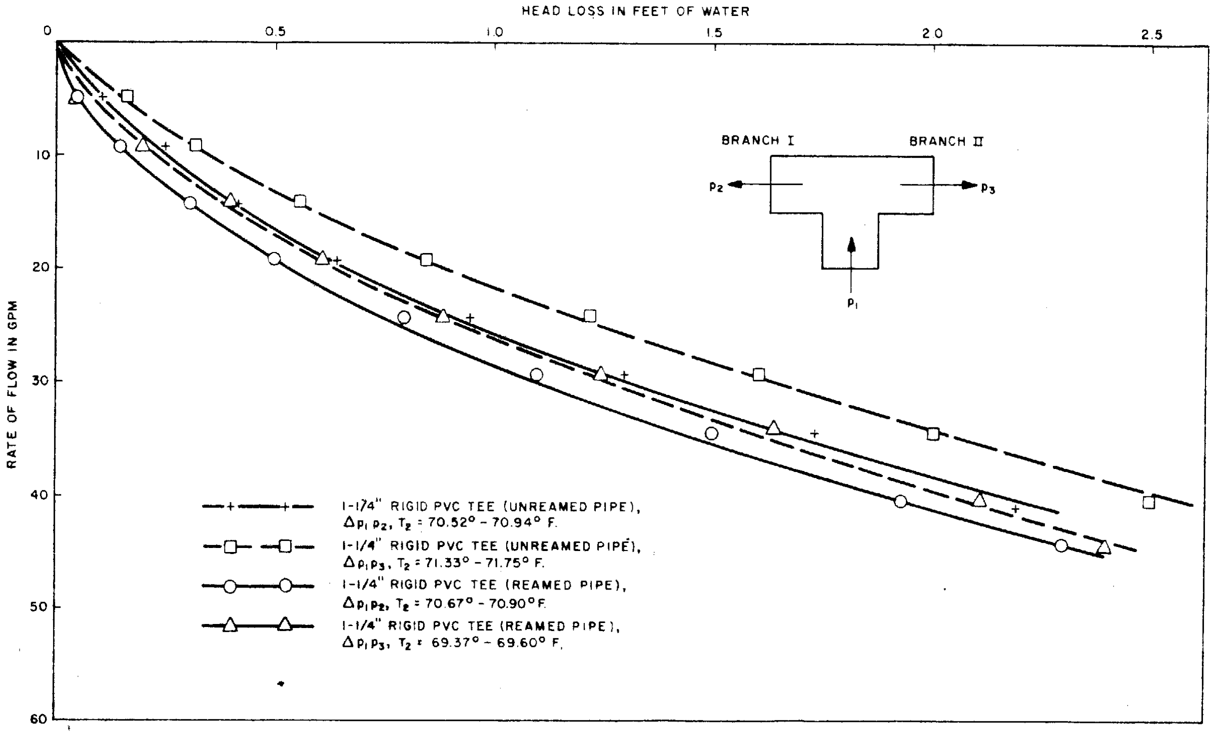

Figure 2-11. Δp for PVC Tee

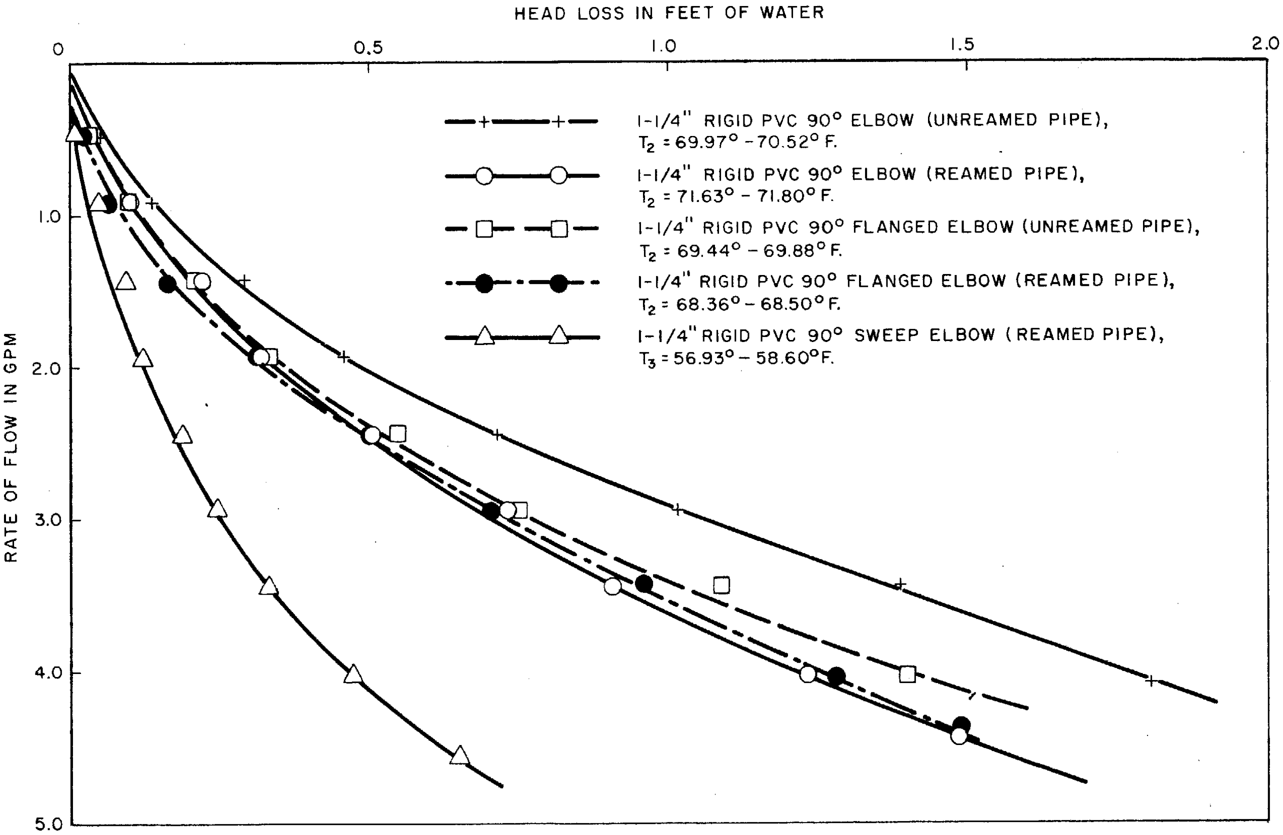

Figure 2-12. Δp's for 90-Degree PVC Elbows

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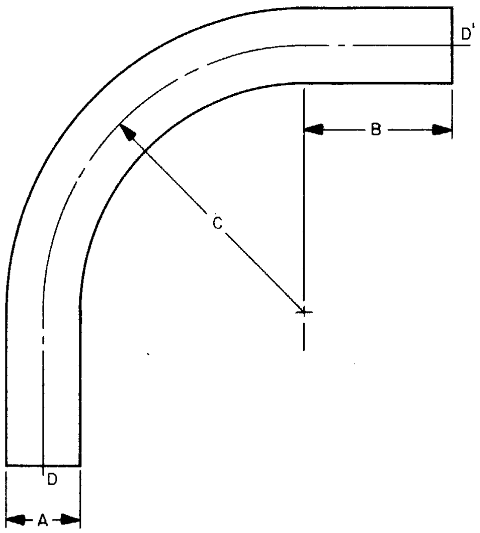
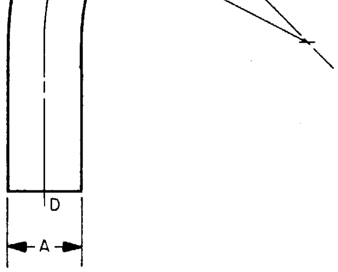


90° PVC SWEEP ELBOW-SCHEDULE 40

SIZE	A	B MIN.	C	D-D'MIN
1-1/4"	1.660	2"	7-1/4"	15.40



45° PVC SWEEP ELBOW-SCHEDULE 40

SIZE	A	B MIN.	C	D-D'MIN.
1-1/4"	1.660	2"	7-1/4"	9.70

Figure 2-13. Dimensions of Sweep Elbows

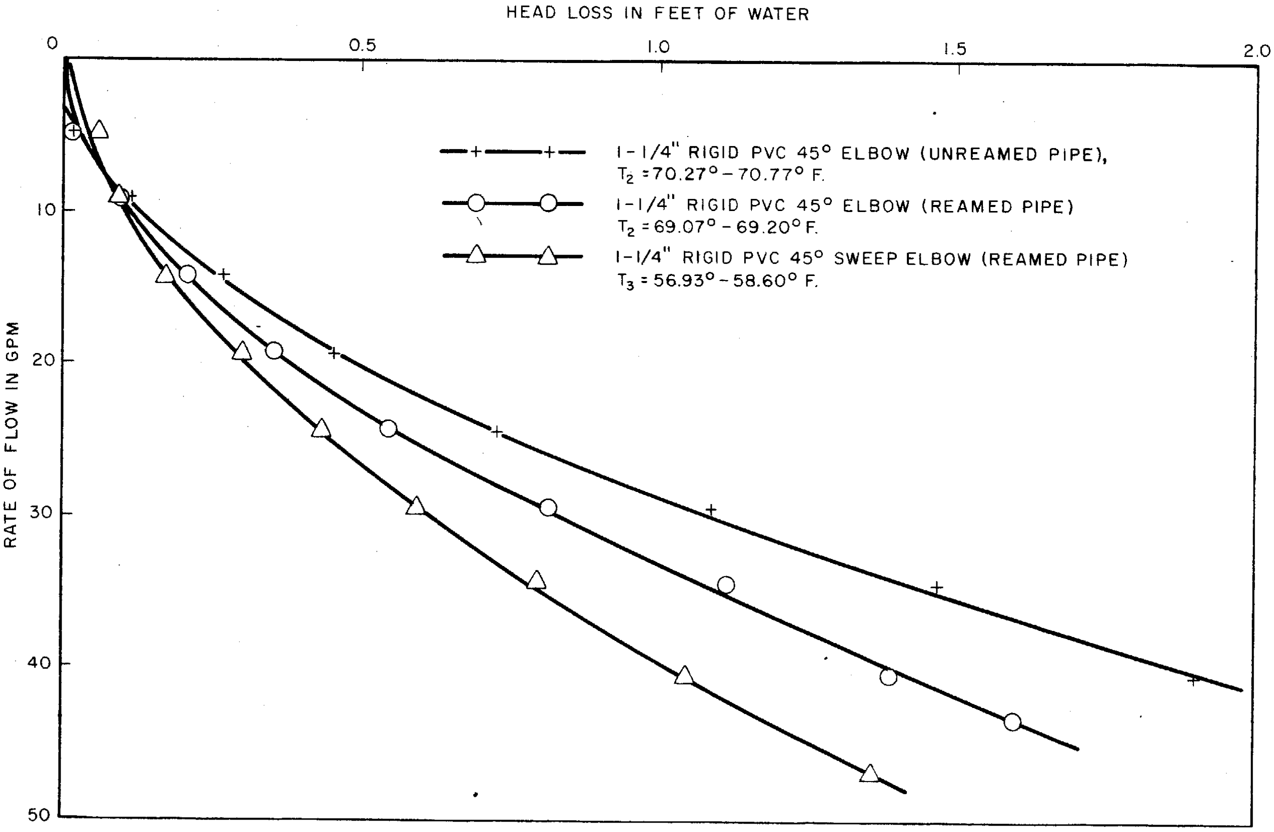


Figure 2-14. Δp's for 45-Degree PVC Elbows

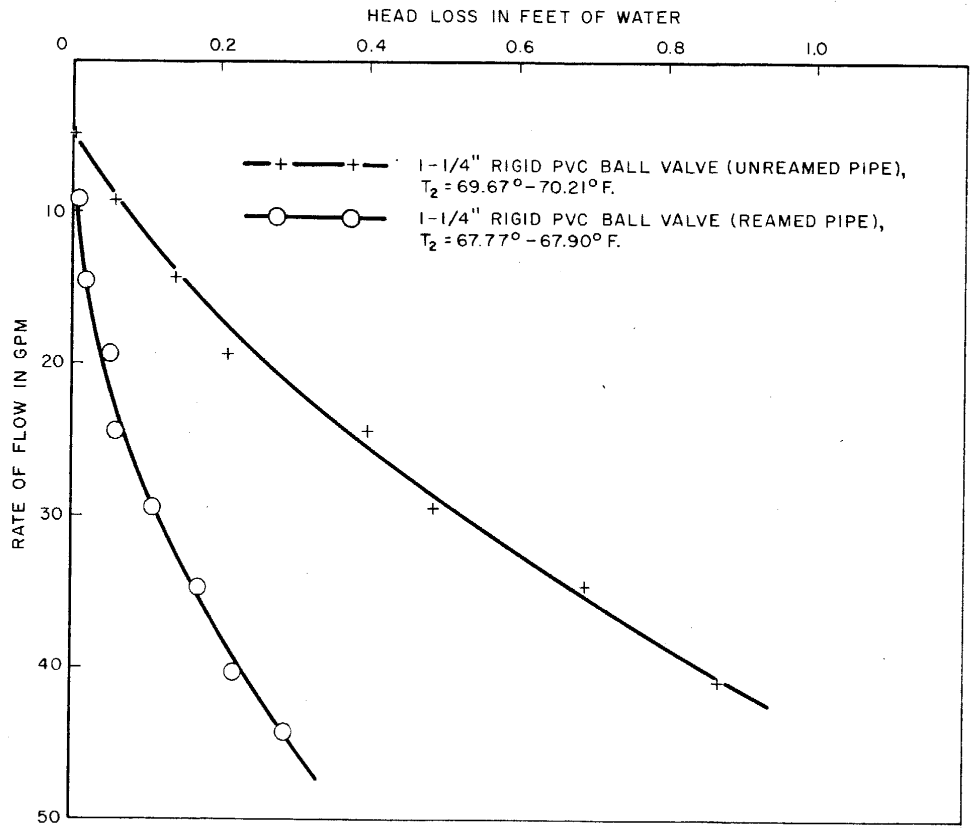


Figure 2-15. $\Delta\phi$ For PVC Ball Valve

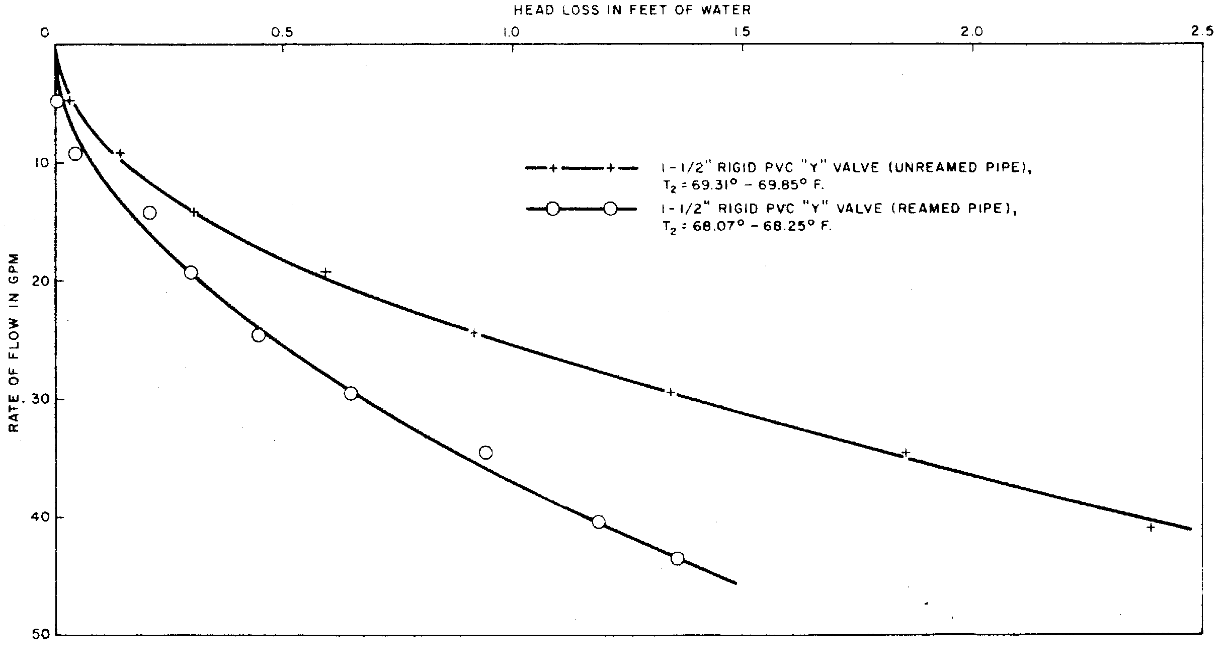


Figure 2-16. Δp For PVC "Y" Valve

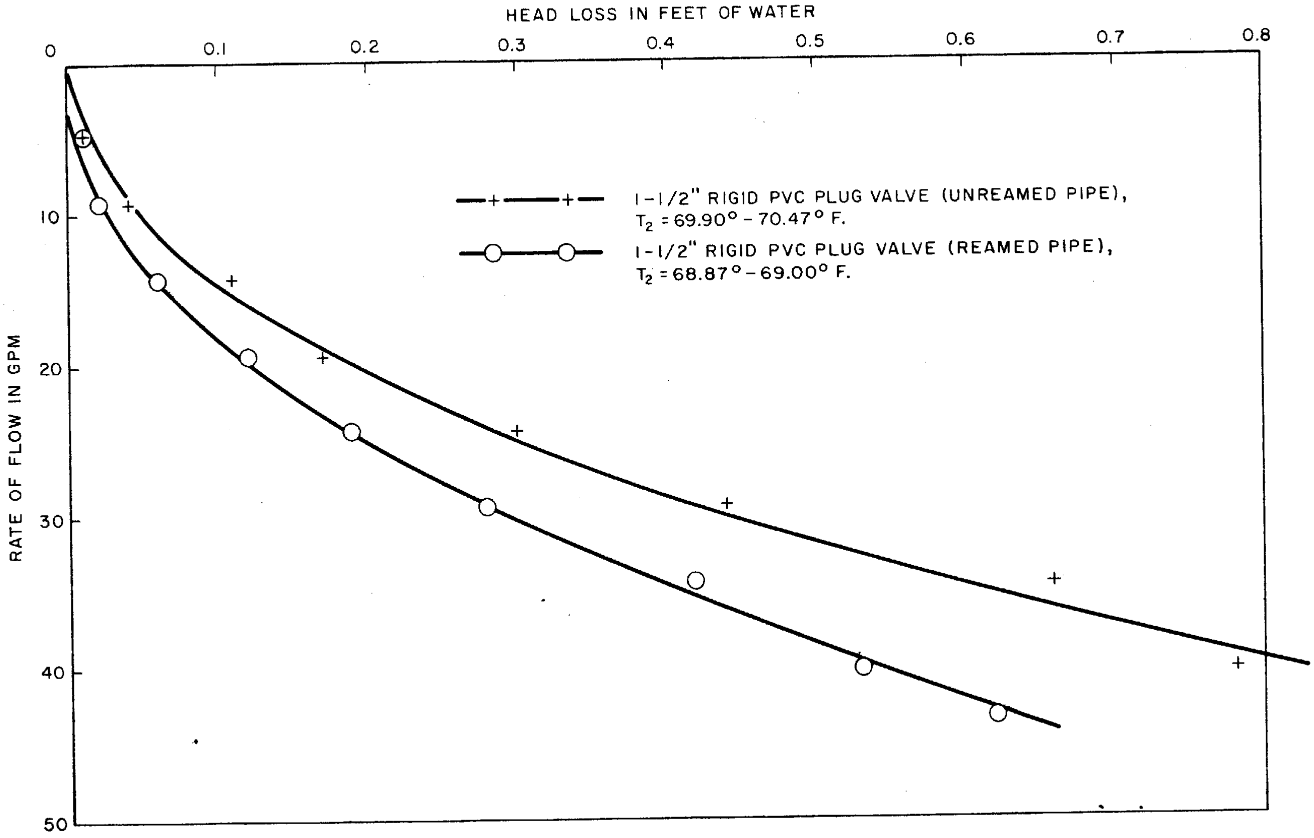


Figure 2-17. Δϕ For PVC Plug Valve

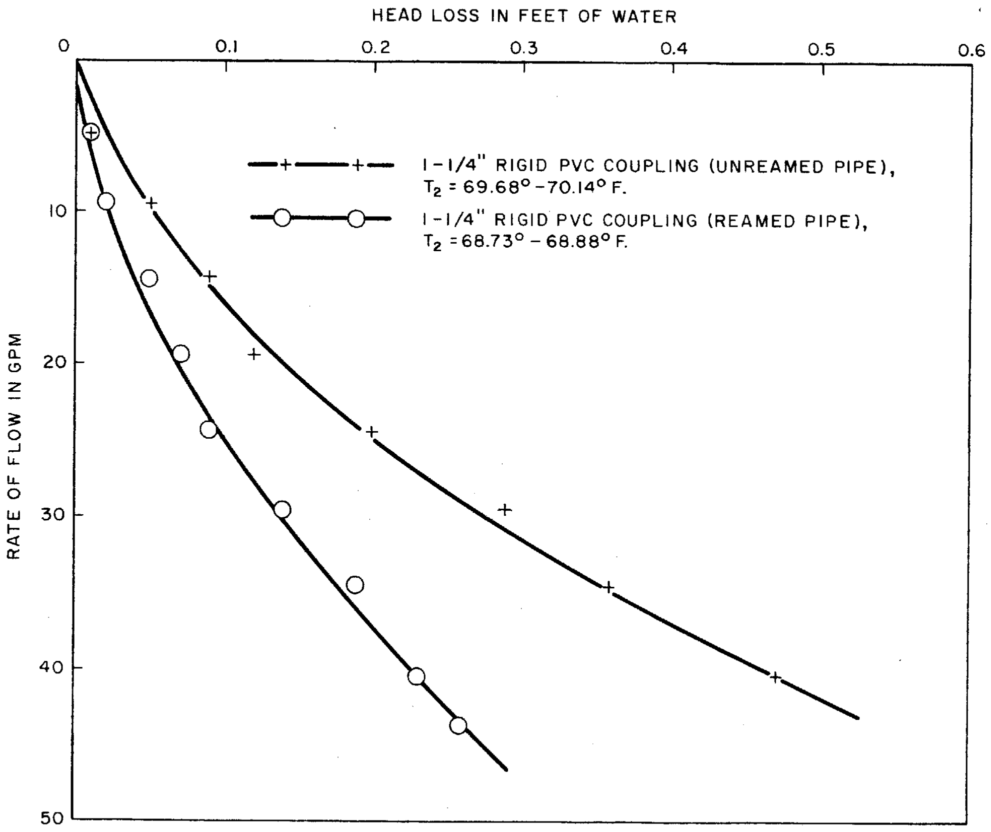


Figure 2-18. $\Delta\phi$ For PVC Coupling

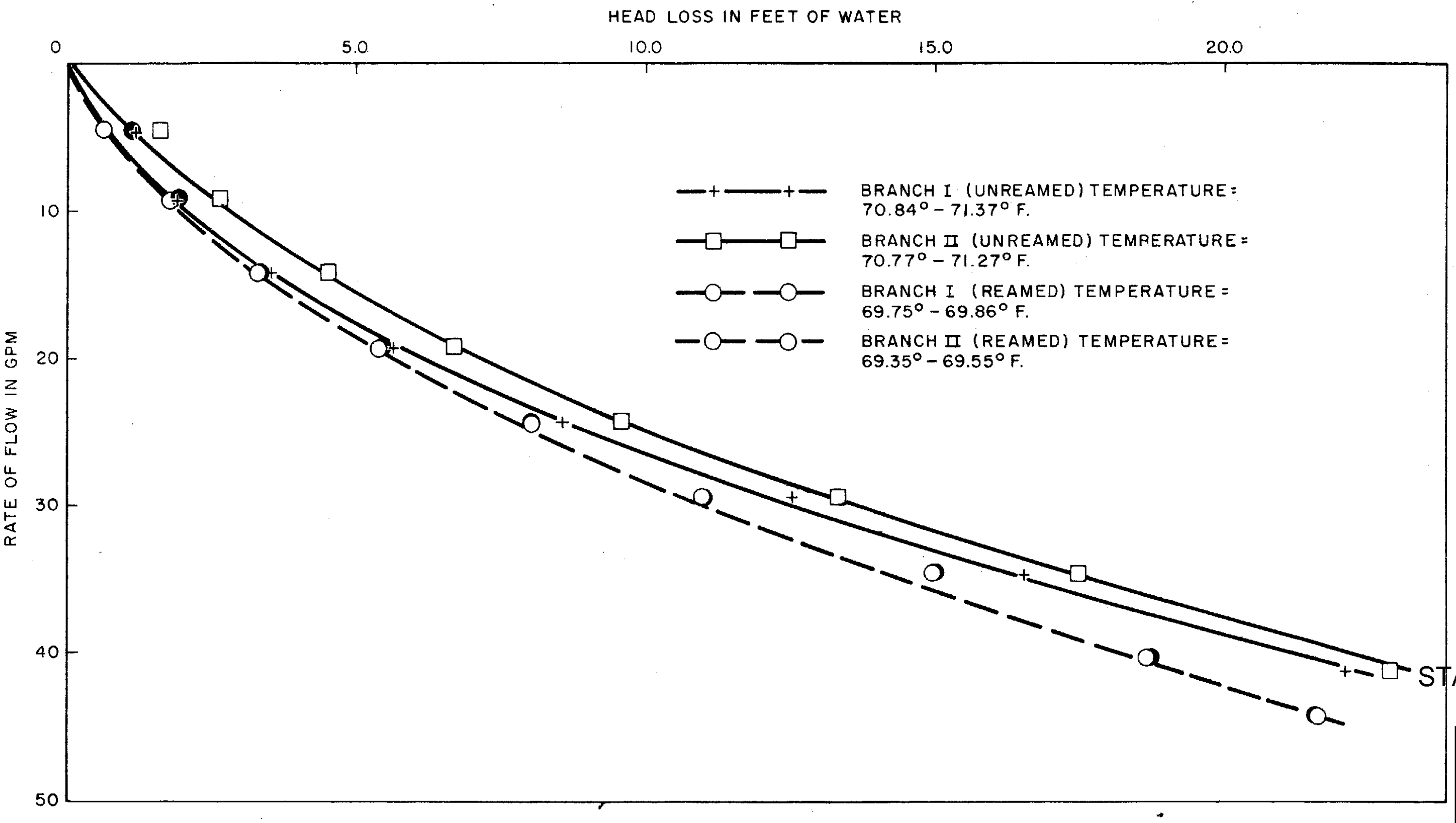
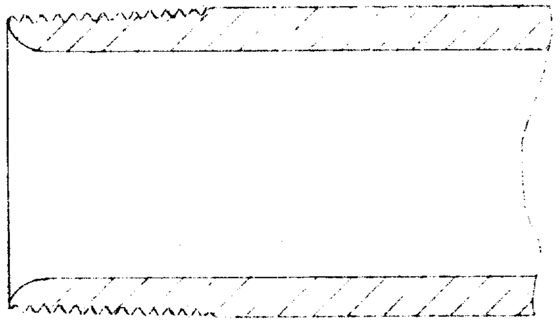
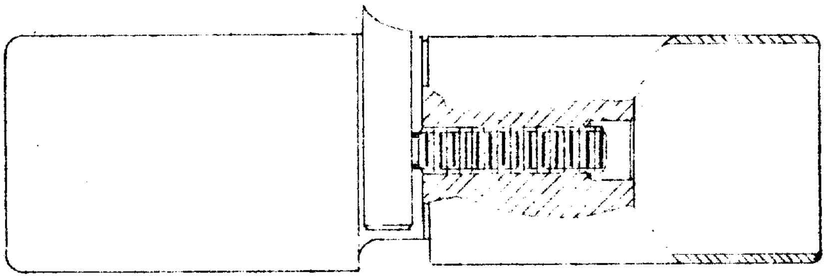


Figure 2-19. Δp's for PVC Pipe and Fittings

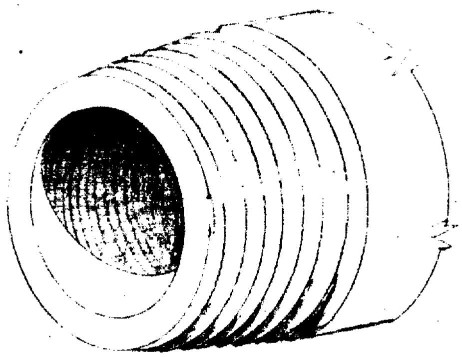


CROSS-SECTION OF FAIRED PIPE



MOUNTING OF FAIRING TOOL BIT

FAIRING TOOL



UNREAMED PIPE

Figure 2-20. Fairing Tool and Pipe

SECTION 3
CONCLUSIONS

3.1 PUMP TESTS

In order to apportion time and budget most efficiently among the high priority facets of the research contract, a rigid schedule for each was set up and followed. Thus, a few of the proposed tests itemized in the list of objectives were necessarily postponed until a later date. This was true of some of the pump tests outlined, but a number of significant conclusions can be drawn, nevertheless.

The pump had an excellent rated capacity for a given horsepower input. The drive motor used showed only a fraction of its rated rise (55°C.) after over three hours of continuous service. The flow was not sensitive to angle of discharge from the centrifugal plenum. It could be completely disassembled in less than a minute. It proved to be a simple shop procedure to modify the impeller to exactly match the load. The unit produced almost no entrainment of air, even without a bleed cock on the plenum. The plenum pressure plate, impeller, shaft, and gland fittings are all stainless steel, designed so that they can easily be cleaned or replaced. Optionally, the unit can be supplied with a splash-proof housing of polished stainless steel. Appendix D gives some typical pump calculations.

The design has not yet been tested with curved (an optional feature) blades or with ordinary corrosive photographic chemicals. The latter test will require some carefully planned safety precautions (automatic leak-sensing unit and circuit breaker) to avoid the hazards of continuous unattended operation. Three of the other tests outlined in the list of objectives were not performed, i.e., falling head, constricted inlet, and breakdown. Since there was some risk of permanent damage to either the pump or the motor and since the unit under test was on loan, this latter series should be run on a purchased unit.

3.2 PRESSURE DROP TESTS

As mentioned previously, some of the published proprietary data on pressure drops is suspect. This conclusion is based on the fact that the data do not agree with the standard charts of Reynolds numbers which are supported by more experimental data than even the International Critical Steam Tables.

STATOTHR

Of the three types of valve tested, the ball valve proved to have the lowest pressure drop. This is the type used almost exclusively on [redacted] STATOTHR [redacted] designed equipment. Technically speaking, they are not "ball" valves, but plug valves in which the rotating unit is spherical rather than a truncated cone. They are well designed, have no sharp internal protrusions, and, because of their modular assembly, can be used in place of a standard union. They are not wholly satisfactory, however, when used as throttling valves to regulate flow.

The standard plug valve had the next lowest pressure drop. While the readings were approximately 2-1/2 times those of the ball valve, they cannot be accepted as fully definitive. The smallest valve of this type obtainable was 1-1/2 inches. It was designed for slip fittings and was modified by inserting slip-to-thread collars. This left an irregular plenum at each side which would have been largely eliminated in a 1-1/4-inch fitting.

The "Y" valve design was excellent for throttling, but offered the largest pressure drop of the three. This was to be expected because the flow pattern is subjected to two sharp changes in direction as it passes through the valve. All of the tests on the three valves were performed in the full-open position; any intermediate readings would have been meaningless.

The measured pressure drops for the union and the coupling, with reamed pipe, were almost identical, besides being the lowest for the series. This was not surprising in the case of the coupling because of its short overall length, the only irregularity being a few exposed threads when the joint was made up. Note, however, that the internal section of the union was full diameter and quite smooth so as to be comparable to straight pipe, whose loss in feet of water per inch is only 0.0289 at 40 gpm.

Several pressure drop runs (Appendix E) were made across the rotameter alone. Psig readings were converted to inches of mercury and then reduced to an equivalent length of 1-1/4-inch PVC pipe. Thus, for a flow of 40.8 gpm, the pressure loss was equivalent to 30.2 feet of standard pipe. Lack of time and money prevented testing other types of flowmeters, particularly venturis, whose losses are relatively low. The other pressure-drop readings were not recalculated as equivalent lengths of pipe; this is rarely required in design and can be readily obtained from the data presented.

The data presented in this report, while somewhat limited in scope, have been carefully prepared and are unusually accurate. They should adequately fill a gap in present technical design reference literature.

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4.1 CONTINUED EXPERIMENTATION

The type of experimental measurement described in preceding sections is extremely painstaking and time consuming. Since its worth is invaluable to the design engineer, its further expansion should be funded by a group such as the Bureau of Standards or the National Science Foundation. It is difficult to justify fundamental research on a short-term development or state-of-the-art improvement contract, notwithstanding the immediate benefits to a design program such as could evolve. In this case, these benefits include smaller pump size, increased flow, increased pressure, less pulsation and air entrainment, and finally, no "cut-and-fit" trials for power sizing or line losses.

There was no opportunity, for instance, to run comparative tests on sanitary stainless-steel dairy pipe and fittings. These promise to have singular advantages. Despite the fact that a running foot of stainless costs more than five times that of the plastic in a comparable size, it is virtually indestructible. It is designed for minimum interstices (to be microorganism-free) which simplifies cleaning. Each joint can be broken open so that unions are unnecessary. Its pressure drops should be in the same range as plastic, plus the advantage of not being sensitive to thermal shock. With the exception of long runs, no supporting structure is necessary to prevent sag and fracture. No joint could be made up too tightly as each is joined with a single-lever quick clamp. The use of stainless steel should be thoroughly explored.

Some of the plastic fittings, particularly in plastic-to-metal joints, split after sitting for periods of a few days to a few weeks. This strain aging might be avoided by making up the joints with an adaptation of a torsion wrench. None is available for this purpose and not all joints can be assembled with the standard strap wrenches recommended for plastic. Profitable research results could be anticipated by the design and testing of such a specialized tool.

There was little question that the dairy pump used for the tests was superior, in a number of parameters which could be compared, to one model of presently used equipment. The most salient of these features were outlined in Section 3 of this report. These included trouble-free performance, simplified maintenance, high efficiency, low line pulsation, freedom in choice of plenum orientation, low air entrainment, and ease of matching capacity to load. Additionally, the operation of the pump with the manufacturer's recommended inlet head was extremely quiet. This would tend to lessen greatly the ambient sound level when a number of pumps and blowers must be combined for an operating processor. The importance of supplementing the present data with life tests and the relative imperviousness of the gaskets to photographic solutions cannot be emphasized too strongly. Other manufacturers' sanitary pumps should be tested also.

It is further recommended that a series of comparative tests be performed to determine the optimum type of flowmeter for this application, i.e., most accurate, least expensive, easiest to maintain, and lowest pressure drop.

Because of the singular performance of the two sweep fittings tested, continued experimentation should be directed toward enlarging the variety of low-loss fittings such as these. For example, several types of sweep tees could be fabricated from sections of the sweep elbows and straight pipe. Predictably, the low pressure drops obtainable could usher in a whole new design concept for the plastic fabricators and a distinct advance in the state-of-the-art.

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11. "Standards of the Hydraulic Institute," Page B(VIII)-13. Revised November 1958.

APPENDIX A

A1. 1 Sample flowmeter calibration calculation.

A spin-flow stainless steel bucket held 33 lbs. of water at 75.00°F.

At start of run, 11:04 A.M.:

T_1= Temperature at pump inlet = 71.15°F.
T_2= Temperature at pump outlet = 71.05°F.
P_1= Pressure at pump outlet = 14.0 ±0.5 psi
Flowmeter reading = 41.2 gpm
Time to fill calibrated bucket (aver.) = 5.8 seconds
T_3= Temperature in tank = 22.45°C.

Density of water (Reference 3):

	°C	p gm/ml
	21	0.99802
71.05°F =	21.70	0.99787
	22	0.99780
	23	0.99756
75.00°F =	23.90	0.99734
	24	0.99732

W=Mass Rate of Flow #/sec

$$= \frac{33}{5.8} \times \frac{.99787}{.99734} = 5.693 \text{ \#/sec}$$

	#/min	gal min. @39.2°F	gal/min. @71.05°F
$\frac{\#}{\text{Sec.}}$	x 60	x .1198	x .99787

5.693 x 60 x .1198 x .99787 = 40.83 gpm measured vs
41.2 Flow Meter

A 1.2 SAMPLE REYNOLDS NUMBER CALCULATION

$$\text{Reynolds Number} = Re = \frac{DV\rho}{\mu} = \frac{DG}{\mu} = \frac{4W}{\pi D\mu} = \frac{4mG}{\mu} = \frac{4\gamma}{\mu}$$

Where:

D = Diameter, feet

V = Velocity, feet per second

ρ = Density, pounds per cubic foot

μ = Viscosity, pounds per cubic foot per second

W = Mass rate of flow, pounds per second

m = Hydraulic radius, feet

$G = W/S = V\rho$

S = Cross section, square feet

$$Re = \frac{4W}{\pi D\mu} = \frac{4 \times 5.693}{\pi \times .1048 \times .000648}$$

$$= 1.067 \times 10^5$$

Darcy-Weisbach Expression =

$$h = f\left(\frac{l}{D}\right)\frac{V^2}{2g}$$

where:

h = head loss in feet

l = length of pipe, feet

g = acceleration of gravity, feet per second^2

f = friction factor, or coefficient, dimensionless solving:

$$f = h\left(\frac{D}{l}\right) \quad \frac{29}{V^2}$$

$$= \frac{3.48 \times .1048 \times 2 \times 32.17}{10.02 \times (10.36)^2}$$

$$= .00218$$

APPENDIX B

B1. 1 SAMPLE THERMOMETER STEM CORRECTION

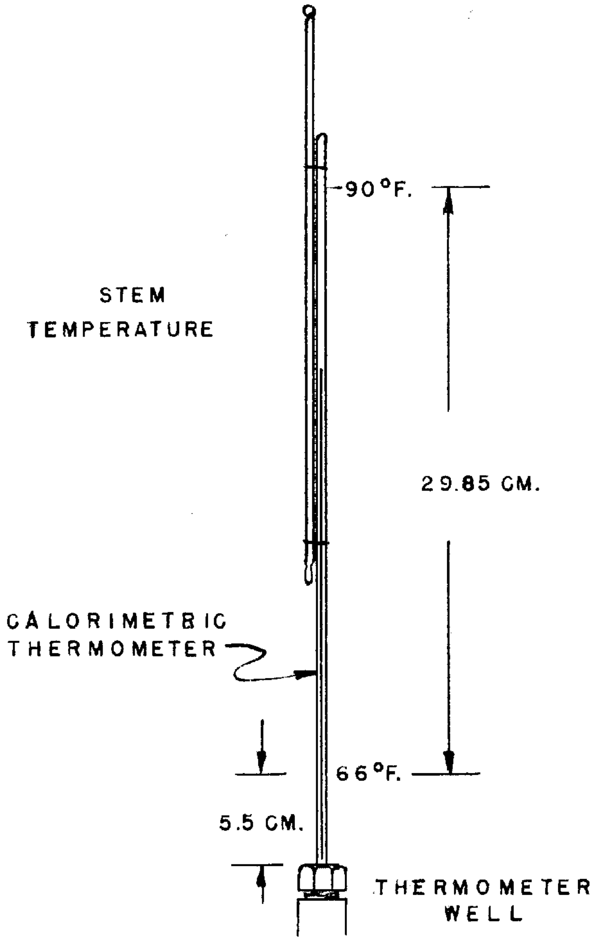

FIGURE B1-1

$Tc = To + fxlx(To - Tm)$

Where:

Tc = corrected temperature

To = observed temperature

l = column length in degrees above liquid surface

Tm = mean temperature of mercury

f = correction factor = .000157 (Coming 0041)

To calculate l:

$$\frac{24^{\circ}F}{29.85\ cm} \times 5.5\ cm = 4.33^{\circ}F$$

$$l = 71.05 - 66.00 + 4.33 = 9.38^{\circ}F$$

$$Tc = 71.05 + .000157 \times 9.38\ (71.05 - 74.3)$$

$$= 71.05 - .006$$ Correction factor less than error of reading

APPENDIX C

C1. 1 CALCULATION OF PROBABLE ERROR OF MEASUREMENT

The most direct way to calculate the validity of the pressure drop data is to compare the actual total pressure loss in each Branch of the Test Rack with the value obtained when individual losses for each fitting and the connecting pipes are added together. This was done as follows:

I. $\sum \Delta p$ pipe and fittings. Branch I

Where 24. 178 feet = total length of connecting pipe

and .3473 = pressure loss per foot in feet of water

24. 178 x .3473 = 8. 397

90° elbow 4 x 1. 81 = 7. 24

Union 1 x .29 = .29

Tee 1 x 2. 19 = 2. 19

Ball Valve 1 x .87 = .87

"Y" Valve 1 x 2. 48 = 2. 48

21. 467

Actual Reading = 22. 19

Calculated Reading = 21. 47

Percentage error = 3. 24%

II. $\sum \Delta p$ pipe and fittings. Branch II

24. 465 x .3473 = 8. 497

90° Elbow 3 x 1. 81 = 5. 43

Union 1 x .29 = .29

Tee 1 x 2. 50 = 2. 50

Flanged Elbow 1 x 1. 40 = 1. 40

Coupling 1 x .47 = .47

Plug Valve 1 x .78 = .78

45° Elbow 2 x 1. 90 = 3. 80

23. 167

[redacted] STAT

Calculated Reading = 23.167
Actual Reading = 22.84
Percentage Error = 1.44%

The foregoing calculations were made at the maximum flow rates obtained in the two Branches. When it is considered that the calculated error in each case would be cumulative and that Branch I had a total of eight fittings, while Branch II had ten, the average error of measurement per fitting is less than 0.5 percent (0.41 percent for I and 0.14 percent for II).

In the instances of low flows for the small-loss fittings (ball valve, union, coupling, etc.), reference to the data tables shows that the correction for line loss between manometer taps and the fitting being measured was, in many cases, 1/3 to 1/2 of the total pressure drop. Since the manometer readings themselves were rounded off to the nearest hundredth, the percentage of error could be quite high. The significance of such error, however, is minimal as it occurs at flow rates much below operating levels of any stage in a large production processor.

As stated in Subsection 2.1, the manometer could be read to an accuracy of 0.2 percent full scale when temperature-compensated. The pressure fluctuations introduced by the pump were of greater magnitude, in all cases, than the error of reading. The two calorimetric thermometers could be read to within ± 0.01°F. and the Centigrade thermometer to ± 0.01°C.

The pipe lengths were measured with a 100-foot Lufkin Chrome-Clad surveyor's tape, accurate to 0.001 foot. The manometer tap distances were measured with an L. S. Starrett 12-inch steel rule, No. C305R, accurate to 0.01 inch. Since maximum pressure drops were on the order of 0.03 foot per inch of pipe, any conceivable error of measurement in pipe length would be much below manometer error.

APPENDIX D

D1. 1 SAMPLE PUMP CALCULATIONS

Two typical calculations follow in which total head, suction head, and liquid horsepower were determined for the pump and for two different bearings, a 1-1/2-inch ID copper bearing and an identical stainless steel one. In both cases, barometric pressure was 29.99 inches of mercury at the time of recording the data and thus, a correction was unnecessary.

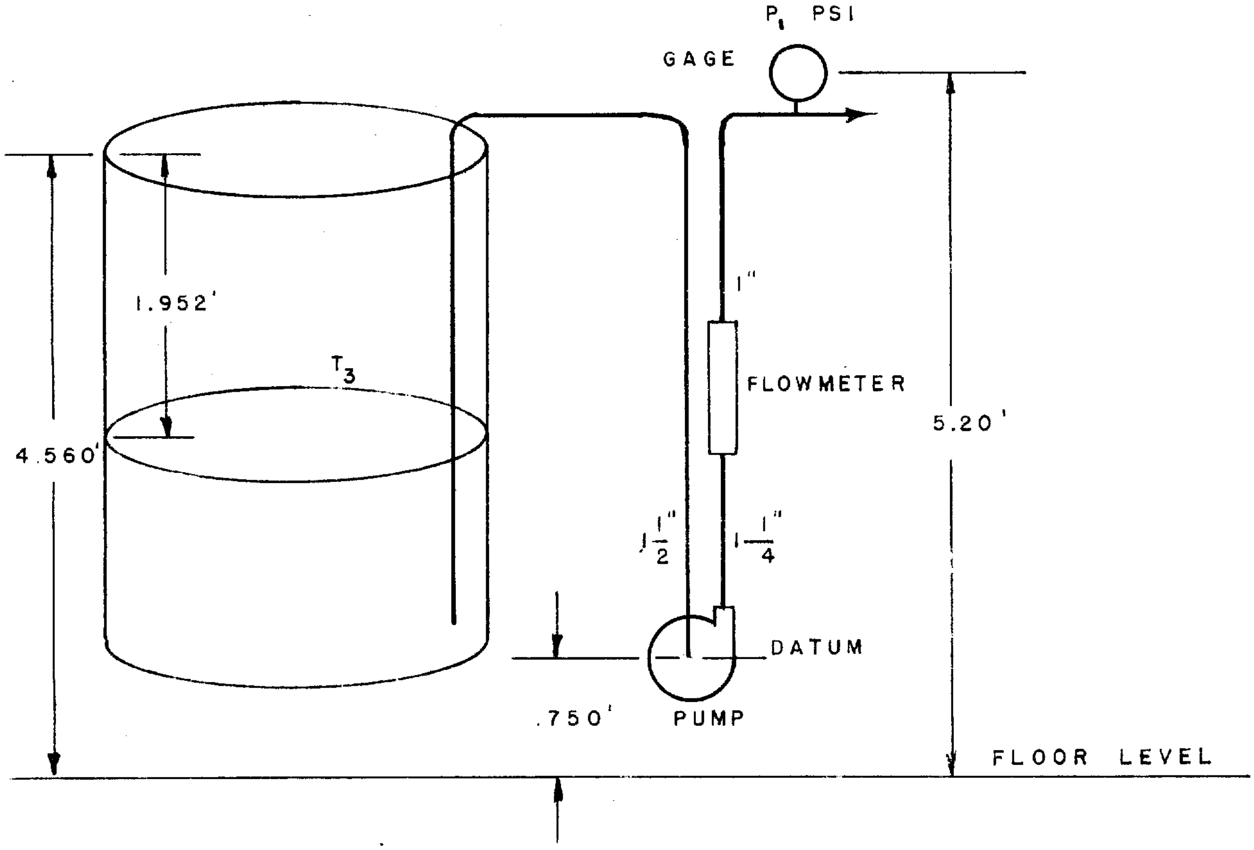

FIGURE D1-1

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$$\text{Pump Suction Head} = h_s = h_{sg} + Z_s + \frac{V_s{}^2}{2g}$$

$$\text{Pump Discharge Head} = h_d = h_{dg} + Z_d + \frac{V_d{}^2}{2g}$$

Where $h_{dg}{}^{2}$ discharge gage reading in feet of water

h_{sg} = suction gage reading in feet of water

Z_d = elevation of discharge gage zero above datum elev., feet

Z_s = elevation of suction gage zero above datum elev., feet

V_d = aver. water veloc. in discharge pipe @ discharge gage, ft/sec.

V_s = aver. water veloc. in suction pipe @ suction gage, ft/sec.

For 1.5" ID Cu Tube

$P_1 = 5.0$ psi

Flow = 34.0 gpm

$T_3 = 22.4^{\circ}$C.

$$h_{sg} = 4.560 - 1.952 - .750$$
$$= 1.858'$$

$$Z_s = 0$$

$$V_s = \frac{\text{gal}}{\text{min}} \times \frac{\text{fT}^3}{\text{gal}} \times \frac{1}{\text{fT}^2} = \text{ft/min}$$

$$V_s = 34.0 \times \frac{\overset{.1340}{0.1337}}{0.99782} \times \frac{1}{.0124}$$

$$= 367.4 \text{ ft/min}$$

$$\text{Where } A = \left(\frac{1.507}{12}\right)^2 \frac{\pi}{4} = .0124$$

gal to ft^3 @ 4°C = x (0.1337)

${}^{d}21.9^{\circ}\text{C} = .99782$

$$\frac{V_s{}^2}{2g} = \frac{\left(\frac{367.4}{60}\right)^2}{2 \times 32.17} = \frac{37.49}{64.34}$$

$$= .583'$$

[redacted] STAT

$$\therefore \quad h_s = h_{sg} + Z_s + \frac{V_s^2}{2g}$$

$$= 1.858 + 0 + 0.583$$

$$= 2.441$$

$$h_{dg} = 5.0 \times \frac{27.673}{12} \times \frac{1}{.99782}$$

$$= 11.56'$$

Where:

psi to in. H_2O @ $4^\circ C = x(27.673)$

$$V_d = 34.0 \times \frac{0.1337}{0.99782} \times \frac{1}{.00617}$$

$$= 738.4 \text{ ft/min.}$$

$$\text{Where } A = \left(\frac{.942}{12}\right)^2 - \frac{\pi}{4} = .00785 \times .7854$$

$$= .00617$$

$$\frac{V_d^2}{2g} = \frac{\left(\frac{738.4}{60}\right)^2}{2x32.17} = \frac{151.5}{64.34} = 2.355$$

$$h_c = h_{dg} + Z_d + \frac{V_d^2}{2g}$$

$$= 11.56 + 4.45 + 2.355$$

$$= 18.365$$

$$\text{Liquid Horsepower} = \text{whp} = \frac{(\#/\text{min}) \text{ x } (\text{total head})}{33,000}$$

$$= \frac{\left(34.0 \times 8.337 \times \frac{.99782}{.99905}\right) \times 15.924}{33,000} = \frac{283.1 \times 15.924}{33,000}$$

$$= 0.137 \text{ hp}$$

Where 8.337 # = 1 gal. water @ $60^\circ F$

$60^\circ F = 15.56^\circ C$

$d_{15.56^\circ C} = .99905$

$$\text{Total Head} = H = h_d - h_s$$

$$= 18.365 = 2.441 = 15.924$$

For 1.5" ID S.S. Tube

$P_1 = 5.0$ psi

Flow = 39.3 gpm

$T_3 = 22^\circ$ C

$$V_s = 39.3 \times \frac{.1337}{.99780} \times \frac{1}{.0124}$$

$$= 424.7 \text{ ft/min}$$

$$\frac{V_s^2}{2g} = \frac{\left(\frac{424.7}{60}\right)^2}{2 \times 32.17} = \frac{50.1}{64.34} = 0.779$$

$$h_s = 1.858 + 0 + .779$$

$$= 2.637$$

$$V_d = 39.3 \times .1340 \times \frac{1}{.00617} = 853.5$$

$$\frac{V_d^2}{2g} = \frac{\left(\frac{853.5}{60}\right)^2}{2 \times 32.17} = \frac{202.4}{64.34} = 3.146$$

$$h_d = 11.56 + 4.45 - 3.146 = 19.156$$

$$\therefore H = 19.156 - 2.637 = 16.519$$

$$\text{whp} = \frac{(39.3 \times 8.337 \times \frac{.99780}{.99905}}{33,000} = 16.519 = \frac{54052}{33000}$$

$$= 0.164 \text{ hp}$$

D1.2 CONCLUSIONS

When this figure is compared with that for copper (0.137), the penalty in power requirements we are paying for the pressure drop in the welded and drawn stainless tubing can be seen. Since this parameter is so critical, we should select seamless tubing, drawn and polished exclusively for construction of liquid bearings. The higher cost of the seamless tubing will be more than offset by reduced pump horsepower and improved performance.

D1.3 EFFECT OF PUMP DISCHARGE ANGLE

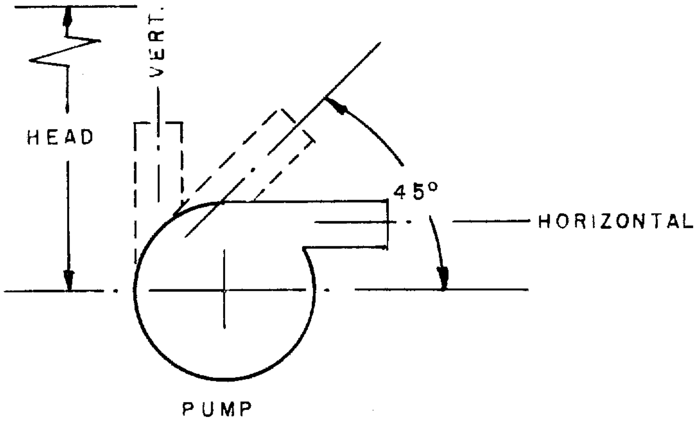

FIGURE D1-3

Eight feet of 1-5/8-inch ID flexible hose was added to circuit so plenum could be revolved easily. For each series, Branch II was open, Branch I closed.

APPENDIX E

E1. 1 ROTAMETER PRESSURE LOSSES

In order to calculate the approximate pressure drop across the flowmeter, the inlet pressure P_1 was measured with the pressure gage and the outlet pressure P_2 with a mercury manometer. While converting pressure gage readings to inches of mercury introduced some error, it avoided extensive changes in the test apparatus.

	T_2	P_1	P_2	P_1 (feet water)		P_2	
Flow	°F	psi	in. Hg.	x2.3066	@39.2°F	Corr.	Δp
40.8	72.90	14.0	20.76	32.29	32.21*	21.73	10.48
39.5	74.05	14.3	21.74	32.98	32.90*	22.76	10.14
37.5	74.35	14.6	22.62	33.68	33.59*	23.68	9.91

* Corrected for density at measured temperature.

°F	°C	gm/ml
72.90	22.73	.99762
74.05	23.35	.99748
74.35	23.53	.99743

In the case of the 40.8 gpm flow, the pressure drop is equivalent to 30.2 feet of 1-1/4-inch pipe.

$$\frac{10.48}{.3473} = 30.2 \text{ ft. where } .3473 \text{ is the pressure drop in } \frac{\text{feet}}{\text{foot}}$$

[redacted] STAT

Plenum Position	Time	Flow gpm	T_3 °F	P_1 psi	Head feet	Impeller
Vertical	1:53 PM	42.8	69.69	13.9	6,500	SPL.
45°	1:59 PM	42.8	69.69	13.9	6,500	SPL.
Horizontal	2:03 PM	42.5	69.69	13.9	6,500	SPL.
Vertical	2:42 PM	55.0	69.60	22.8	6.120	S
45°	2:46 PM	55.5	69.70	23.0	6.120	S
Horizontal	2:48 PM	55.5	69.75	22.9	6.120	S

As can be readily seen from the above compilation, in no case does the position of the plenum discharge outlet make even 1 percent difference in flow. Note that two different impellers were used in the test.

APPENDIX F

1. 1 DETAILED DESCRIPTION OF APPARATUS AND INSTRUMENTATION

1. 1. 1 Hold Tank

The hold tank was a [redacted] unit fabricated from stainless steel, welded and ground, with a rounded bottom and support skirt. Its capacity was 147. 2 gallons. The inside diameter was 33-3/4-inches; the overall depth at the center was 39 inches and, at the edge, 37 inches. Its 2-inch bottom drain had a vortex-breaking cover and the tank had a single one-inch side drain.

1. 1. 2 Pump

The liquid flow was provided by a 2-horsepower [redacted] "Flexflow" pump, Model VAH, Model No. 12566-0, Serial No. 25720. The motor was manufactured by the [redacted] It is a three-phase, 220/440 volt, 5. 2/2. 6 ampere, Type CDIX, Frame 204C, Class AO9, rated at 3495 rpm and 55^{o}C. full load temperature rise. The pump used had three optional impeller lengths available. The shortest, "Spe, " (special) was 3-inches long, "S" (short) was 3-3/4-inches long and "MM" (medium) was 4-7/16-inches long. All pressure drop tests except those for the sweep elbows were performed with the "Spe. " blade and some additional pump tests with the "S" blade. Maximum rating with the "Spe. " impeller was 35, 000 pounds per hour (4 198 gallons) at a 17-foot head. With the "S" impeller, rating was 30, 000 pounds per hour (3598) gallons) at a 50-foot head, manufacturer's rating. The "M" blade was not used because the "S" gave greater flow than our rotameter capacity.

1. 1. 3 Pipe

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The pump inlet pipe was [redacted] 2-inch LPS, Schedule 80, PVC II, CS 207-60, rated at 222 psi working pressure at 77°F. Interconnecting 1-1/4-inch PVC pipe was all [redacted] Schedule 80, high temperature "Koroseal," WP 415 psi at 75°F PE, 150 psi at 180°F PE, 065, R28GK, 0050.

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1. 1. 4 List of Fittings

Branch I

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1) 1-1/4-inch TTP [redacted] PVC union.
2) 1-1/4-inch TTP, PVC tee.
3) 1-1/4-inch TTP, PVC 90-degree elbow.
4) 1-1/4-inch Chemtrol PVC ball valve, with Teflon gaskets.
5) 1-1/2-inch Walworth PVC "Y" valve, reduced to 1-1/4-inch IPS.

Branch II

1) 1-1/4-inch PVC 90-degree elbow, with flanges.
2) 1-1/4-inch TTP, PVC coupling.
3) 1-1/2-inch Injection molded UPVC plug valve, 125 psi air at 75°F, limited to 150°F, TTP reduced to 1-1/4-inch IPS.
4) 1-1/4-inch TTP, PVC 45-degree elbow.

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All remaining connecting fittings were manufactured by [redacted] [redacted]

1. 1. 5 Thermometers

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Two of the thermometers used (T1 and T2) were [redacted], ASTM-56F Bomb calorimeter types, total immersion, graduated from 66° to 95°F in 0.05°F divisions. Their numbers were 1362102 and 1362112, respectively.

[redacted] STAT

All tank temperatures (designated T3) were measured on a [redacted] STAT STAT [redacted] "Permafused," etched-stem Centigrade thermometer. It was a gas-filled mercury type, 381mm long, ASTM 63C precision, No. 4173820, with a range of -8° to $+32^{\circ}$C. It reads to 0.1°C with interpolation to 0.01°C.

1.1.6 Flowmeter

STATOTHR

The flowmeter was a [redacted] STATOTHR [redacted] instrument. It was designed to measure gpm of liquids with a specific gravity of 1.0 (see Table 2-1 and Calibration Chart, Figure 2-5). Its serial number was D-7498 and its range was 5 to 55 gpm.

1.1.7 Pressure Gage

The inlet pressure measurements were made on a [redacted] STAT STAT [redacted] Model No. 1811-T "Supergauge." Its range was zero to 60 psi pressure, its movement, connection, and bourdon tube were made from STATOTHR Type 316 stainless steel and its gearing was Nylon. It was calibrated and certified by the [redacted] 16 October 1964. It reads to 0.5 psi with interpolation to 0.1 psi.

1.1.8 Manometers

All pressure drops were read on one of two manometers. The first was a Meriam U-tube vertical cleanout type whose range was 30 inches, graduated in increments of 0.10 inch. With mercury, 0.10 inch, was equivalent to 0.0491 psi.

Since many of the Δp's were very small, a specially sensitive mercury inclined manometer was constructed. This second instrument was made of accurate-bore Pyrex tubing, 122 centimeters long and 7mm in diameter. Its maximum reading was 40 inches scale, which reduced to 20 inches actual because of its 2:1 slope ratio. This was equivalent to

[redacted] STAT

9.82 psi gage. It could be read to 0.01 inch and had an accuracy of 0.2 percent full scale when temperature-compensated. Each leg was provided with a glass tee and pinch clamps for bleeding the lines of entrapped air and filling the instrument with water.

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