GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ____

Project No. E-20-639 GTRI/GIT DATE 3 / 12/ 84

Project Director: Dr. C. S. Martin School/Lab Civil Engineering

Sponsor: Kamyr Valves, Inc.

Type Agreement: P. O. No. P020353F583-3018 + Revision No. 1

Award Period: From 2/27/84 To ~~5/26/84~~ 7-30-84 (Performance) 5/26/84 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ 4,800	$ 4,800
Funded:	$ 4,800	$ 4,800

Cost Sharing Amount: $ ____ Cost Sharing No: ____

Title: Water and Steam Testing of Kamyr-Neles Ball Value

ADMINISTRATIVE DATA

OCA Contact Brian J. Lindberg X4820

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Defense Priority Rating: N/A

Military Security Classification: N/A
(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Sponsor

COMMENTS:

Revision No. 1 to P.O. adds mailing address for Dr. Martin.

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FORM OCA 4:383

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 11/20/86

Project No. E-20-639 School/XXX CE

Includes Subproject No.(s) N/A

Project Director(s) Dr. C. S. Martin GTRC / XXX

Sponsor Kamyr Valves, Inc.

Title Water and Steam Testing of Kamyr-Neles Ball Value

Effective Completion Date: 7/30/84 (Performance) ______ (Reports)

Grant/Contract Closeout Actions Remaining:

- [X] None
- [ ] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______

Continues Project No. ______ Continued by Project No. ______

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A. Jones
R. Embry

FORM OCA 69.285

HYDRAULIC CHARACTERISTICS OF ANTI-CAVITATION KAMYR-NELES BALL VALVES

by

C. Samuel Martin

Prepared for

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ABSTRACT

The discharge characteristics of KNI ball valves packed with various elements were determined for a range of valve opening angles. The flow coefficient C_v was determined for the 4-inch packed ball valves for valve angles ranging from 27° to 90° (full open) for a range of flowrates and cavitation conditions. Seven valve trims consisted of either small balls 1/4 inch to 3/4 inch in diameter or sleeves (short tubes) 1/2 inch or 3/4 inch in diameter. For a given valve opening the flow coefficient C_v exhibited only a weak dependence upon both the cavitation index and the Reynolds number.

Noise measurements determined by employment of both a piezoelectric pressure transducer and a quartz accelerometer yielded inconclusive correlations with cavitation level because of apparent influence of noise associated with motion and vibration of the packed elements within the valve body.

INTRODUCTION

Hydraulic characteristics of seven designs of Kamyr-Neles STEM-BALL 4-inch diameter ball valves were determined under cavitating and non-cavitating flow conditions. The valves are specially designed as anti-cavitation valves, being configured by packing the spherical space within the ball cavity with spheres or sleeves. Spherical end plates with slits provided a cage around the packed elements. Although the valves were tested under cavitating conditions as well as with no cavitation, the principal purpose of the tests was the determination of the flow coefficients of the seven trims for vavious openings. The testing was accomplished by installing the 4-inch valve body in a 30-ft long 4-inch diameter PVC pipe, through which water was forced by a centrifugal pump.

EXPERIMENTAL APPARATUS

The test rig consisted of a pressure tank into which city water was directed, a centrifugal pump, 12 ft of 4-inch diameter schedule 80 PVC pipe, the test valve, followed by 18 ft of PVC pipe and an orifice meter, terminating with a control valve which regulated the flow into a sump. Under steady operating conditions the air pressure in the upstream tank was regulated by an air pressure regulator and a valve in the city water line. The water flow through the pipe system could be regulated to a fixed value by means of the two valves.

The flow was measured with a sharp-edged orifice meter, which had been calibrated earlier gravimetrically. The pressure difference across the orifice was determined by means of a Pace KP15 differential pressure transducer, which was calibrated using a dead-weight tester. For the purpose of ease of setting the flowrate the differential pressure across the orifice meter was also registered, in parallel, on a mercury manometer. Ten pressure taps were installed at 20-inch intervals upstream and downstream of the test valve for the measurement of static pressure along the pipe. Each of these pressures could be directed to another Pace KP15 differential pressure transducer by means of a scanning valve. As the pressure gradient upstream and downstream of the test valve was very small because of the very low velocity within the pipe, the only static pressure eventually measured was that at 20 inches downstream of the downstream flange of the valve body. This pressure is referred to as P_d. The pressure difference across the valves was measuring using a third Pace KP15 differential pressure transducer, connected to the P_d pressure tap and the tap 20 inches upstream of the upstream flange of the valve body. This pressure is referred to as P_u.

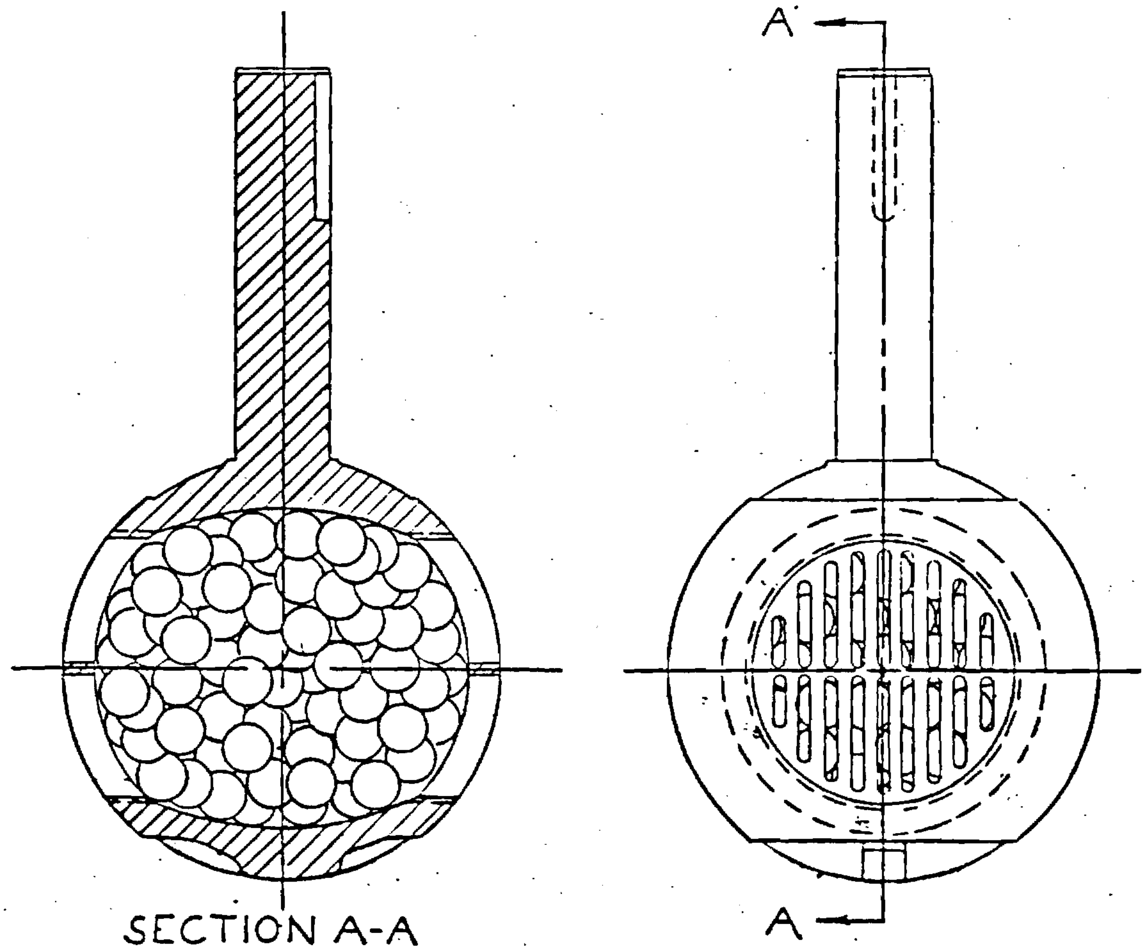
At another pressure tap 20 inches downstream of the downstream flange of the valve body a 0.099 inch PCB 105A piezoelectric pressure transducer was flush mounted to monitor pressure fluctuations. A PCB 308B accelerometer was mounted on the body of the valve for the purpose of determining the effect of flow and cavitation on vibrations. Both of these fluctuating signals were input into a HP 5420A Digital Signal Analyzer for online signal processing. Spectral analyses were conducted on the two signals over a bandwidth between 0 and

25.6 kHz. Experience confirmed that the signals were generally quite stationary between 50 and 100 ensemble averages. The purpose of analyzing spectra was to determine the onset and degree of cavitation by comparing spectra under cavitating conditions with those under no cavitation, as outlined in Martin et al. [1] and Martin and Rao [2].

The steady flow mean quantities of static pressure, valve pressure drop, and differential pressure across the orifice were determined by feeding the output from the respective amplifiers into a HP data acquisition system. This system, which was controlled by a HP 9825A Desktop Computer, consisted of a HP 3455 6-1/2 Digit Multimeter, a HP 3495 Multiplexer, a HP Printer, and a HP 9872A Plotter. The programmable features of the multimeter allowed for display of the flow, pressures, and cavitation index on the multimeter LED before making a decision to scan the channels for the final measurement of mean quantities. For each test 50 values of each signal were taken, the average of which could be stored on tape if desired.

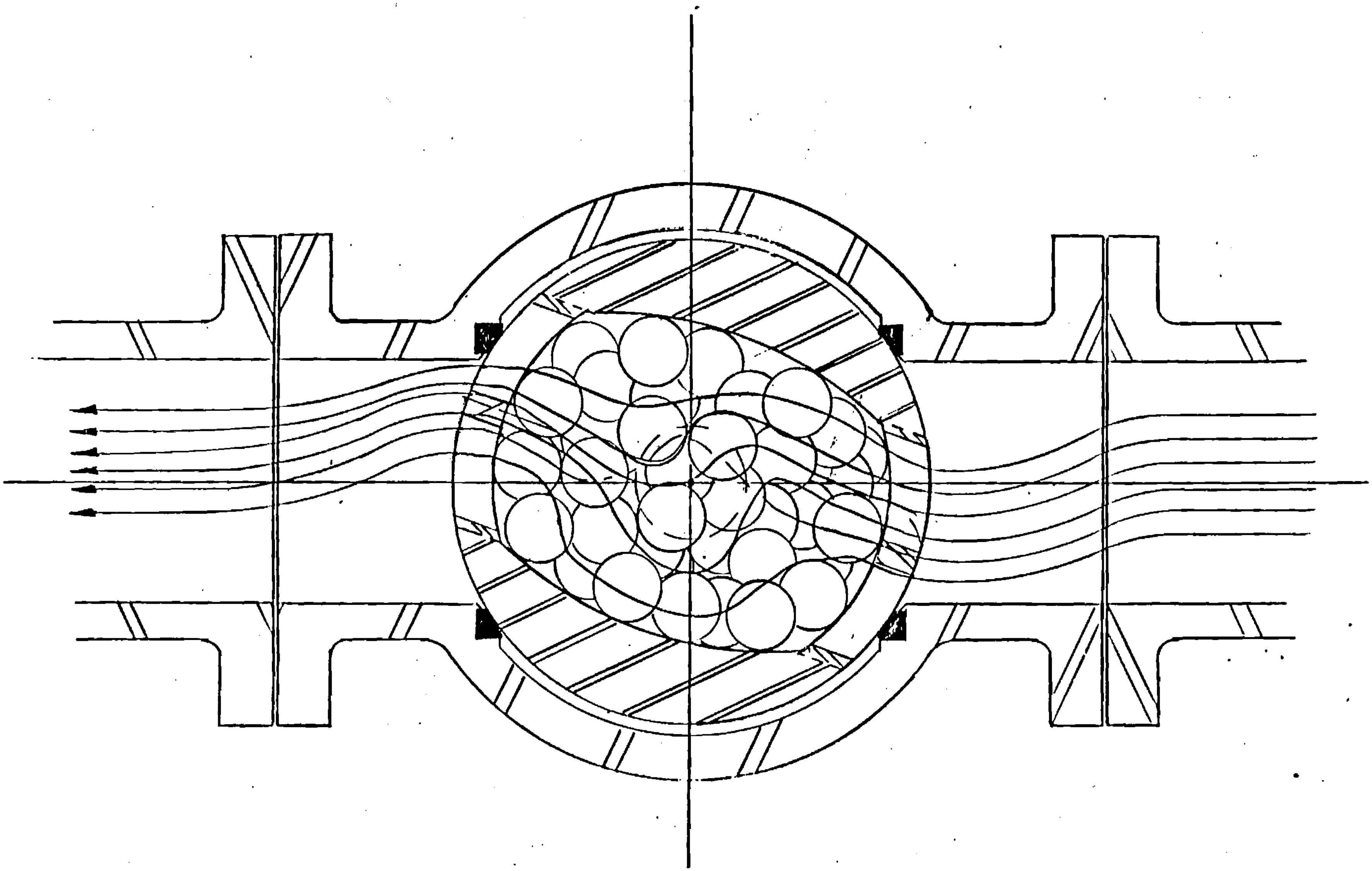
TEST PROGRAM

The configuration of the packed elements for Trim Nos. 1, 2, and 3 are shown in Figures 1 and 2. These trims consisted of stainless steel balls packed within the ball cavity as tight as possible. The diameters of the small balls were 1/4, 1/2, and 3/4 inch for Trims 1, 2, and 3, respectively. As shown by Figures 3 and 4, Trim No. 4 consisted of a combination of 1/4 inch and 3/4 inch balls, separated by a cylindrical baffle. For Trim Nos. 5 and 6, the valve body was packed by 1/2 inch or



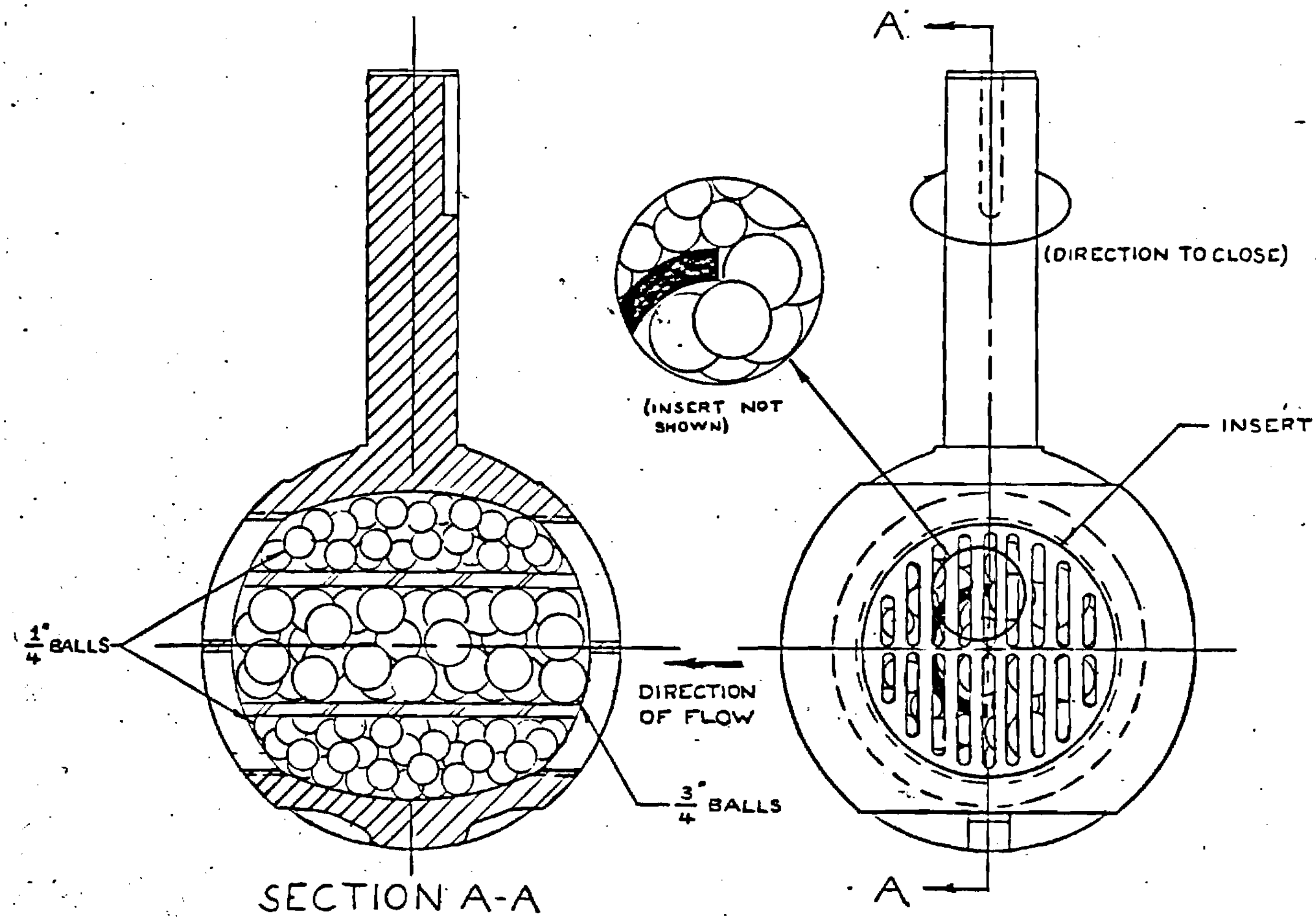
Valve Trim #1 - .25" Diameter Balls
Valve Trim #2 - .50" Diameter Balls
Valve Trim #3 - .75" Diameter Balls

Figure 1 Valve trims with uniform balls



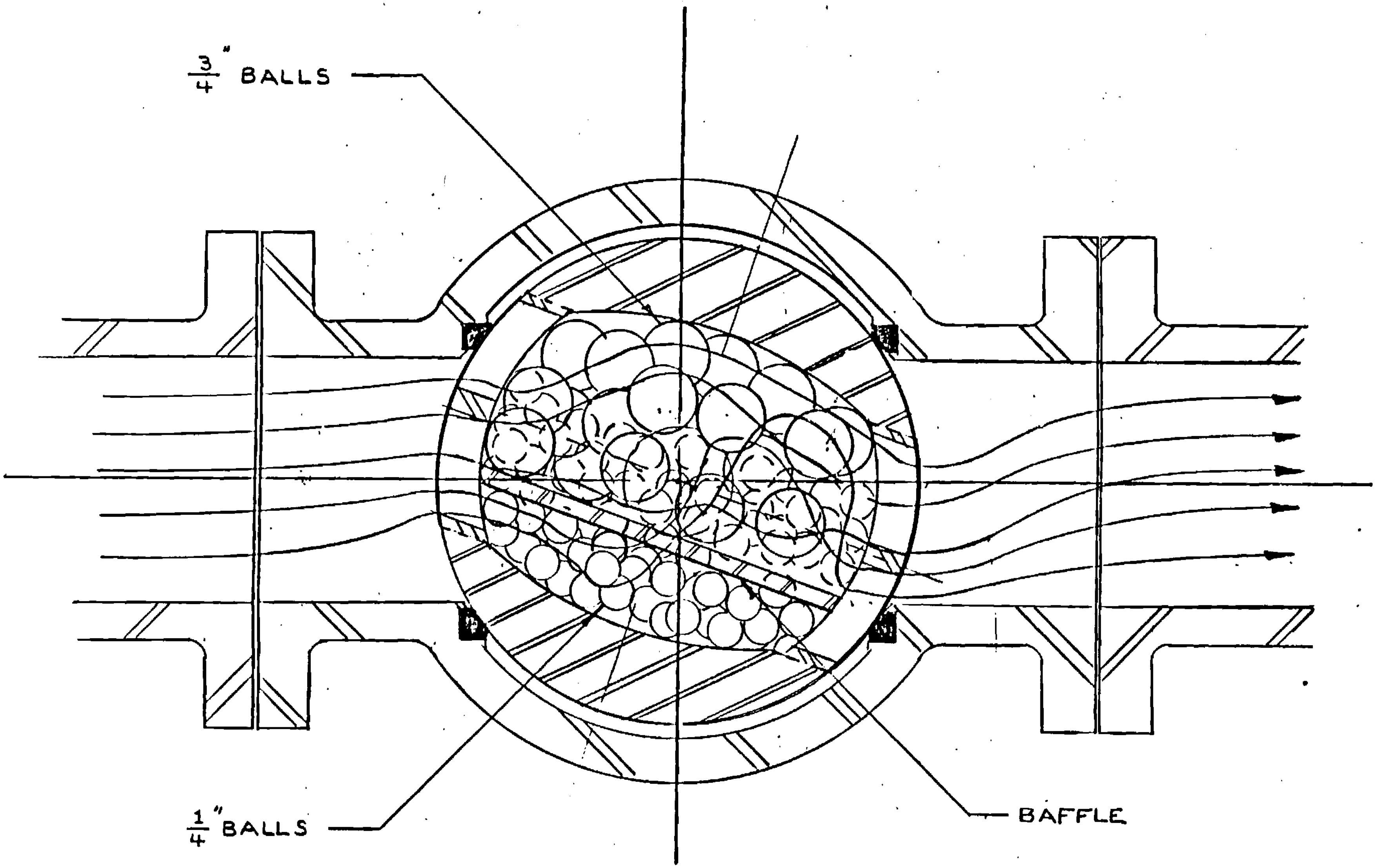
Valve Trim #1 - .25" Diameter Balls
Valve Trim #2 - .50" Diameter Balls
Valve Trim #3 - .75" Diameter Balls

Figure 2 Valve trims with uniform balls



TRIM NO. 4

Figure 3 Valve trim with mixture of two ball sizes



TRIM NO. 4

Figure 4 Valve trim with mixture of two ball sizes

3/4 inch sleeves, respectively, as shown in Figure 5. Finally, Trim No. 7 was configured by 1/2 inch sleeves contained between the valve body and 1-1/2 inch OD and 3 inch OD cylindrical baffles, as illustrated in Figure 6.

The hydraulic characteristics of each valve trim were determined for seven angle settings--90°, 81°, 72°, 63°, 54°, 45°, 36°, and 27°, with 90° corresponding to full open position. For each valve position the differential pressure across the valve $P_u - P_d$, and the flowrate Q were determined for a range of downstream pressures P_d, corresponding to various values of the cavitation index, defined by

$$\sigma = \frac{P_d - P_v}{P_u - P_d} \qquad (1)$$

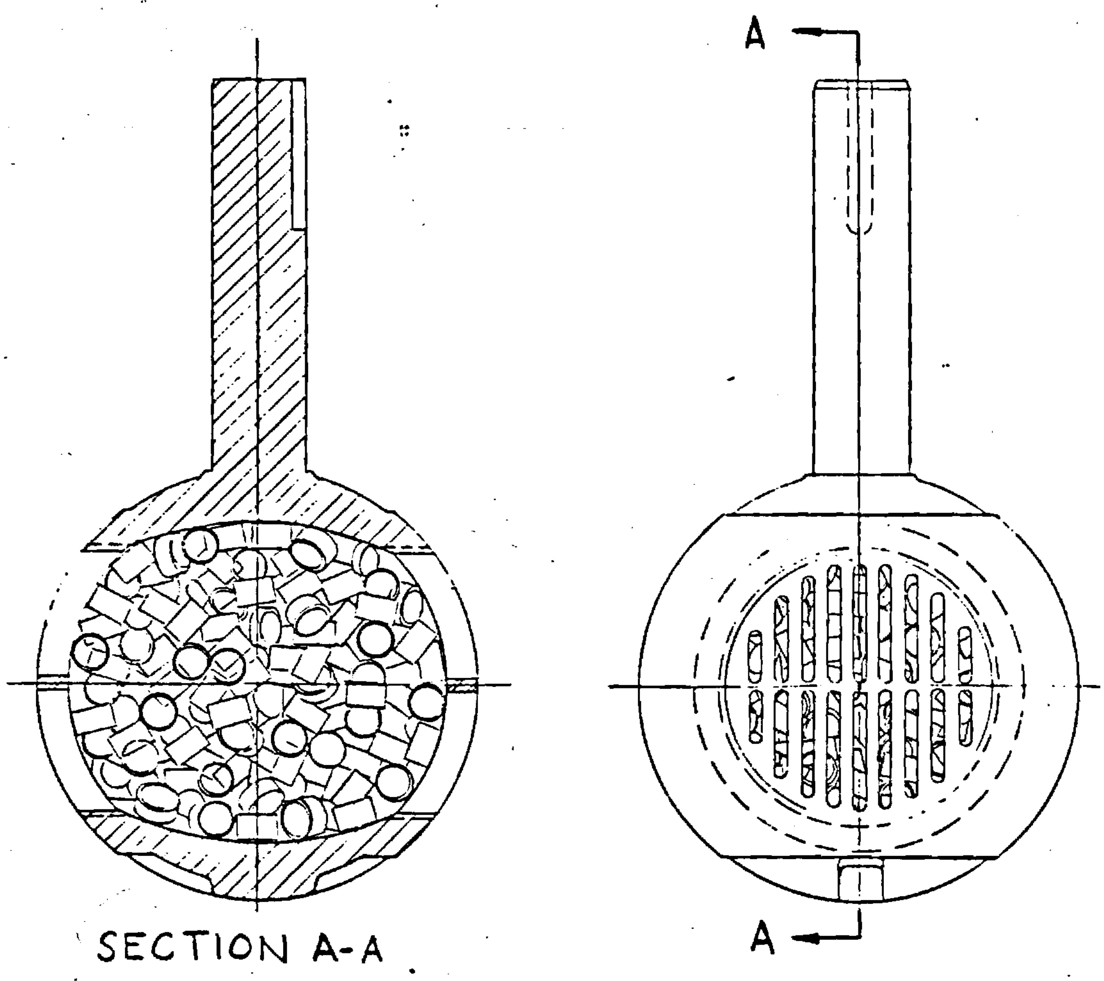
where P_v is the vapor pressure of water. The flow coefficient of the valve is defined by

$$C_v = \frac{Q}{\sqrt{\Delta P}} \qquad (2)$$

Where Q is the flowrate in gpm, and $\Delta P = P_u - P_d$ is the differential pressure in psi.

RESULTS

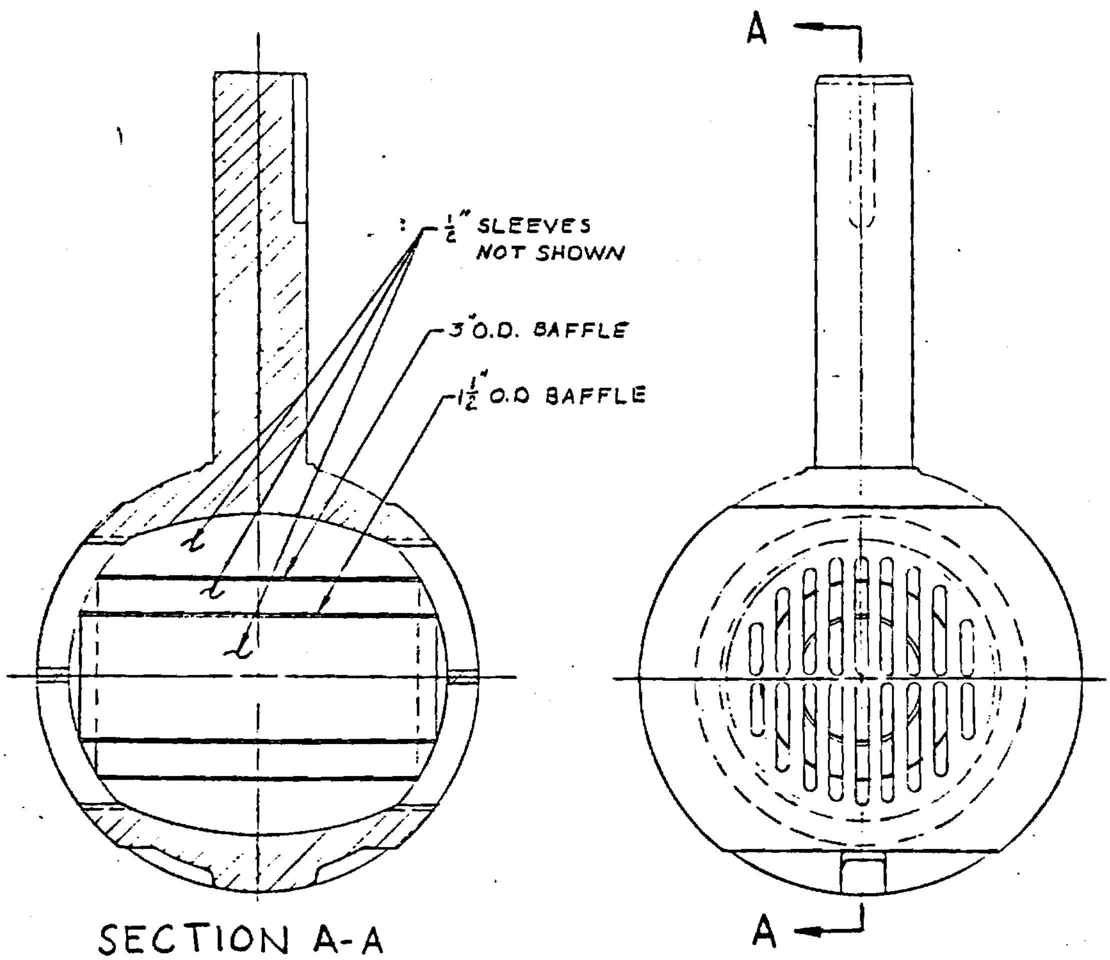
The variation of the flow coefficient C_v versus valve angle Θ is plotted in Figure 7 for the four valve trims consisting of steel balls. These values of C_v are average values of several tests at a given angle, obtained from Tables A-1 through A-6 in Appendix A. In general there should not only be a dependence of C_v on the cavitation index σ, but also on the Reynolds number, defined by



Valve Trim #5 - .5" Sleeves

Valve Trim #6 - .75" Sleeves

Figure 5 Valve trims with uniform sleeves



Valve Trim #7 - .5" Sleeves and Baffles

Figure 6 Valve trim with mixture of sleeves

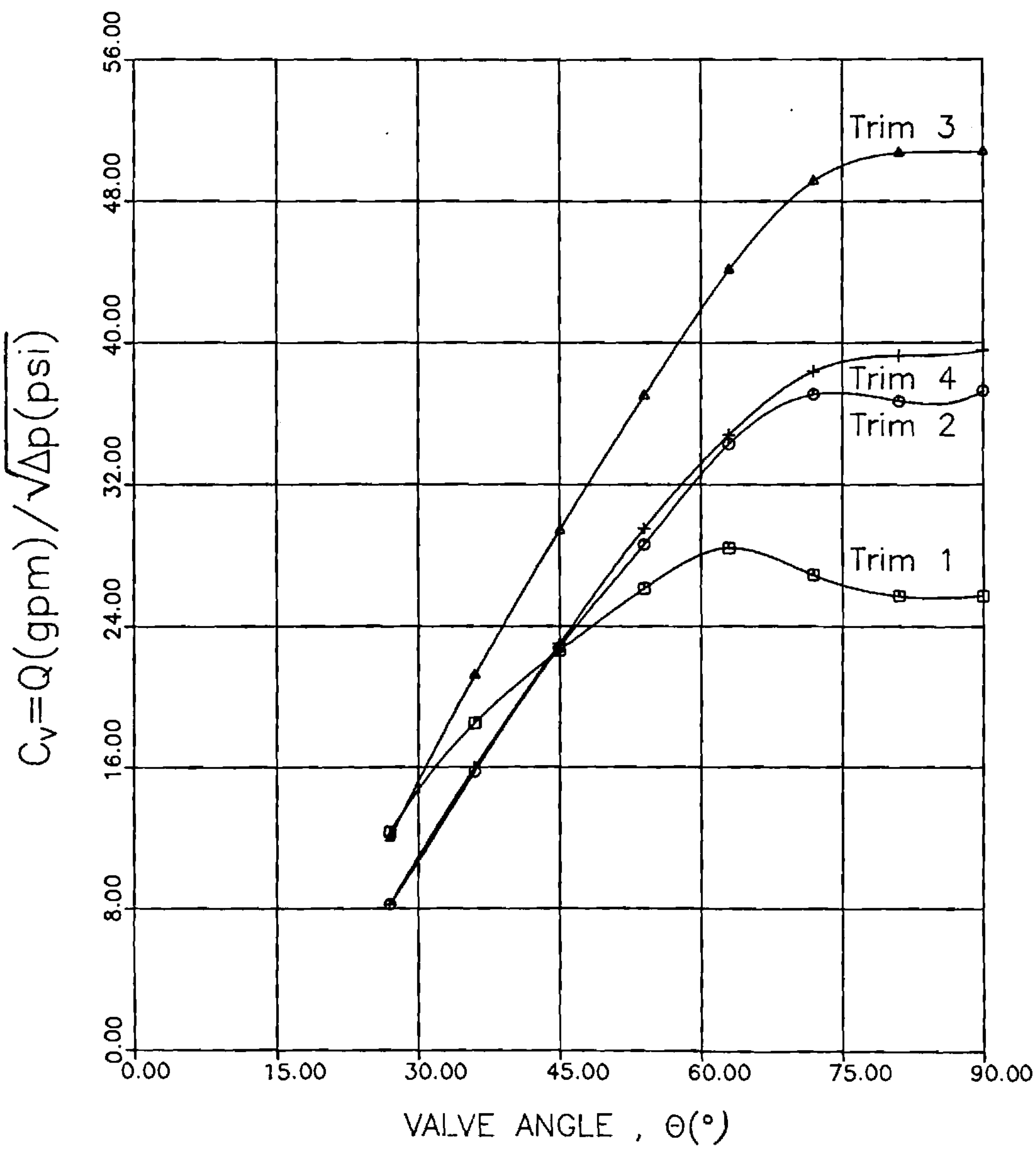


Figure 7 Flow coefficient versus valve angle for trims with steel balls

$$R = \frac{\rho V d}{\mu} \qquad (3)$$

in which ρ and μ are the water density and viscosity, respectively, V is the macroscopic velocity through the bore (pipe area) and d is the diameter of the small spheres. Fortunately, however, the effect of σ and R on C_V is rather small over the range of values of these parameters covered in these tests, as illustrated by the plots in Figues 8 and 9.

Figure 8, at an expanded scale, shows effects of both cavitation and viscosity on the flow coefficient for Trim No. 2 at a full open valve condition. For both of the constant flow series of tests, 200 gpm and 300 gpm, there is a gradual decrease of C_V with an increasing cavitation index. The higher flowrate of 300 gpm, corresponding to a somewhat higher Reynolds number R, yielded a slight increase in C_V for the same range of the cavitation index. Although the increase in C_V with increasing Reynolds number is understandable, and in concurrence with similar trends in the packed bed literature, the decrease in C_V with increasing σ at a constant R is not readily explainable. For a constant flowrate (200 gpm) through Valve Trim No. 4, which consisted of 1/4 and 3/4 inch balls, there is a similar trend of C_V versus σ for valve angles of 45° and 90°, as shown in Figure 9.

The pressure drop through Valve Trims 1, 2, and 3 corresponds closely to that of flow through a packed bed of uniform spheres, for which the head drop can be related to the

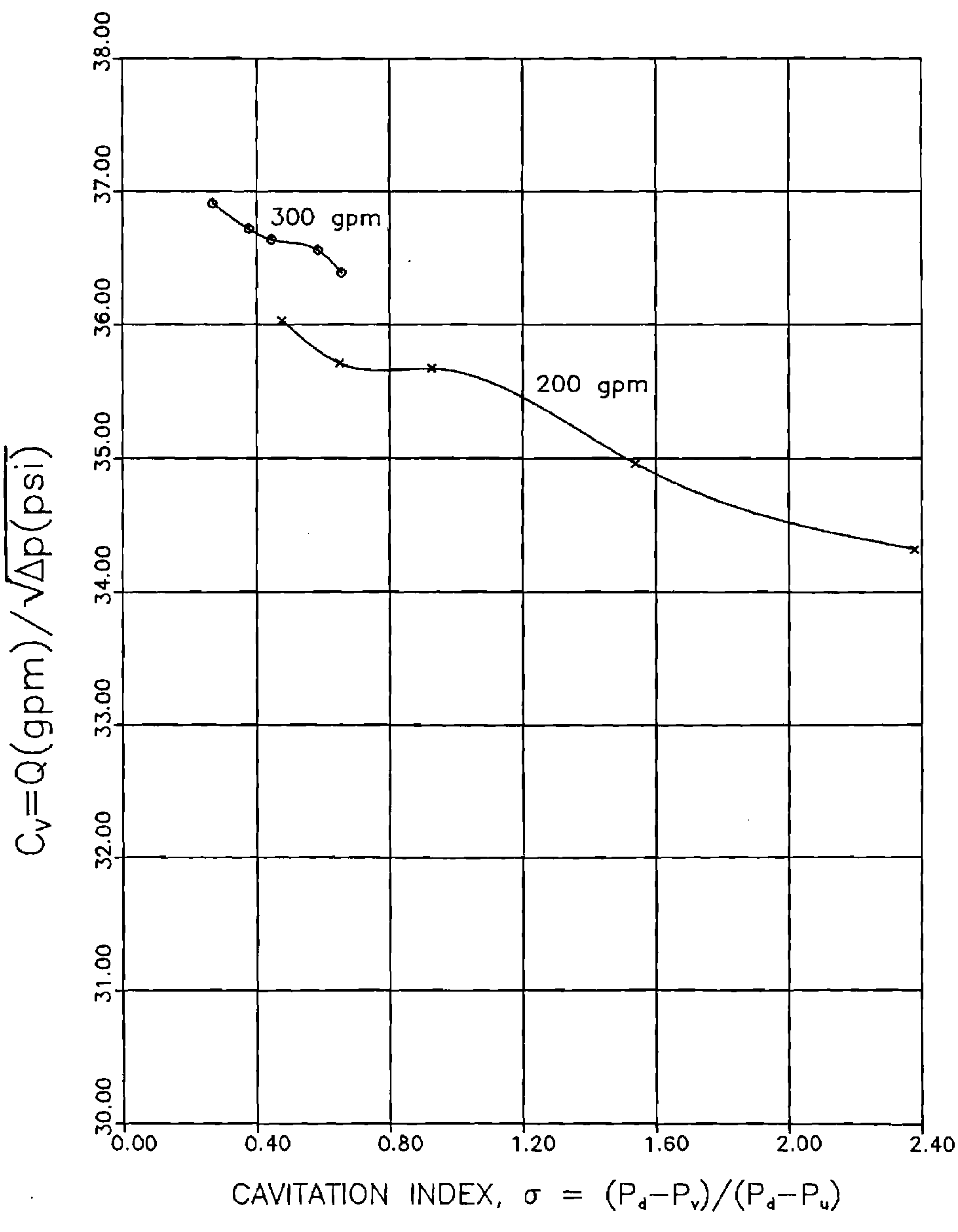


Figure 8 Flow coefficient versus cavitation index for Trim 2 with 1/2 inch balls and $\Theta = 90°$

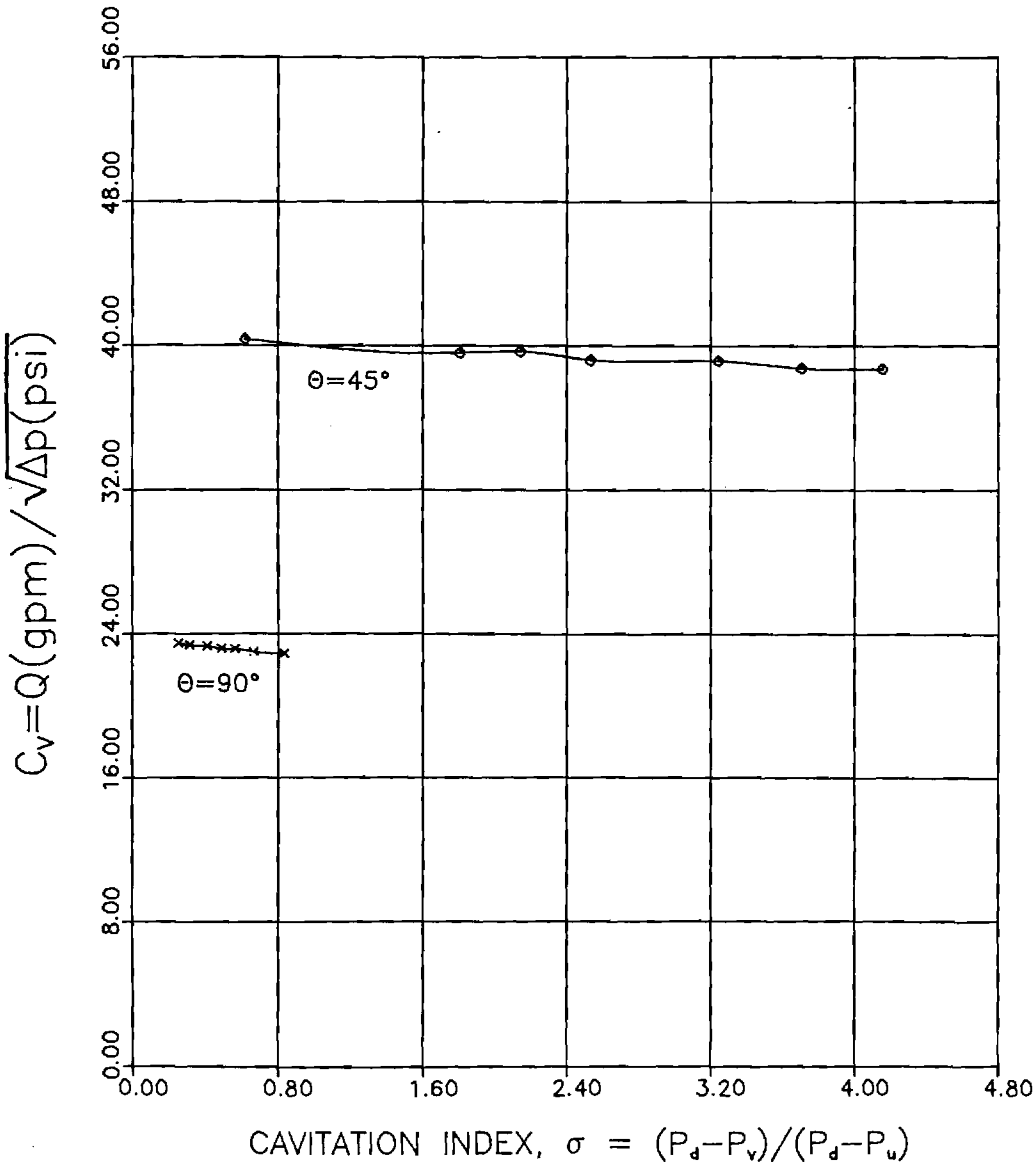


Figure 9 Flow coefficient versus cavitation index for Trim 4 with 1/4 and 3/4 inch balls and Q = 200 gpm

flow by an equation similar to the Darcy-Weisbach resistance coefficient

$$H_L = \frac{fL}{d} \frac{V^2}{2g} \tag{4}$$

In equation (4) V is the macroscopic velocity, equal to the velocity in the PVC pipe, d is the diameter of the small balls, and L, the flow path, is assumed to be the pipe diameter D. Combining equations (2) and (4), and introducing proper units, the Darcy f becomes

$$f = 18\ \pi^2\ (449)^2\ \frac{D^3 d}{\rho C_v^{\ 2}} \tag{5a}$$

or $$f = 35.8\ (10^6)\ \frac{D^3 d}{\rho C_v^{\ 2}} \tag{5b}$$

For Valve Trims 1, 2, and 3, the corresponding values of f are 21.6, 20.5, and 16.6, respectively. Although the flow through the relatively short length of packed bed, assumed in equation (4) to be D, the values of Darcy's f just listed compared reasonably with those reported by Bahtmeteff and Feodoroff [3], who determined f in long packed columns for values of R up to nearly 4,000, for which f = 22.0. For the packed valves, the Reynolds number varied from 14,000 to 54,000.

The results for the valve trims with sleeves, Nos. 5, 6, and 7, are tabulated in Appendix A in Tables A-7, A-8, and A-9, respectively. The average values of C_V for each of the seven valve positions are plotted in Figure 10. In contrast to two packed ball trims, C_V does not have a pronounced peak at a

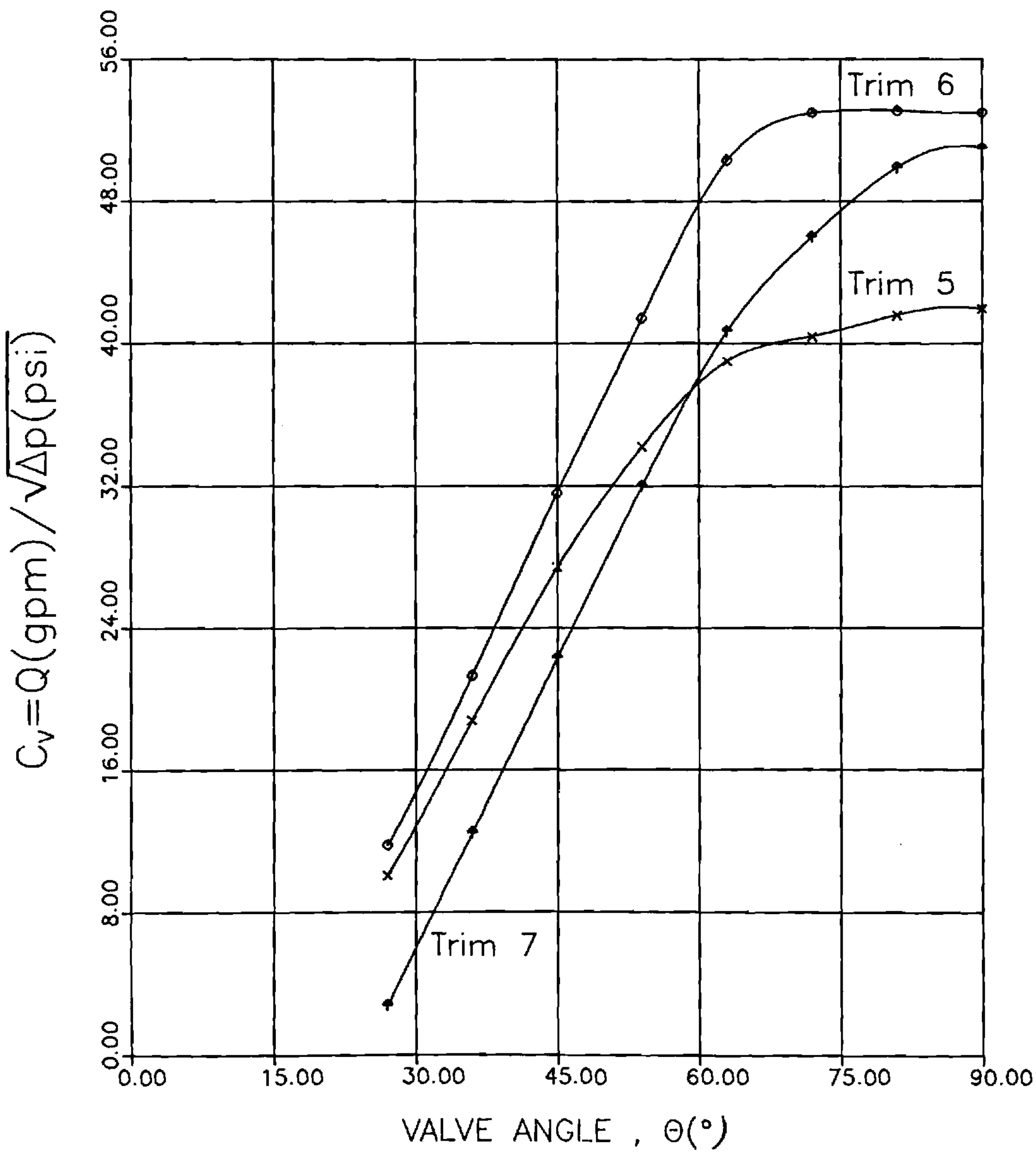


Figure 10 Flow coefficient versus valve angle for trims made of sleeves

valve position less than 90°. Clearly, the effect of the baffles is to reduce the flow to a C_V less than that for Trims 5 and 6 for values of Θ less than 60° because of their interference.

Effect of Cavitation

For tests with Valve Trims 1-4, readings from the piezoelectric pressure transducer and the quartz accelerometer were fed into the digital signal analyzer, which processed the signal and produced power spectra with 50 ensemble averages. Using the techniques of Martin and Rao [2], the various pressure and acceleration spectra were compared with each other, especially under conditions of fixed Θ and constant Q. Although an increase in cavitation intensity as reflected by the magnitude in σ had an apparent influence on the fluctuating energy levels from both instruments, no definitive correlation of energy level with σ could be made for the following reasons. It finally became apparent that the noise emanating from the valve was not only an effect of cavitation, but also influenced by either vortex shedding from the packed elements or vibrations associated from motion of the elements within the value body, or both. For all values of σ, even in excess of 4, for which there was obviously no cavitation, there was always an audible noise within the valve body--thought to be caused by movement of the packed elements. Attempts to separate noise associated with cavitation from noise caused by other effects were not successful inasmuch as the cavitation noise was not significantly greater.

In summary, the effect of cavitation on the flow characteristics of the packed ball valve is relatively small for values of σ as low as 0.1. In Table 1 are listed the values of C_V plotted in Figures 7 and 10.

Table 1

SUMMARY OF AVERAGE VALUES OF C_v

Valve Trim

θ(°)	1	2	3	4	5	6	7
90	25.7	37.3	50.8	39.6	41.9	53.0	51.0
81	25.7	36.7	50.7	39.3	41.6	53.1	49.9
72	26.9	37.1	49.1	38.4	40.4	53.0	46.0
63	28.4	34.3	44.1	34.8	39.0	50.3	40.7
54	26.1	28.6	37.0	29.5	34.2	41.4	32.0
45	22.6	22.8	29.4	23.0	27.4	31.6	22.3
36	18.5	15.8	21.2	16.0	18.8	21.3	12.5
27	12.4	8.2	12.0	8.2	10.1	11.8	2.8

REFERENCES

1. Martin, C.S., Medlarz, H., Wiggert, D.C., and Brennen, C., "Cavitation Inception in Spool Valves," Journal of Fluids Engineering, ASME, Vol. 103, No. 4, December 1981, pp. 564-576.

2. Martin, C.S. and Rao, P.V., "Application of Signal Analysis to Cavitation," Journal of Fluids Engineering, ASME, Vol. 106, September 1984, pp. 342-346.

3. Bakhmeteff, B.A. and Feodoroff, N.V., "Flow Through Granular Media," Prodeedings, 5th International Congress of Applied Mechanics, 1938, pp. 555-560.

APPENDIX A

TABULATION OF DATA

TABLE A-1

BALL VALVE CAVITATION STUDY

DATE: 12/08/83

RUN NUMBER: 2

TRIM #1

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff-eren. (psi)	Down-stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	267.1	107.6	3.0	25.746	0.0	0.158	1-2
2	90.0	253.4	97.6	16.4	25.644	0.0	0.311	3-4
3	90.0	242.2	87.7	30.4	25.869	0.0	0.506	5-6
4	90.0	204.3	65.3	61.9	25.287	0.0	1.162	7-8
5	81.0	204.3	65.2	62.3	25.300	0.0	1.170	9-10
6	81.0	231.9	82.3	38.3	25.567	0.0	0.635	11-12
7	81.0	253.0	96.5	17.8	25.757	0.0	0.330	13-14
8	81.0	263.4	104.3	7.2	25.791	0.0	0.203	15-16
9	72.0	270.6	101.8	7.9	26.826	0.0	0.215	
10	72.0	272.6	102.2	8.5	26.968	0.0	0.221	17-18
11	72.0	260.0	93.7	18.2	26.866	0.0	0.344	19-20
12	72.0	251.2	86.1	29.2	27.070	0.0	0.501	21-22
13	72.0	235.1	76.5	43.3	26.883	0.0	0.750	23-24
14	63.0	241.3	71.9	46.3	28.456	0.0	0.839	25-26
15	63.0	254.1	80.9	33.2	28.245	0.0	0.583	27-28
16	63.0	271.0	90.6	19.7	28.475	0.0	0.372	29-30
17	63.0	279.0	96.9	9.9	28.338	0.0	0.247	31-32
18	54.0	264.8	102.3	8.7	26.179	0.0	0.222	33-34
19	54.0	253.7	94.8	20.1	26.056	0.0	0.360	35-36
20	54.0	245.7	87.8	29.7	26.225	0.0	0.498	37-38
21	54.0	227.0	76.1	45.6	26.030	0.0	0.783	39-40
22	45.0	211.1	87.4	38.2	22.579	0.0	0.597	41-42
23	45.0	222.5	96.4	27.4	22.658	0.0	0.429	43-44
24	45.0	229.1	103.4	18.0	22.534	0.0	0.309	45-46
25	45.0	238.2	110.7	9.2	22.636	0.0	0.209	47-48
26	36.0	201.9	123.6	6.0	18.166	0.0	0.162	49-50
27	36.0	194.5	109.9	22.2	18.555	0.0	0.329	51-52
28	36.0	188.0	102.6	30.9	18.556	0.0	0.438	53-54
29	36.0	177.0	91.8	43.1	18.468	0.0	0.622	55-56
30	27.0	125.0	103.0	42.7	12.320	0.0	0.551	57-58
31	27.0	130.0	110.6	34.1	12.360	0.0	0.435	59-60
32	27.0	137.9	123.2	19.8	12.429	0.0	0.274	61-62
33	27.0	140.5	130.9	11.9	12.283	0.0	0.198	63-64

##

TABLE A-2

##

BALL VALVE CAVITATION STUDY

DATE: 12/07/83

RUN NUMBER: 1

TRIM #2

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff-eren. (psi)	Down-stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	333.8	81.3	5.6	37.029	5.4	0.241	1-2
2	90.0	304.7	68.2	4.3	36.910	0.0	0.269	3-4
3	90.0	269.7	54.0	2.9	36.704	0.0	0.313	5-6
4	90.0	259.0	50.2	2.5	36.566	0.0	0.330	7-8
5	90.0	228.8	40.0	1.5	36.171	0.0	0.388	9-10
6	90.0	199.7	30.7	0.6	36.028	0.0	0.476	11-12
7	90.0	200.1	31.4	6.4	35.705	0.0	0.649	13-14
8	90.0	200.1	31.5	15.2	35.673	0.0	0.927	15-16
9	90.0	199.1	32.4	35.9	34.961	0.0	1.539	17-18
10	90.0	199.1	33.6	66.1	34.324	0.0	2.380	19-20
11	90.0	299.4	66.5	4.4	36.718	0.0	0.277	21-22
12	90.0	300.0	67.0	15.8	36.635	0.0	0.445	23-24
13	90.0	302.2	67.9	25.7	36.659	0.0	0.584	25-26
14	90.0	299.6	67.8	30.4	36.389	0.0	0.656	27-28
15	81.0	329.1	81.5	5.9	36.455	0.0	0.244	
16	72.0	331.7	81.3	5.9	36.777	0.0	0.245	
17	63.0	315.0	88.0	5.2	33.586	0.0	0.218	
18	54.0	280.3	100.9	3.8	27.903	0.0	0.176	
19	45.0	235.7	115.2	2.2	21.960	0.0	0.140	
20	36.0	171.0	134.3	0.4	14.753	0.0	0.107	
21	27.0	81.3	141.2	8.0	6.846	0.0	0.156	

##

TABLE A-3

BALL VALVE CAVITATION STUDY

DATE: 12/08/83

RUN NUMBER: 1

TRIM #2

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff-eren. (psi)	Down-stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	297.1	63.0	24.7	37.433	0.0	0.614	29-30
2	90.0	320.6	72.7	5.0	37.602	0.0	0.262	31-32
3	90.0	273.6	54.4	41.6	37.082	0.0	1.022	33-34
4	81.0	271.8	55.1	41.3	36.618	0.0	1.003	35-36
5	81.0	291.9	63.3	25.1	36.677	0.0	0.617	37-38
6	81.0	317.7	74.3	5.0	36.860	0.0	0.255	39-40
7	72.0	320.2	73.8	5.1	37.269	0.0	0.258	41-42
8	72.0	301.2	65.3	20.8	37.260	0.0	0.533	43-44
9	72.0	275.7	56.4	39.4	36.707	0.0	0.947	45-46
10	63.0	263.2	59.7	40.1	34.052	0.0	0.906	47-48
11	63.0	282.9	68.0	26.1	34.317	0.0	0.590	49-50
12	63.0	292.2	72.4	18.0	34.355	0.0	0.442	51-52
13	63.0	306.6	79.2	4.6	34.462	0.0	0.235	53-54
14	54.0	276.0	92.0	5.0	28.771	0.0	0.207	55-56
15	54.0	267.1	86.1	13.8	28.794	0.0	0.323	57-58
16	54.0	261.1	82.4	20.7	28.763	0.0	0.422	59-60
17	54.0	244.6	74.7	32.2	28.297	0.0	0.619	61-62
18	45.0	194.9	74.9	48.7	22.528	0.0	0.838	63-64
19	45.0	208.2	84.5	33.8	22.646	0.0	0.565	65-66
20	45.0	222.8	95.1	19.4	22.839	0.0	0.351	67-68
21	45.0	236.7	105.0	6.5	23.095	0.0	0.195	69-70
22	36.0	178.4	126.1	3.0	15.892	0.0	0.135	71-72
23	36.0	175.2	118.3	10.4	16.106	0.0	0.207	73-74
24	36.0	156.6	98.2	34.8	15.806	0.0	0.497	75-76
25	36.0	135.1	78.8	58.7	15.219	0.0	0.922	77-78
26	27.0	83.0	109.1	37.3	7.949	0.0	0.471	79-80
27	27.0	89.9	121.3	23.9	8.164	0.0	0.312	81-82
28	27.0	97.6	136.9	8.8	8.343	0.0	0.167	83-84
29	27.0	101.3	140.5	4.5	8.548	0.0	0.132	85-86
30	27.0	60.5	80.4	69.2	6.751	0.0	1.036	87-88

TABLE A-4

##

BALL VALVE CAVITATION STUDY

DATE: 12/09/83

RUN NUMBER: 1

TRIM #3

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff- eren. (psi)	Down- stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	296.2	33.6	7.3	51.141	0.0	0.634	65-66
2	90.0	371.4	53.8	13.3	50.610	0.0	0.507	67-68
3	90.0	340.3	44.9	37.7	50.780	0.0	1.150	69-70
4	81.0	280.4	30.2	16.0	51.014	0.0	0.994	71-72
5	81.0	371.0	53.5	14.2	50.720	0.0	0.527	73-74
6	81.0	378.8	56.4	7.0	50.428	0.0	0.373	75-76
7	72.0	285.6	33.5	12.0	49.340	0.0	0.776	77-78
8	72.0	364.5	55.1	17.0	49.115	0.0	0.563	79-80
9	72.0	374.3	58.6	9.5	48.893	0.0	0.401	81-82
10	63.0	358.9	66.6	8.6	43.970	0.0	0.339	83-84
11	63.0	346.2	61.6	19.6	44.121	0.0	0.546	85-86
12	63.0	331.1	56.1	31.5	44.218	0.0	0.811	87-88
13	54.0	307.6	68.7	26.8	37.111	0.0	0.594	89-90
14	54.0	317.4	73.6	18.2	36.988	0.0	0.437	91-92
15	54.0	327.6	78.4	10.5	37.004	0.0	0.313	93-94
16	45.0	286.6	96.6	7.5	29.171	0.0	0.223	95-96
17	45.0	279.3	89.7	16.2	29.484	0.0	0.337	97-98
18	45.0	266.9	81.7	28.3	29.530	0.0	0.517	99-100
19	36.0	219.1	106.4	17.6	21.239	0.0	0.297	
20	36.0	219.1	106.4	17.6	21.239	0.0	0.297	101-02
21	36.0	227.3	115.2	6.1	21.176	0.0	0.175	103-04
22	36.0	197.1	85.9	42.5	21.270	0.0	0.657	105-06
23	27.0	134.6	126.6	16.0	11.959	0.0	0.237	107-08
24	27.0	138.2	134.3	7.7	11.928	0.0	0.162	109-10
25	27.0	125.8	107.5	36.6	12.140	0.0	0.471	111-12

##

TABLE A-5

##

BALL VALVE CAVITATION STUDY

DATE: 12/10/83

RUN NUMBER: 1

TRIM #4

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff-eren. (psi)	Down-stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	342.9	75.1	5.3	39.580	0.0	0.257	1-2
2	90.0	333.7	71.0	13.5	39.616	0.0	0.388	3-4
3	90.0	319.3	64.5	25.9	39.772	0.0	0.619	5-6
4	81.0	316.5	65.0	26.0	39.260	0.0	0.615	7-8
5	81.0	332.7	71.8	13.6	39.278	0.0	0.385	9-10
6	81.0	337.2	74.0	7.1	39.202	0.0	0.285	11-12
7	72.0	335.4	76.5	7.0	38.339	0.0	0.275	13-14
8	72.0	326.8	72.5	14.6	38.386	0.0	0.394	15-16
9	72.0	307.7	64.3	30.0	38.369	0.0	0.684	17-18
10	63.0	292.7	70.6	27.1	34.824	0.0	0.581	19-20
11	63.0	307.3	77.9	16.2	34.824	0.0	0.388	21-22
12	63.0	315.8	82.2	8.9	34.842	0.0	0.278	23-24
13	54.0	287.1	95.4	6.8	29.389	0.0	0.218	25-26
14	54.0	279.1	89.0	15.6	29.579	0.0	0.332	27-28
15	54.0	255.0	74.6	37.5	29.528	0.0	0.691	29-30
16	45.0	212.8	85.3	38.1	23.042	0.0	0.611	31-32
17	45.0	227.5	97.1	22.3	23.087	0.0	0.374	33-34
18	45.0	237.4	107.1	10.3	22.940	0.0	0.227	35-36
19	36.0	178.8	127.7	4.8	15.821	0.0	0.147	37-38
20	36.0	173.8	115.1	19.2	16.204	0.0	0.288	39-40
21	36.0	157.8	95.9	41.3	16.108	0.0	0.576	41-42
22	27.0	95.6	137.2	10.4	8.161	0.0	0.178	43-44
23	27.0	94.5	128.8	20.1	8.330	0.0	0.264	45-46
24	27.0	85.3	108.4	40.8	8.194	0.0	0.505	47-48

##

TABLE A-6

##

BALL VALVE CAVITATION STUDY

DATE: 12/14/83

RUN NUMBER: 1

TRIM #4

PUMP OFF FOR TESTS 6-7

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff-eren. (psi)	Down-stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	200.6	26.9	97.7	38.709	0.0	4.158	49-50
2	90.0	201.1	26.9	85.9	38.735	0.0	3.705	51-52
3	90.0	200.5	26.2	71.1	39.165	0.0	3.245	53-54
4	90.0	201.8	26.5	53.1	39.212	0.0	2.534	55-56
5	90.0	200.7	25.6	40.8	39.691	0.0	2.145	57-58
6	90.0	201.1	25.8	32.6	39.611	0.0	1.809	59-60
7	90.0	199.5	24.5	1.2	40.335	0.0	0.620	61-62
8	45.0	200.4	76.6	50.1	22.899	0.0	0.836	63-64
9	45.0	200.9	76.3	37.1	23.007	0.0	0.669	65-66
10	45.0	200.1	74.7	28.1	23.155	0.0	0.564	67-68
11	45.0	200.6	74.9	22.6	23.173	0.0	0.489	69-70
12	45.0	200.6	73.9	16.3	23.327	0.0	0.410	71-72
13	45.0	200.3	73.5	9.0	23.370	0.0	0.313	73-74
14	45.0	199.8	72.4	4.3	23.485	0.0	0.252	75-76
15	45.0	200.9	72.3	1.4	23.633	0.0	0.214	77-78

DATA ON FILE: 6

##

TABLE A-7

###

BALL VALVE CAVITATION STUDY

DATE: 03/26/84

RUN NUMBER: 1

TRIM #5

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff-eren. (psi)	Down-stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	224.4	29.0	1.4	41.641	0.0	0.531	
2	90.0	354.4	71.3	7.0	41.971	0.0	0.294	
3	90.0	354.2	71.6	7.0	41.864	0.0	0.294	
4	81.0	353.6	71.0	6.9	41.982	0.0	0.295	
5	81.0	272.1	43.4	29.6	41.297	0.0	1.004	
6	72.0	270.1	45.1	29.1	40.201	0.0	0.956	
7	72.0	344.1	72.2	6.8	40.512	0.0	0.289	
8	63.0	338.1	75.3	6.6	38.974	0.0	0.273	
9	54.0	316.5	85.6	5.6	34.204	0.0	0.228	
10	45.0	278.4	103.6	3.9	27.359	0.0	0.173	
11	36.0	211.8	126.3	1.7	18.849	0.0	0.124	
12	27.0	123.0	148.2	-0.0	10.105	0.0	0.094	

DATA ON FILE: 7

###

TABLE A-8

BALL VALVE CAVITATION STUDY

DATE: 03/27/84

RUN NUMBER: 1

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff-eren. (psi)	Down-stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	289.8	30.2	10.5	52.733	0.0	0.811	
2	90.0	373.1	49.0	18.7	53.288	0.0	0.667	
3	81.0	295.3	30.9	11.1	53.132	0.0	0.812	
4	81.0	371.7	49.1	18.5	53.055	0.0	0.663	
5	72.0	295.3	31.0	11.1	53.035	0.0	0.810	
6	72.0	294.8	31.0	11.2	52.948	0.0	0.812	
7	72.0	371.8	49.0	18.8	53.122	0.0	0.669	
8	63.0	291.6	33.7	7.7	50.248	0.0	0.644	
9	63.0	366.3	52.9	11.8	50.357	0.0	0.487	
10	54.0	267.3	42.1	6.3	41.201	0.0	0.482	
11	54.0	340.6	67.3	10.2	41.509	0.0	0.359	
12	45.0	233.7	55.2	4.8	31.439	0.0	0.341	
13	45.0	297.6	88.0	7.8	31.727	0.0	0.248	
14	36.0	178.5	70.1	3.0	21.320	0.0	0.242	
15	36.0	229.2	115.6	4.8	21.324	0.0	0.163	
16	27.0	108.7	84.0	1.3	11.865	0.0	0.182	
17	27.0	139.2	143.4	1.9	11.628	0.0	0.111	

DATA ON FILE: 8

TRIM #6

##

TABLE A-9

BALL VALVE CAVITATION STUDY

DATE: 03/27/84

RUN NUMBER: 2

TRIM #7

	Valve Angle (Deg.)	Flow Rate (gpm)	Diff-eren. (psi)	Down-stream (psi)	Cv (gpm, ,psi)	Recovery P[10] (psi)	Sigma	Files
1	90.0	285.7	31.8	10.3	50.640	0.0	0.764	
2	90.0	366.3	50.8	18.3	51.384	0.0	0.636	
3	90.0	365.9	51.4	18.3	51.042	0.0	0.628	
4	81.0	284.9	32.9	9.6	49.707	0.0	0.719	
5	81.0	361.8	52.1	17.7	50.133	0.0	0.609	
6	72.0	275.9	36.4	8.9	45.715	0.0	0.628	
7	72.0	353.1	58.3	16.6	46.246	0.0	0.524	
8	63.0	262.8	42.3	7.6	40.427	0.0	0.511	
9	63.0	334.4	66.8	14.6	40.918	0.0	0.427	
10	54.0	230.6	52.5	5.1	31.818	0.0	0.364	
11	54.0	298.8	85.8	10.9	32.249	0.0	0.290	
12	45.0	178.9	67.1	1.7	21.841	0.0	0.235	
13	45.0	238.2	110.1	5.5	22.696	0.0	0.177	
14	36.0	108.8	79.6	-1.6	12.187	0.0	0.156	
15	36.0	148.2	136.6	0.2	12.676	0.0	0.104	
16	27.0	34.5	154.8	-2.9	2.772	0.0	0.072	

DATA ON FILE: 9

##