Alpha-I Reference Manual
Version 20
March 2020
Table of Contents

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Installed Characteristics

To display the installed characteristic graph, you must perform sizing calculations for at least two sets of process conditions. After the sizing calculations have been completed, select Installed Characteristics under Calculations on the Menu Bar. If the process data entered is valid (see below), Alpha-I will create the valve's installed characteristic graph and display it in the Installed Characteristic dialog box. The graph contains two vertical lines. These lines represent the minimum and maximum calculated position open for the process conditions input. Installed characteristics for two valves can be overlaid on the same graph to depict the difference between them. To overlay two installed characteristic graphs, select Overlay Installed Characteristics under Calculations on the Menu Bar. Alpha-I will display the Installed Characteristic Overlay dialog box. The current tag will be identified and tags which have identical process conditions will be listed in a selection box. Click on the tag in the selection box that you want to overlay and Alpha-I will create the graph. To overlay two installed characteristic graphs, both valves must have been sized and saved in the same project for identical process conditions.

Definitions:

Valve Characteristic - The relationship a specific valve or valve trim combination exhibits between the position open of the valve and the flow rate through the valve.

Inherent Characteristic - The characteristic of a valve under test conditions. When a valve is tested for Cv (Valve Capacity) it is tested with a constant pressure drop. The inherent characteristic of a valve is the relationship (graph) between the position open of the valve and the flow rate with a constant pressure drop.

Installed Characteristic - The characteristic of a valve (the relationship of flow versus position open) when the valve is installed in actual process conditions. This can vary substantially from the inherent characteristic as the pressure drop across the valve decreases as the process flow increases.

Valve Pressure Drop - The amount of pressure a valve must dissipate to operate the system at the desired flow rate. Valve pressure drop is determined by the system characteristic. Every system has a pressure source. It could be a pump, blower, header, tank etc. The valve pressure drop is the value of the pressure source at a given flow rate minus the friction losses of the fluid at the same flow rate, minus the elevation head, static head and/or branch pressure.

In most systems the value of the pressure source decreases as the flow rate increases, and the value of the friction loss increases as the flow rate increases. The net effect is the valve pressure drop decreases as the flow rate increases.

Why is the Installed Characteristic important?

In most systems it is desirable for the installed characteristic to be somewhat linear. This is represented by a straight line for an Installed Characteristic graph. If the installed characteristic is linear, a given movement of the valve will provide a consistent change in the flow rate regardless of whether the valve is operating at a low or high position open. With a linear installed characteristic, the valve is predictable to the other components of the control system.

Conversely, if the installed characteristic of the valve is not linear, the valve can exhibit different gains (variable flow rate changes for the same position movement) when throttling at a low position open compared to a high position open. This can make the valve unpredictable to the other components of the control system.

How else is the Installed Characteristic helpful?

The Installed Characteristic Graph visually shows you how much of the valve span you are utilizing, if the valve will exhibit a high or low gain, and if you are throttling near the closed or open position of the valve.

It is desirable to utilize a large portion of the valve span. This greatly increases the accuracy of the valve. A control valve (valve, actuator and positioner) can make a finite number of movements between fully open and fully closed. Each movement can be equated to a specific change in flow rate. If the valve is sized to utilize a large portion of its span, it can make smaller incremental changes in flow rate. This can dramatically improve the accuracy and stability of the control loop.

In most instances, the valve gain is related to the span of the valve. If the installed characteristic graph is closer to vertical than to horizontal, the gain of the valve will be relatively high. This means a small change in valve movement will produce a large change in flow rate. If the gain is too high, the valve can be "sensitive". If the installed characteristic graph is closer to horizontal than vertical, the gain of the valve will be relatively low. A large change in valve movement will produce a small change in flow rate. If the gain is too low, the valve can be sluggish.

It is not desirable to throttle near the fully open or fully closed position of the valve. When throttling near the closed position, the torque can increase; the valve is more likely to plug; and the inherent characteristic becomes undefined. All of these negatively affect the performance of the valve. When sizing a valve to throttle near the open position you run the risk of under-sizing the valve. The valve may not be able to pass the capacity required to control the system.

What are the limitations of the Installed Characteristic?

In trying to determine if the valve is predictable to the other components of the control system, the dynamics of the actuator and positioner can affect the predictability. Most actuators do not have a linear relationship between output torque, actuator volume or actuator travel. The linearity of positioners (I/P or P/P) can vary based on the type and manufacturer.

If you are using system design values to predict the control valve's installed characteristic, you will introduce error due to the safety factors and estimations used in determining the system characteristic. Typically these errors will cause the valve to have a higher pressure drop in actual service. This higher pressure drop will change the position open at which the valve operates and can significantly affect the installed characteristic.

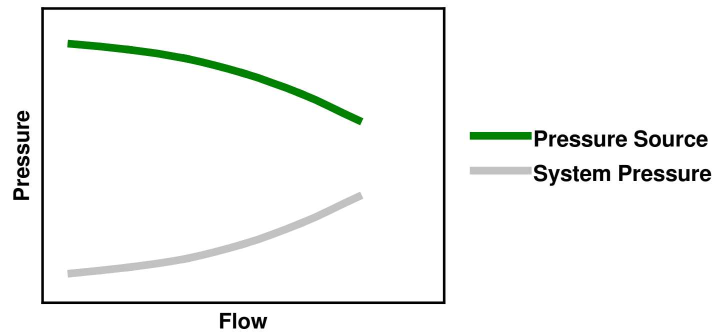
Other systems can interact with systems you are analyzing and affect the prediction of the installed characteristic. If your pressure source is a tank on level control, as the level drops or raises, the pressure source (and thus the valve pressure drop) changes unpredictably. This will have a negative impact on the prediction of the installed characteristic.

How is the Installed Characteristic determined?

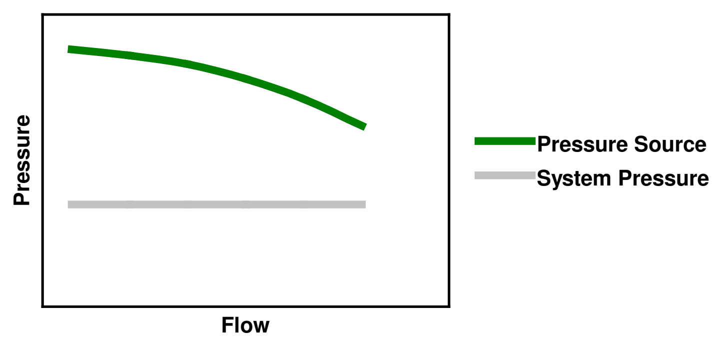
To determine the installed characteristic of a valve, Alpha-I must first predict the type of system in which the valve is installed. Alpha-I tests the input process conditions against four models. If the conditions input meet one of the models, Alpha-I will calculate the installed characteristic.

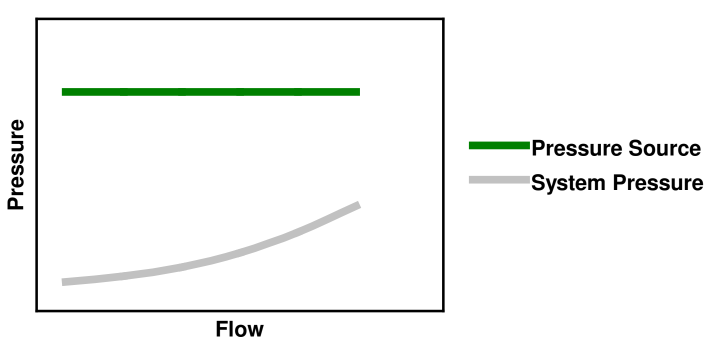
Definition of the four system models:

<ins>Model One</ins> - Valve inlet pressure decreases as the flow rate increases and the valve outlet pressure increases as the flow rate increases. This is the typical pumped system with a medium to long run of piping.



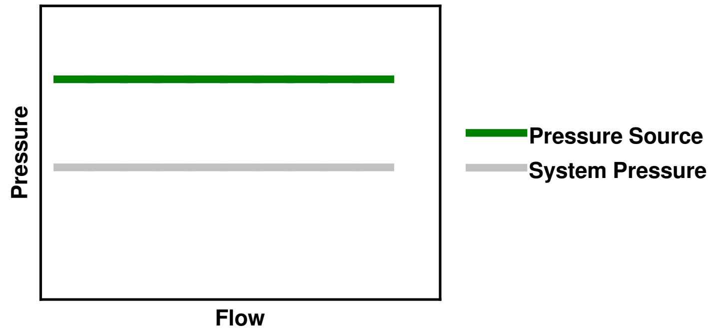
<ins>Model Two</ins> - Valve inlet pressure decreases as the flow rate increases and the valve outlet pressure remains constant as the flow rate increases. This is the typical pumped system with a short run of piping that has negligible friction losses.





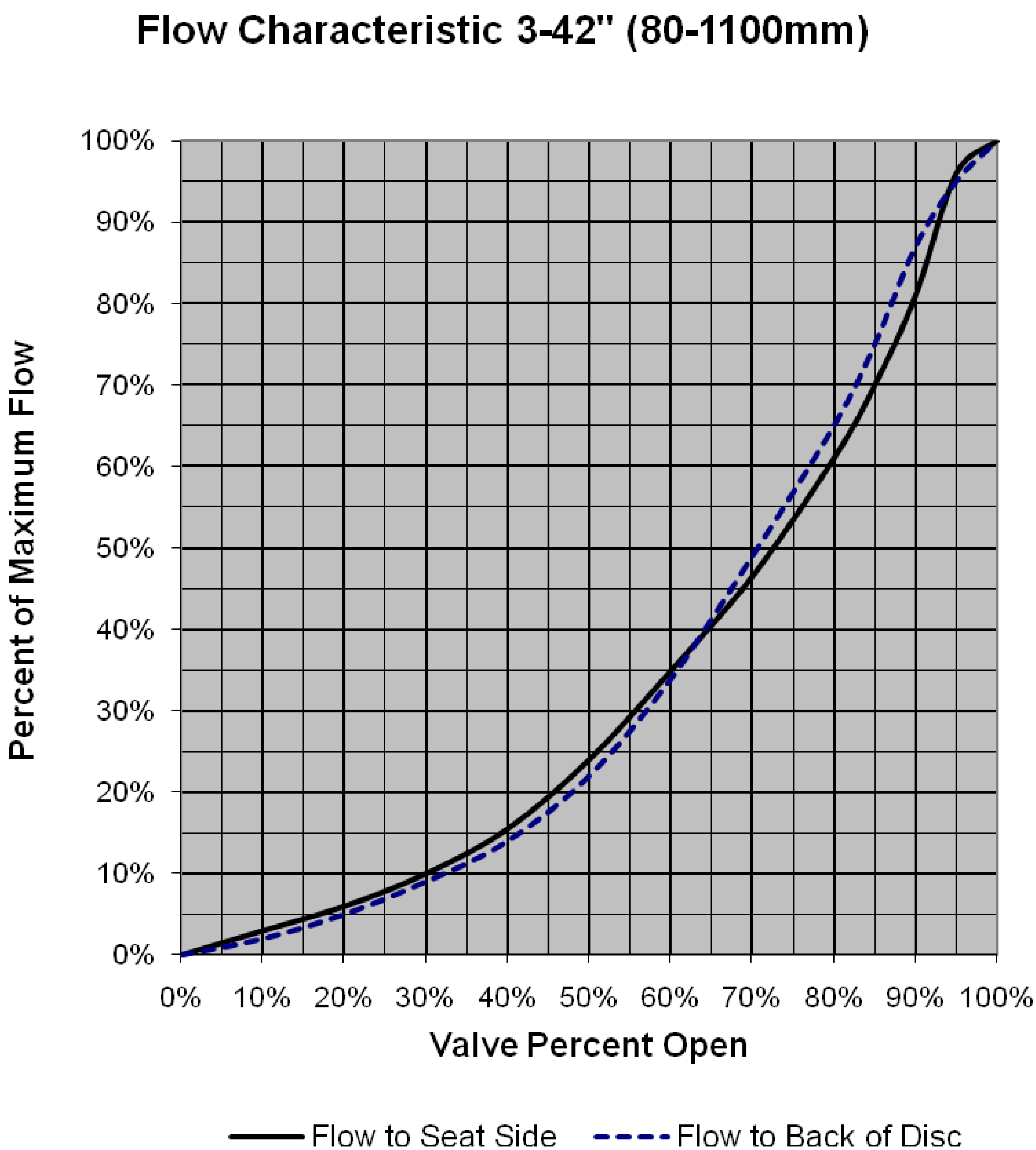
<ins>Model Three</ins> - Valve inlet pressure remains constant as the flow rate increases and the valve outlet pressure increases as the flow rate increases. This is typical when the pressure source is a header with a medium to long run of piping.

<u>Model Four</u> - Valve inlet pressure remains constant as the flow rate increases and the valve outlet pressure remains constant as the flow rate increases. This is typical when the pressure source is a header with a short run of piping that has negligible friction losses.

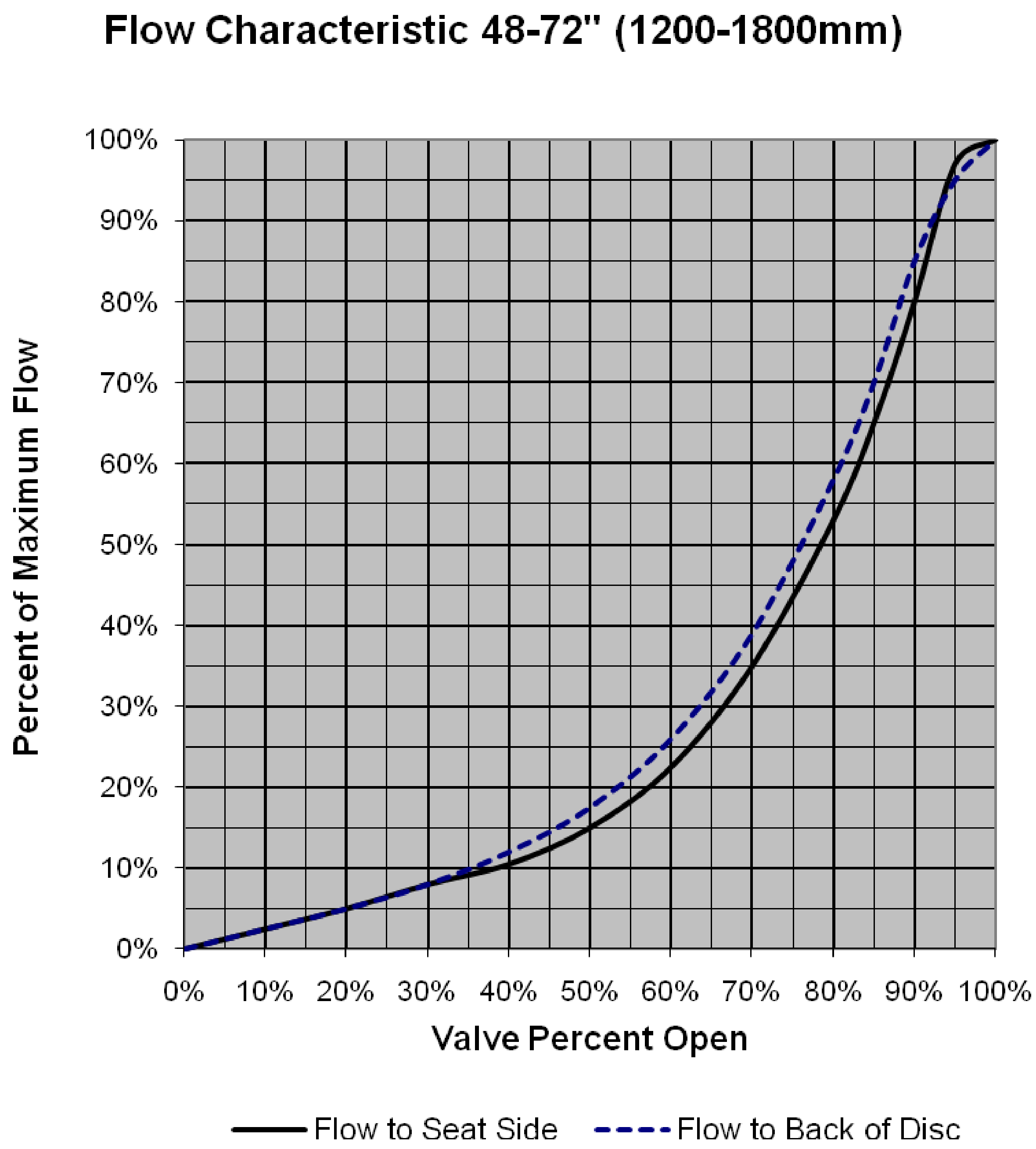


Based on the system model, Alpha-I predicts the maximum flow rate of the system with the valve installed, and develops equations that predicts the inlet pressure and pressure drop for any given flow rate. From these equations, Alpha-I sizes the valve for 1% through 99% of the maximum flow rate and determines the position open for each flow rate. This is the data used to plot the installed characteristic graph.

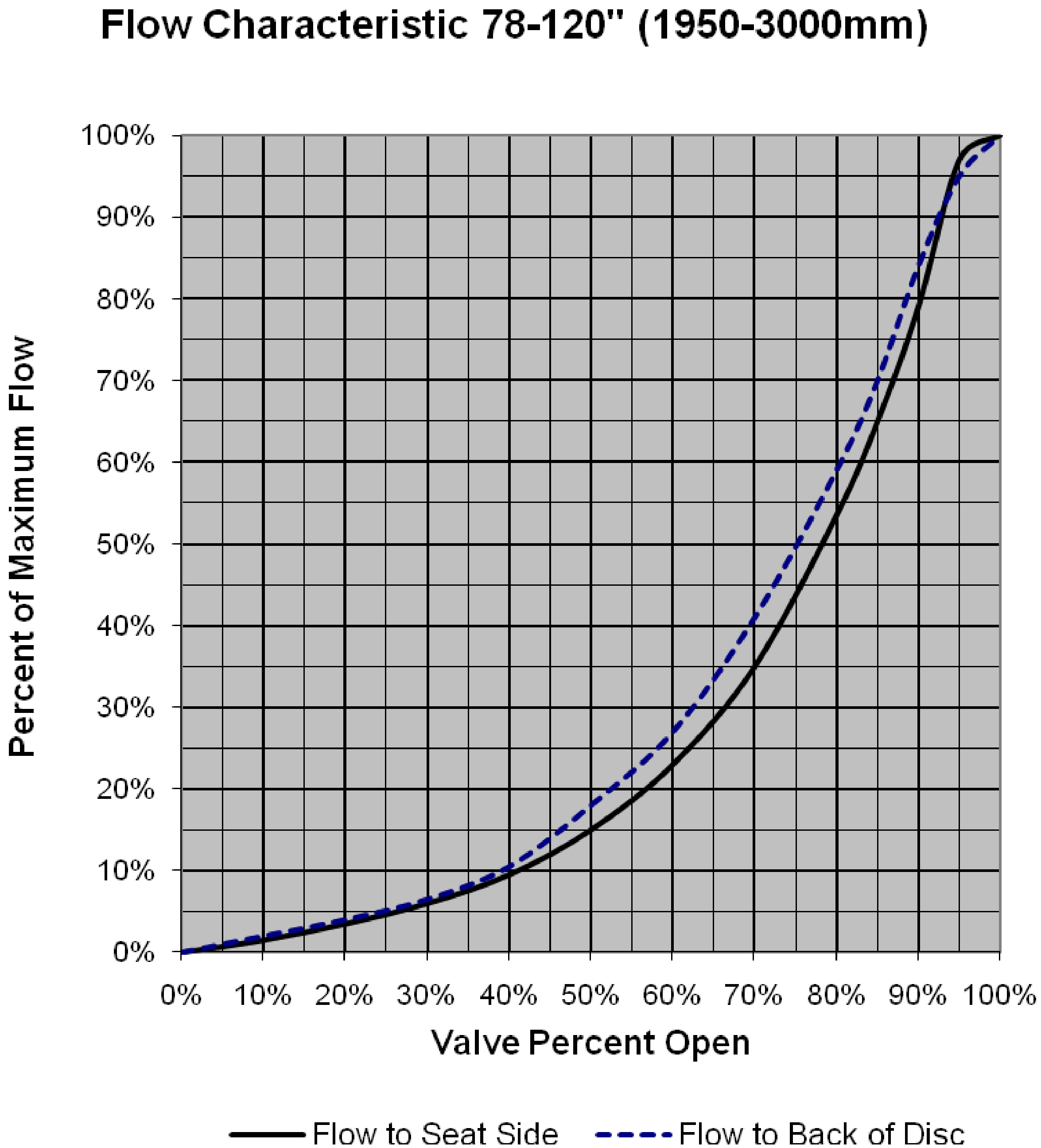
BAW / AWWA Butterfly Valves



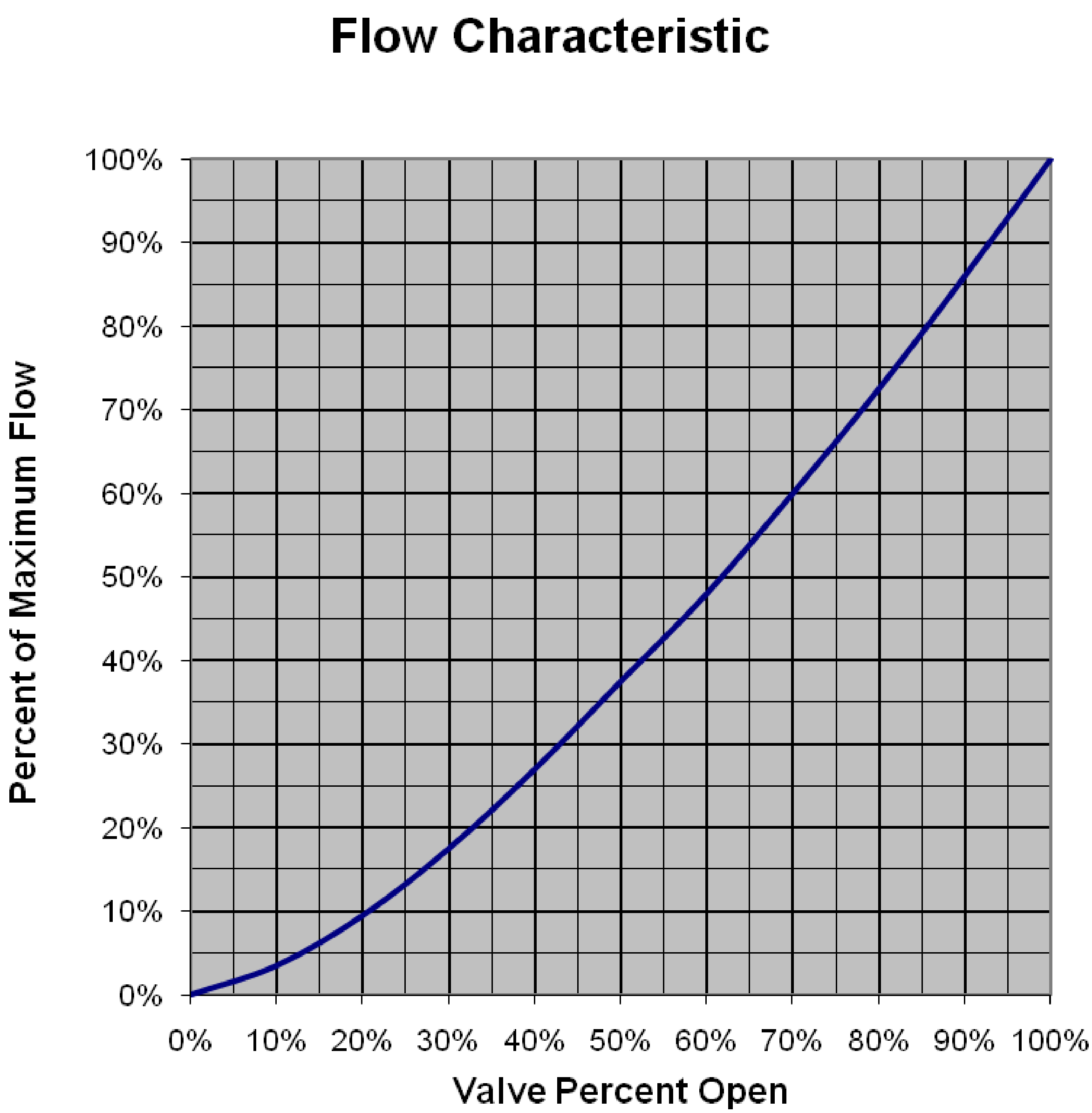
BAW / AWWA Butterfly Valves



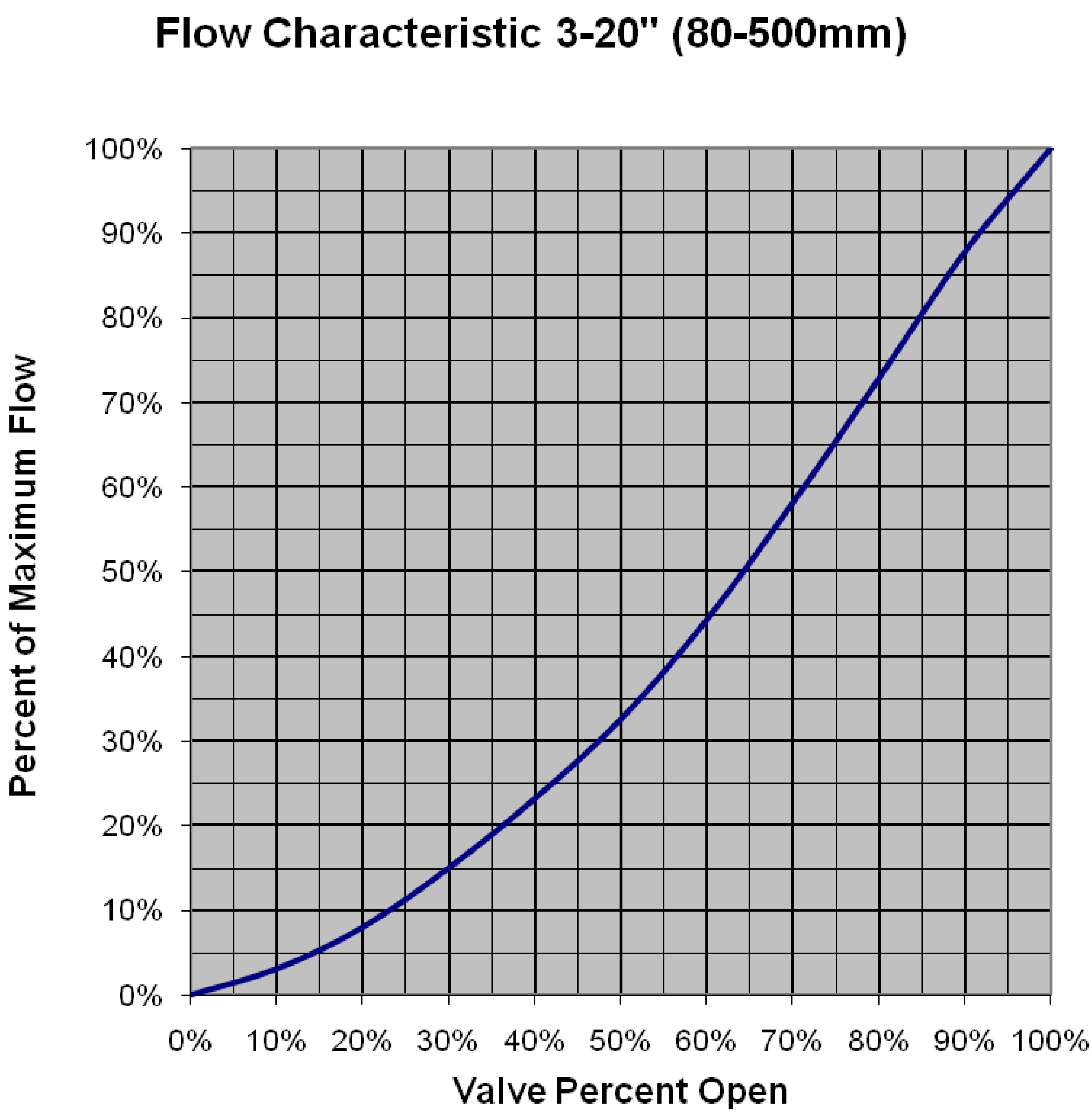
BAW / AWWA Butterfly Valves



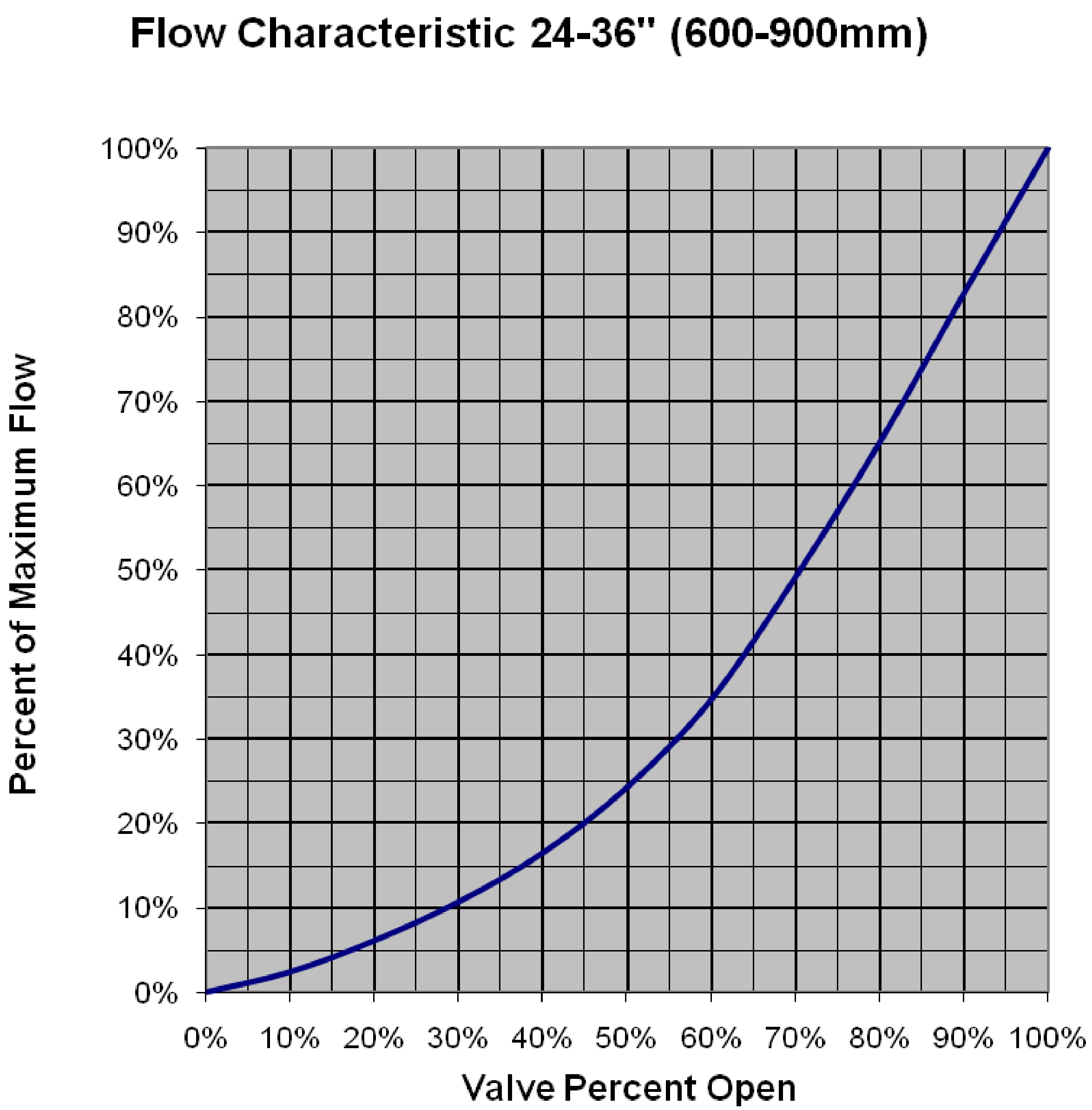
PEC Eccentric Plug Valves



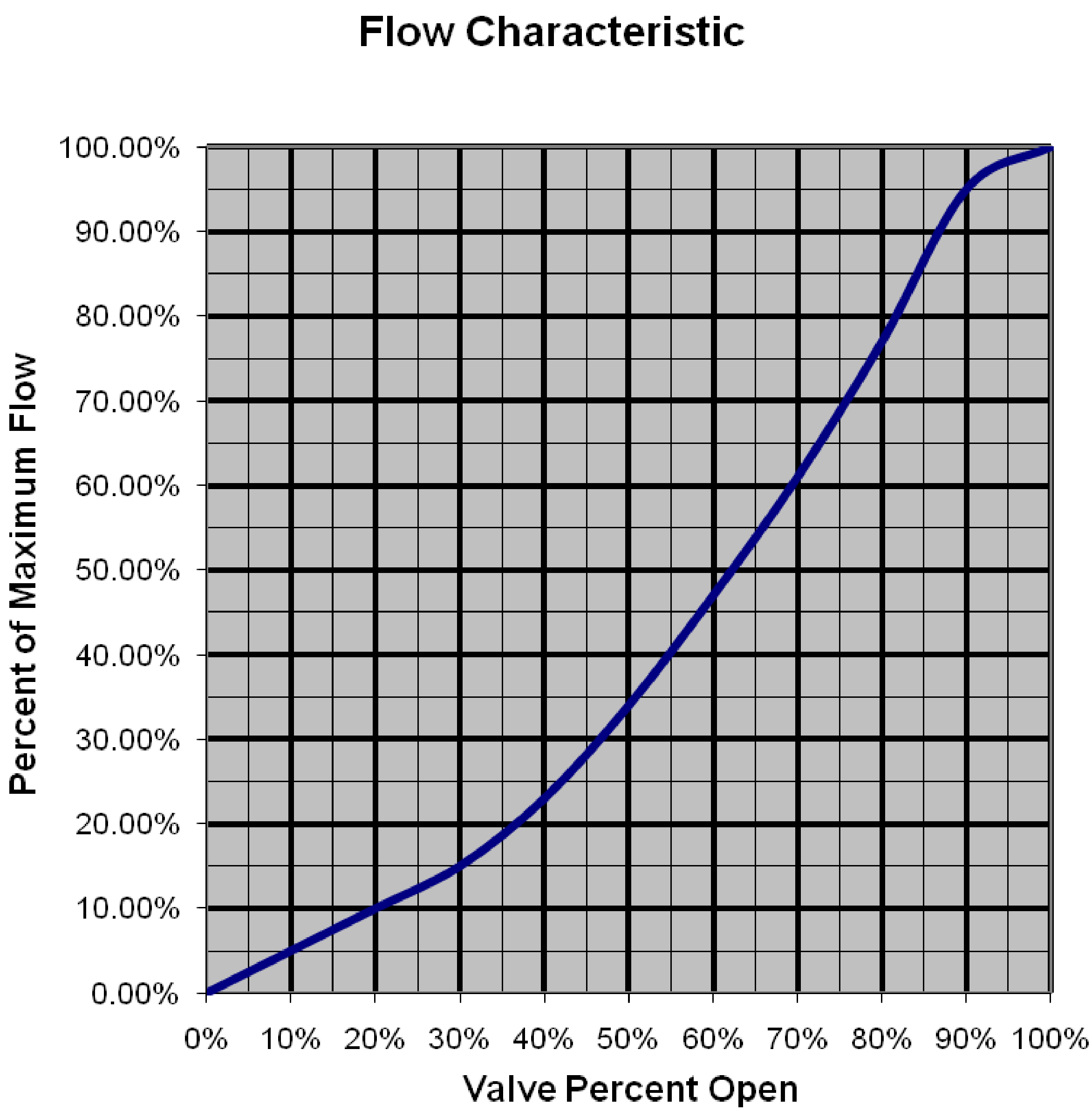
PEF Eccentric Plug Valves



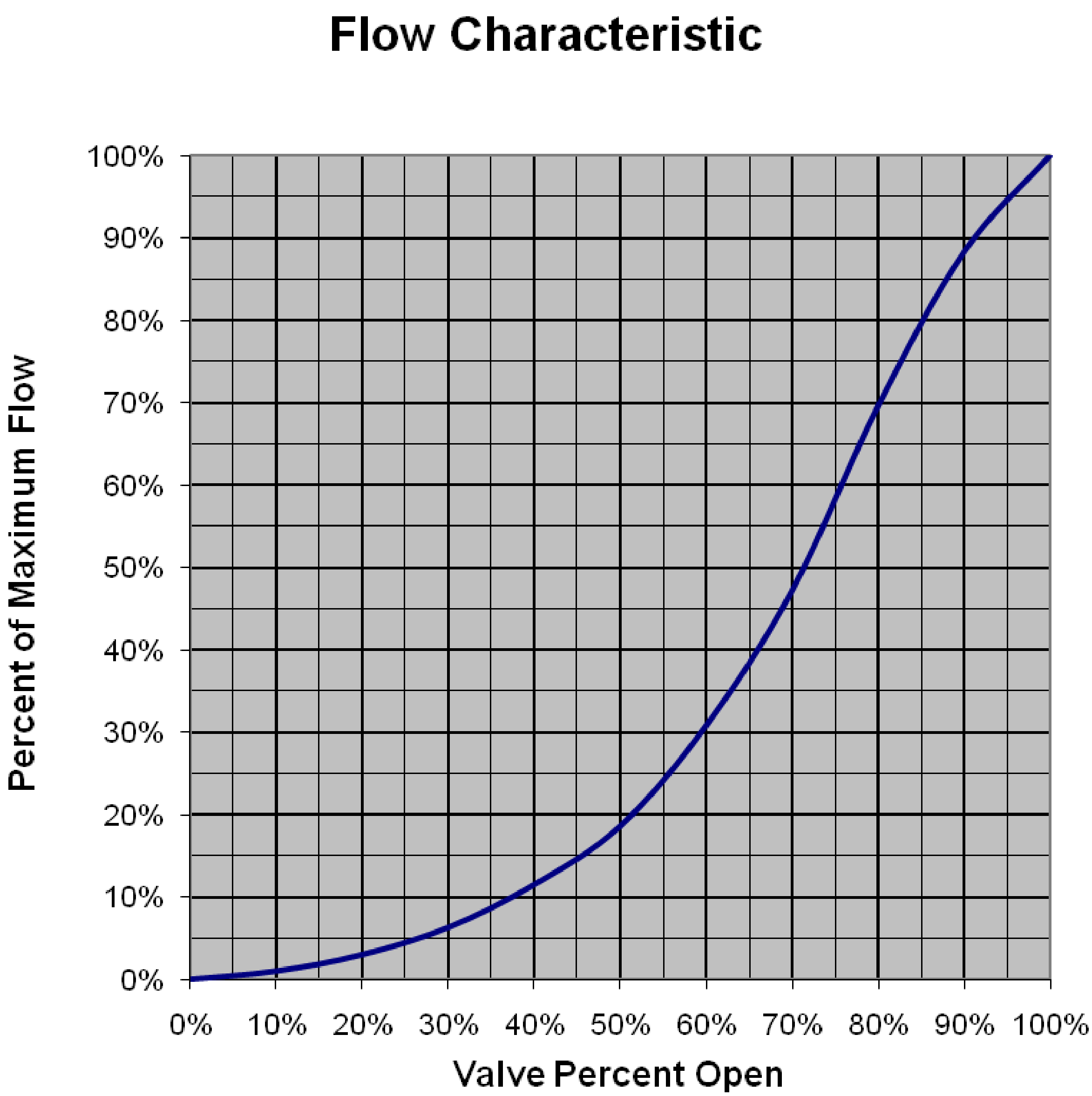
PEF Eccentric Plug Valves



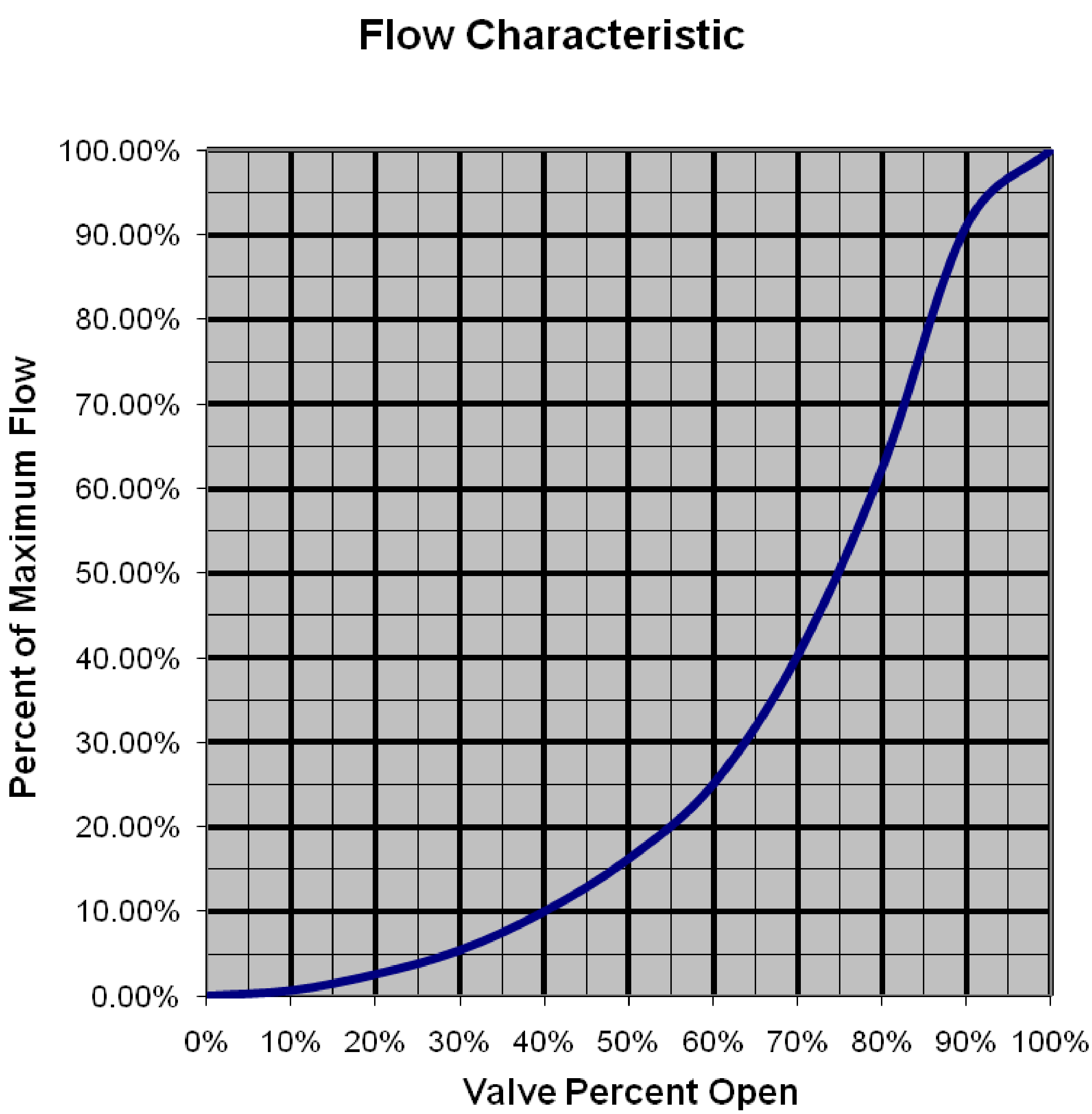
BHP High Performance Butterfly Valves



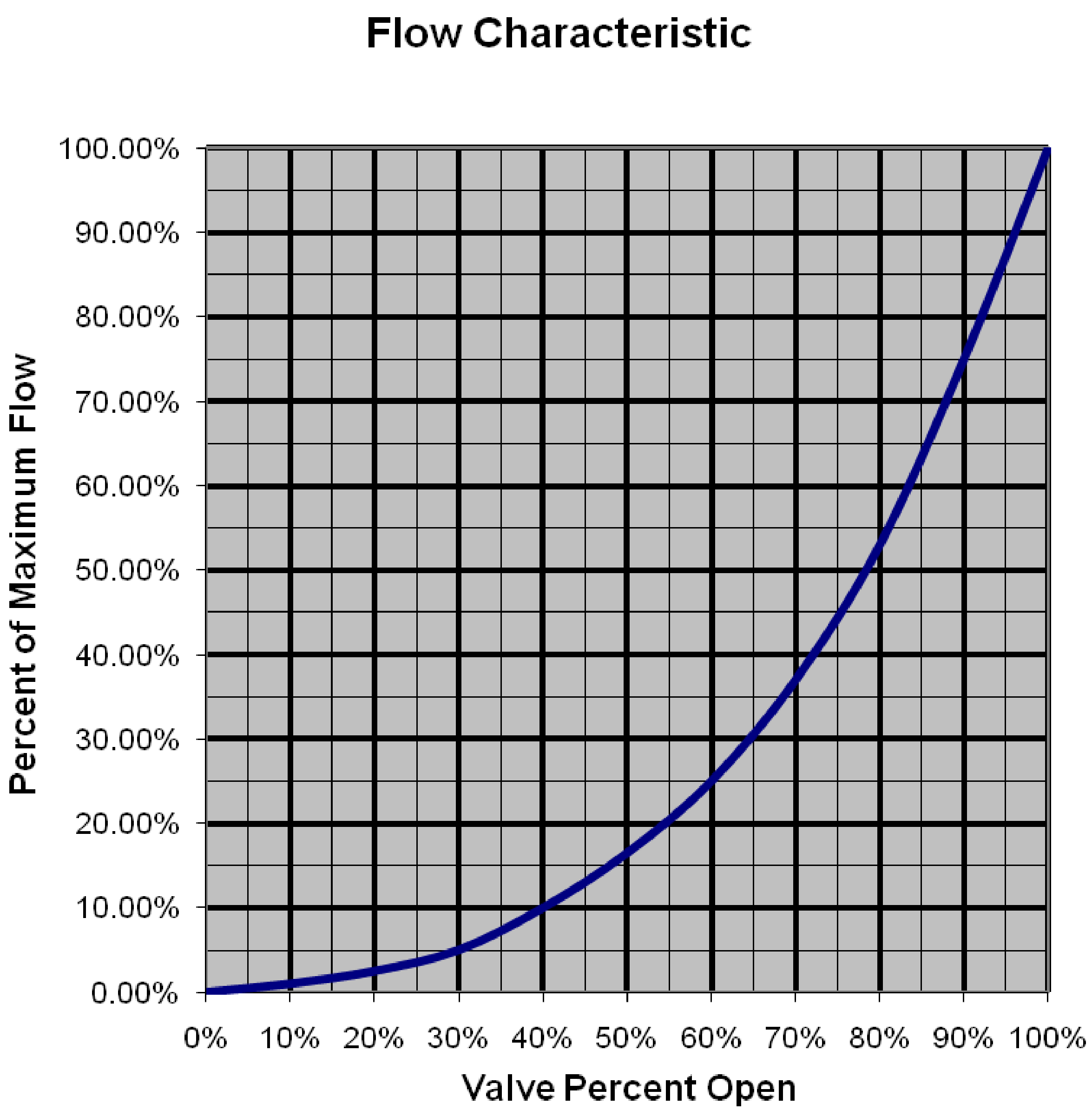
BOS-US Resilient Seated Butterfly Valves



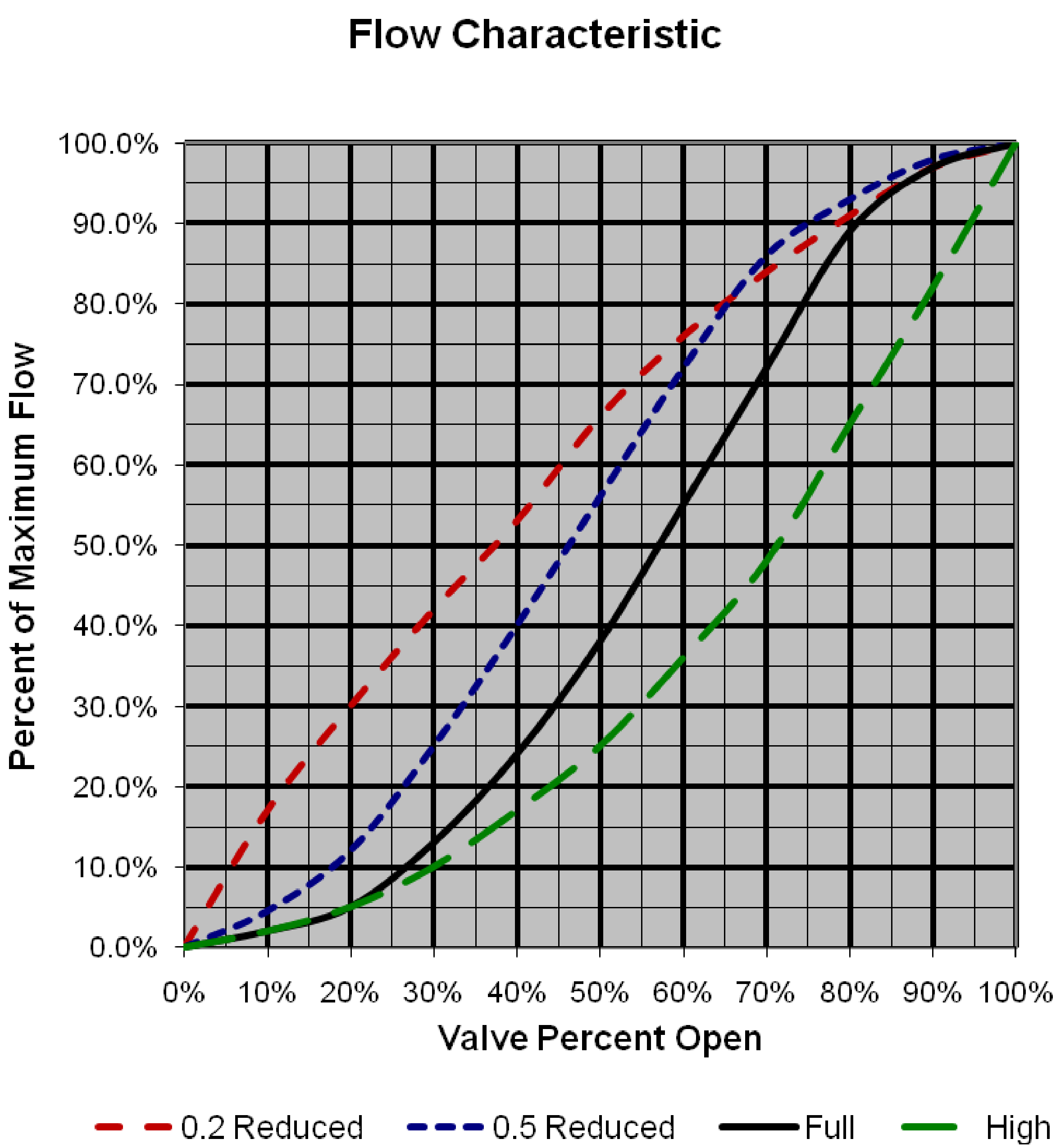
BOS-CL Resilient Seated Butterfly Valves



VPB V-Port Ball Control Valves



RCV Rotary Control Valves



VELOCITY RECOMMENDATIONS

MAX. INLET VELOCITY — LIQUIDS

Body Material	Velocity (Ft./Sec.)
Cast Iron	18
Carbon Steel	25
316 Stainless Steel	35
317 Stainless Steel	35
Alloy 20	35
Hastelloy C	35
Monel	35
C-5 Chrome Moly	35

PROPERTIES OF SATURATED STEAM AND SATURATED WATER

Absolute Pressure		Vacuum Inches of Hg	Temper-ature	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume $\bar{V}$	
Lbs. per Sq. In. P'	Inches of Hg		t Degrees F	Btu/lb.	Btu/lb.	h_g Btu/lb.	Water Cu. ft. per lb	Steam Cu. ft. per lb.
0.08859	0.02	29.90	32.018	0.0003	1075.5	1075.5	0.016022	3302.4
0.10	0.20	29.72	35.023	3.026	1073.8	1076.8	0.016020	2945.5
0.15	0.31	29.61	45.453	13.498	1067.9	1081.4	0.016020	2004.7
0.20	0.41	29.51	53.160	21.217	1053.5	1084.7	0.016025	1526.3
0.25	0.51	29.41	59.323	27.382	1060.1	1087.4	0.016032	1235.5
0.30	0.61	29.31	64.484	32.541	1057.1	1089.7	0.016040	1039.7
0.35	0.71	29.21	68.939	36.992	1054.6	1091.6	0.016048	898.6
0.40	0.81	29.11	72.869	40.917	1052.4	1093.3	0.016056	792.1
0.45	0.92	29.00	76.387	44.430	1050.5	1094.9	0.016063	708.8
0.50	1.02	28.90	79.586	47.623	1048.6	1096.3	0.016071	641.5
0.60	1.22	28.70	85.218	53.245	1045.5	1098.7	0.016085	540.1
0.70	1.43	28.49	90.09	58.10	1042.7	1100.8	0.016099	466.94
0.80	1.63	28.29	94.38	62.39	1040.3	1102.6	0.016112	411.69
0.90	1.83	28.09	98.24	66.24	1038.1	1104.3	0.016124	368.43
1.0	2.04	27.88	101.74	69.73	1036.1	1105.8	0.016136	333.60
1.2	2.44	27.48	107.91	75.90	1032.6	1108.5	0.016158	280.96
1.4	2.85	27.07	113.26	81.23	1029.5	1110.7	0.016178	243.02
1.6	3.26	26.66	117.98	85.95	1026.8	1112.7	0.016196	214.33
1.8	3.66	26.26	122.22	90.18	1024.3	1114.5	0.016213	191.85
2.0	4.07	25.85	126.07	94.03	1022.1	1116.2	0.016230	173.76
2.2	4.48	25.44	129.61	97.57	1020.1	1117.6	0.016245	158.87
2.4	4.89	25.03	132.88	100.84	1018.2	1119.0	0.016260	146.40
2.6	5.29	24.63	135.93	103.88	1016.4	1120.3	0.016274	135.80
2.8	5.70	24.22	138.78	106.73	1014.7	1121.5	0.016287	126.67
3.0	6.11	23.81	141.47	109.42	1013.2	1122.6	0.016300	118.73
3.5	7.13	22.79	147.56	115.51	1009.6	1125.1	0.016331	102.74
4.0	8.14	21.78	152.96	120.92	1006.4	1127.3	0.016358	90.64
4.5	9.16	20.76	157.82	125.77	1003.5	1129.3	0.016384	83.03
5.0	10.18	19.74	162.24	130.20	1000.9	1131.1	0.016407	73.532
5.5	11.20	18.72	166.29	134.26	998.5	1132.7	0.016430	67.249
6.0	12.22	17.70	170.05	138.03	996.2	1134.2	0.016451	61.984
6.5	13.23	16.69	173.56	141.54	994.1	1135.6	0.016472	57.506
7.0	14.25	15.67	176.84	144.83	992.1	1136.9	0.016491	53.650
7.5	15.27	14.65	179.93	147.93	990.2	1138.2	0.016510	50.294
8.0	16.29	13.63	182.86	150.87	988.5	1139.3	0.016527	47.345
8.5	17.31	12.61	185.63	153.65	986.8	1140.4	0.016545	44.733
9.0	18.32	11.60	188.27	156.30	985.1	1141.4	0.016561	42.402
9.5	19.34	10.58	190.80	158.84	983.6	1142.4	0.016577	40.310
10.0	20.36	9.56	193.21	161.26	982.1	1143.3	0.016592	38.420
11.0	22.40	7.52	197.75	165.82	979.3	1145.1	0.016622	35.142
12.0	24.43	5.49	201.96	170.05	976.6	1146.7	0.016650	32.394
13.0	26.47	3.45	205.88	174.00	974.2	1148.2	0.016676	30.057
14.0	28.50	1.42	209.56	177.71	971.9	1149.6	0.016702	28.043

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PROPERTIES OF SATURATED STEAM AND SATURATED WATER

Pressure Lbs. per Sq. In. Absolute P'	Pressure Lbs. per Sq. In. Gage P	Temperature t Degrees F.	Heat of the Liquid Btu/lb.	Latent Heat of Evaporation Btu/lb.	Total Heat of Steam h_g Btu/lb.	Specific Volume $\overline{V}$ Water Cu. ft. per lb.	Specific Volume $\overline{V}$ Steam Cu. ft. per lb.
14.696	0.0	212.00	180.17	970.3	1150.5	0.016719	26.799
15.0	0.3	213.03	181.21	969.7	1150.9	0.016726	26.290
16.0	1.3	216.32	184.52	967.6	1152.1	0.016749	24.750
17.0	2.3	219.44	187.66	965.6	1153.2	0.016771	23.385
18.0	3.3	222.41	190.66	963.7	1154.3	0.016793	22.168
19.0	4.3	225.24	193.52	961.8	1155.3	0.016814	21.074
20.0	5.3	227.96	196.27	960.1	1156.3	0.016834	20.087
21.0	6.3	230.57	198.90	958.4	1157.3	0.016854	19.190
22.0	7.3	233.07	201.44	956.7	1158.1	0.016873	18.373
23.0	8.3	235.49	203.88	955.1	1159.0	0.016891	17.624
24.0	9.3	237.82	206.24	953.6	1159.8	0.016909	16.936
25.0	10.3	240.07	208.52	952.1	1160.6	0.016927	16.301
26.0	11.3	242.25	210.7	950.6	1161.4	0.016944	15.7138
27.0	12.3	244.36	212.9	949.2	1162.1	0.016961	15.1684
28.0	13.3	246.41	214.9	947.9	1162.8	0.016977	14.6607
29.0	14.3	248.40	217.0	946.5	1163.5	0.016993	14.1869
30.0	15.3	250.34	218.9	945.2	1164.1	0.017009	13.7436
31.0	16.3	252.22	220.8	943.9	1164.8	0.017024	13.3280
32.0	17.3	254.05	222.7	942.7	1165.4	0.017039	12.9376
33.0	18.3	255.84	224.5	941.5	1166.0	0.017054	12.5700
34.0	19.3	257.58	226.3	940.3	1166.6	0.017069	12.2234
35.0	20.3	259.29	228.0	939.1	1167.1	0.017083	11.8959
36.0	21.3	260.95	229.7	938.0	1167.7	0.017097	11.5860
37.0	22.3	262.58	231.4	936.9	1168.2	0.017111	11.2923
38.0	23.3	264.17	233.0	935.8	1168.8	0.017124	11.0136
39.0	24.3	265.72	234.6	934.7	1169.3	0.017138	10.7487
40.0	25.3	267.25	236.1	933.6	1169.8	0.017151	10.4965
41.0	26.3	268.74	237.7	932.6	1170.2	0.017164	10.2563
42.0	27.3	270.21	239.2	931.5	1170.7	0.017177	10.0272
43.0	28.3	271.65	240.6	930.5	1171.2	0.017189	9.8083
44.0	29.3	273.06	242.1	929.5	1171.6	0.017202	9.5991
45.0	30.3	274.44	243.5	928.6	1172.0	0.017214	9.3988
46.0	31.3	275.80	244.9	927.6	1172.5	0.017226	9.2070
47.0	32.3	277.14	246.2	926.6	1172.9	0.017238	9.0231
48.0	33.3	278.45	247.6	925.7	1173.3	0.017250	8.8465
49.0	34.3	279.74	248.9	924.8	1173.7	0.017262	8.6770
50.0	35.3	281.02	250.2	923.9	1174.1	0.017274	8.5140
51.0	36.3	282.27	251.5	923.0	1174.5	0.017285	8.3571
52.0	37.3	283.50	252.8	922.1	1174.9	0.017296	8.2061
53.0	38.3	284.71	254.0	921.2	1175.2	0.017307	8.0606
54.0	39.3	285.90	255.2	920.4	1175.6	0.017319	7.9203
55.0	40.3	287.08	256.4	919.5	1175.9	0.017329	7.7850
56.0	41.3	288.24	257.6	918.7	1176.3	0.017340	7.6543
57.0	42.3	289.38	258.8	917.8	1176.6	0.017351	7.5280
58.0	43.3	290.50	259.9	917.0	1177.0	0.017362	7.4059
59.0	44.3	291.62	261.1	916.2	1177.3	0.017372	7.2879

PROPERTIES OF SATURATED STEAM AND SATURATED WATER

Pressure Lbs. per Sq. In.		Temperature	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume $\overline{V}$	
Absolute P'	Gage P	t Degrees F.	Btu/lb.	Btu/lb	h_g Btu/lb	Water Cu. ft. per lb.	Steam Cu. ft. per lb.
60.0	45.3	292.71	262.2	915.4	1177.6	0.017383	7 1736
61.0	46.3	293.79	263.3	914.6	1177.9	0.017393	7.0630
62.0	47.3	294.86	264.4	913.8	1178.2	0.017403	6.9558
63.0	48.3	295.91	265.5	913.0	1178.6	0.017413	6.8519
64.0	49.3	296.95	266.6	912.3	1178.9	0.017423	6.7511
65.0	50.3	297.98	267.6	911.5	1179.1	0.017433	6.6533
66.0	51.3	298.99	268.7	910.8	1179.4	0.017443	6.5584
67.0	52.3	299.99	269.7	910.0	1179.7	0.017453	6 4662
68.0	53.3	300.99	270.7	909.3	1180.0	0.017463	6.3767
69.0	54.3	301.96	271.7	908.5	1180.3	0.017472	6.2896
70.0	55.3	302.93	272.7	907.8	1180.6	0.017482	6 2050
71.0	56.3	303.89	273.7	907.1	1180.8	0.017491	6.1226
72.0	57.3	304.83	274.7	906 4	1181.1	0.017501	6.0425
73.0	58.3	305.77	275.7	905.7	1181.4	0.017510	5.9645
74.0	59.3	306.69	276.6	905.0	1181.6	0.017519	5.8885
75.0	60.3	307.61	277.6	904.3	1181.9	0.017529	5.8144
76.0	61.3	308.51	278.5	903.6	1182.1	0.017538	5.7423
77.0	62.3	309.41	279.4	902.9	1182.4	0.017547	5.6720
78.0	63.3	310.29	280.3	902.3	1182.6	0.017556	5 6034
79.0	64.3	311.17	281.3	901.6	1182.8	0.017565	5.5364
80.0	65.3	312.04	282.1	900.9	1183 1	0.017573	5.4711
81.0	66.3	312.90	283.0	900.3	1183.3	0.017582	5.4074
82.0	67.3	313.75	283.9	899.6	1183 5	0.017591	5.3451
83.0	68.3	314.60	284.8	899.0	1183.8	0.017600	5.2843
84.0	69.3	315.43	285.7	898.3	1184.0	0.017608	5.2249
85.0	70.3	316.26	286.5	897.7	1184.2	0.017617	5.1669
86.0	71.3	317.08	287.4	897.0	1184.4	0.017625	5.1101
87.0	72.3	317.89	288.2	896.4	1184.6	0.017634	5.0546
88.0	73.3	318.69	289.0	895.8	1184.8	0.017642	5.0004
89.0	74.3	319.49	289.9	895.2	1185 0	0.017651	4 9473
90.0	75.3	320.28	290.7	894.6	1185.3	0.017659	4 8953
91.0	76.3	321.06	291.5	893.9	1185.5	0.017667	4 8445
92.0	77.3	321.84	292.3	893.3	1185.7	0.017675	4.7947
93.0	78.3	322.61	293.1	892.7	1185 9	0.017684	4.7459
94.0	79.3	323.37	293.9	892.1	1186.0	0.017692	4.6982
95.0	80.3	324.13	294.7	891.5	1186.2	0.017700	4.6514
96.0	81.3	324.88	295.5	891.0	1186.4	0.017708	4.6055
97.0	82.3	325.63	296.3	890.4	1186.6	0.017716	4.5606
98.0	83.3	326.36	297.0	889.8	1186.8	0.017724	4.5166
99.0	84 3	327.10	297.8	889.2	1187.0	0.017732	4.4734
100.0	85.3	327.82	298.5	888.6	1187.2	0.017740	4.4310
101.0	86.3	328.54	299.3	888.1	1187.3	0.01775	4.3895
102.0	87.3	329.26	300.0	887.5	1187.5	0 01776	4.3487
103.0	88.3	329.97	300.8	886.9	1187.7	0.01776	4.3087
104.0	89.3	330.67	301.5	886.4	1187.9	0 01777	4.2695
105.0	90.3	331.37	302.2	885.8	1188.0	0 01778	4.2309
106.0	91.3	332.06	303.0	885.2	1188.2	0.01779	4 1931
107.0	92.3	332.75	303.7	884.7	1188.4	0 01779	4.1560
108.0	93.3	333.44	304.4	884.1	1188.5	0.01780	4 1195
109.0	94.3	334.11	305.1	883.6	1188.7	0.01781	4.0837

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PROPERTIES OF SATURATED STEAM AND SATURATED WATER

Pressure Lbs. per Sq. In. Absolute P'	Pressure Lbs. per Sq. In. Gage P	Temperature t Degrees F.	Heat of the Liquid Btu/lb.	Latent Heat of Evaporation Btu/lb.	Total Heat of Steam h_g Btu/lb.	Specific Volume $\overline{V}$ Water Cu. ft. per lb.	Specific Volume $\overline{V}$ Steam Cu. ft. per lb.
110.0	95.3	334.79	305.8	883.1	1188.9	0.01782	4.0484
111.0	96.3	335.46	306.5	882.5	1189.0	0.01782	4.0138
112.0	97.3	336.12	307.2	882.0	1189.2	0.01783	3.9798
113.0	98.3	336.78	307.9	881.4	1189.3	0.01784	3.9464
114.0	99.3	337.43	308.6	880.9	1189.5	0.01785	3.9136
115.0	100.3	338.08	309.3	880.4	1189.6	0.01785	3.8813
116.0	101.3	338.73	309.9	879.9	1189.8	0.01786	3.8495
117.0	102.3	339.37	310.6	879.3	1189.9	0.01787	3.8183
118.0	103.3	340.01	311.3	878.8	1190.1	0.01787	3.7875
119.0	104.3	340.64	311.9	878.3	1190.2	0.01788	3.7573
120.0	105.3	341.27	312.6	877.8	1190.4	0.01789	3.7275
121.0	106.3	341.89	313.2	877.3	1190.5	0.01790	3.6983
122.0	107.3	342.51	313.9	876.8	1190.7	0.01790	3.6695
123.0	108.3	343.13	314.5	876.3	1190.8	0.01791	3.6411
124.0	109.3	343.74	315.2	875.8	1190.9	0.01792	3.6132
125.0	110.3	344.35	315.8	875.3	1191.1	0.01792	3.5857
126.0	111.3	344.95	316.4	874.8	1191.2	0.01793	3.5586
127.0	112.3	345.55	317.1	874.3	1191.3	0.01794	3.5320
128.0	113.3	346.15	317.7	873.8	1191.5	0.01794	3.5057
129.0	114.3	346.74	318.3	873.3	1191.6	0.01795	3.4799
130.0	115.3	347.33	319.0	872.8	1191.7	0.01796	3.4544
131.0	116.3	347.92	319.6	872.3	1191.9	0.01797	3.4293
132.0	117.3	348.50	320.2	871.8	1192.0	0.01797	3.4046
133.0	118.3	349.08	320.8	871.3	1192.1	0.01798	3.3802
134.0	119.3	349.65	321.4	870.8	1192.2	0.01799	3.3562
135.0	120.3	350.23	322.0	870.4	1192.4	0.01799	3.3325
136.0	121.3	350.79	322.6	869.9	1192.5	0.01800	3.3091
137.0	122.3	351.36	323.2	869.4	1192.6	0.01801	3.2861
138.0	123.3	351.92	323.8	868.9	1192.7	0.01801	3.2634
139.0	124.3	352.48	324.4	868.5	1192.8	0.01802	3.2411
140.0	125.3	353.04	325.0	868.0	1193.0	0.01803	3.2190
141.0	126.3	353.59	325.5	867.5	1193.1	0.01803	3.1972
142.0	127.3	354.14	326.1	867.1	1193.2	0.01804	3.1757
143.0	128.3	354.69	326.7	866.6	1193.3	0.01805	3.1546
144.0	129.3	355.23	327.3	866.2	1193.4	0.01805	3.1337
145.0	130.3	355.77	327.8	865.7	1193.5	0.01806	3.1130
146.0	131.3	356.31	328.4	865.2	1193.6	0.01806	3.0927
147.0	132.3	356.84	329.0	864.8	1193.8	0.01807	3.0726
148.0	133.3	357.38	329.5	864.3	1193.9	0.01808	3.0528
149.0	134.3	357.91	330.1	863.9	1194.0	0.01808	3.0332
150.0	135.3	358.43	330.6	863.4	1194.1	0.01809	3.0139
152.0	137.3	359.48	331.8	862.5	1194.3	0.01810	2.9760
154.0	139.3	360.51	332.8	861.6	1194.5	0.01812	2.9391
156.0	141.3	361.53	333.9	860.8	1194.7	0.01813	2.9031
158.0	143.3	362.55	335.0	859.9	1194.9	0.01814	2.8679
160.0	145.3	363.55	336.1	859.0	1195.1	0.01815	2.8336
162.0	147.3	364.54	337.1	858.2	1195.3	0.01817	2.8001
164.0	149.3	365.53	338.2	857.3	1195.5	0.01818	2.7674
166.0	151.3	366.50	339.2	856.5	1195.7	0.01819	2.7355
168.0	153.3	367.47	340.2	855.6	1195.8	0.01820	2.7043

PROPERTIES OF SATURATED STEAM AND SATURATED WATER

Pressure Lbs. per Sq. In. Absolute P'	Pressure Lbs. per Sq. In. Gage P	Temperature t Degrees F.	Heat of the Liquid Btu/lb	Latent Heat of Evaporation Btu/lb.	Total Heat of Steam h_g Btu/lb	Specific Volume $\bar{V}$ Water Cu. ft. per lb.	Specific Volume $\bar{V}$ Steam Cu. ft. per lb.
170.0	155.3	368.42	341.2	854.8	1196.0	0.01821	2.6738
172.0	157.3	369.37	342.2	853.9	1196.2	0.01823	2.6440
174.0	159.3	370.31	343.2	853.1	1196.4	0.01824	2.6149
176.0	161.3	371.24	344.2	852.3	1196.5	0.01825	2.5864
178.0	163.3	372.16	345.2	851.5	1196.7	0.01826	2.5585
180.0	165.3	373.08	346.2	850.7	1196.9	0.01827	2.5312
182.0	167.3	373.98	347.2	849.9	1197.0	0.01828	2.5045
184.0	169.3	374.88	348.1	849.1	1197.2	0.01830	2.4783
186.0	171.3	375.77	349.1	848.3	1197.3	0.01831	2.4527
188.0	173.3	376.65	350.0	847.5	1197.5	0.01832	2.4276
190.0	175.3	377.53	350.9	846.7	1197.6	0.01833	2.4030
192.0	177.3	378.40	351.9	845.9	1197.8	0.01834	2.3790
194.0	179.3	379.26	352.8	845.1	1197.9	0.01835	2.3554
196.0	181.3	380.12	353.7	844.4	1198.1	0.01836	2.3322
198.0	183.3	380.96	354.6	843.6	1198.2	0.01838	2.3095
200.0	185.3	381.80	355.5	842.8	1198.3	0.01839	2.28728
205.0	190.3	383.88	357.7	840.9	1198.7	0.01841	2.23349
210.0	195.3	385.91	359.9	839.1	1199.0	0.01844	2.18217
215.0	200.3	387.91	362.1	837.2	1199.3	0.01847	2.13315
220.0	205.3	389.88	364.2	835.4	1199.6	0.01850	2.08629
225.0	210.3	391.80	366.2	833.6	1199.9	0.01852	2.04143
230.0	215.3	393.70	368.3	831.8	1200.1	0.01855	1.99846
235.0	220.3	395.56	370.3	830.1	1200.4	0.01857	1.95725
240.0	225.3	397.39	372.3	828.4	1200.6	0.01860	1.91769
245.0	230.3	399.19	374.2	826.6	1200.9	0.01863	1.87970
250.0	235.3	400.97	376.1	825.0	1201.1	0.01865	1.84317
255.0	240.3	402.72	378.0	823.3	1201.3	0.01868	1.80802
260.0	245.3	404.44	379.9	821.6	1201.5	0.01870	1.77418
265.0	250.3	406.13	381.7	820.0	1201.7	0.01873	1.74157
270.0	255.3	407.80	383.6	818.3	1201.9	0.01875	1.71013
275.0	260.3	409.45	385.4	816.7	1202.1	0.01878	1.67978
280.0	265.3	411.07	387.1	815.1	1202.3	0.01880	1.65049
285.0	270.3	412.67	388.9	813.6	1202.4	0.01882	1.62218
290.0	275.3	414.25	390.6	812.0	1202.6	0.01885	1.59482
295.0	280.3	415.81	392.3	810.4	1202.7	0.01887	1.56835
300.0	285.3	417.35	394.0	808.9	1202.9	0.01889	1.54274
320.0	305.3	423.31	400.5	802.9	1203.4	0.01899	1.44801
340.0	325.3	428.99	406.8	797.0	1203.8	0.01908	1.36405
360.0	345.3	434.41	412.8	791.3	1204.1	0.01917	1.28910
380.0	365.3	439.61	418.6	785.8	1204.4	0.01925	1.22177
400.0	385.3	444.60	424.2	780.4	1204.6	0.01934	1.16095
420.0	405.3	449.40	429.6	775.2	1204.7	0.01942	1.10573
440.0	425.3	454.03	434.8	770.0	1204.8	0.01950	1.05535
460.0	445.3	458.50	439.8	765.0	1204.8	0.01959	1.00921
480.0	465.3	462.82	444.7	760.0	1204.8	0.01967	0.96677
500.0	485.3	467.01	449.5	755.1	1204.7	0.01975	0.92762
520.0	505.3	471.07	454.2	750.4	1204.5	0.01982	0.89137
540.0	525.3	475.01	458.7	745.7	1204.4	0.01990	0.85771
560.0	545.3	478.84	463.1	741.0	1204.2	0.01998	0.82637
580.0	565.3	482.57	467.5	736.5	1203.9	0.02006	0.79712

PROPERTIES OF SATURATED STEAM AND SATURATED WATER

Pressure Lbs. per Sq. In. Absolute P'	Pressure Lbs. per Sq. In. Gage P	Temperature t Degrees F.	Heat of the Liquid Btu/lb.	Latent Heat of Evaporation Btu/lb.	Total Heat of Steam h_g Btu/lb.	Specific Volume $\bar{V}$ Water Cu. ft per lb	Specific Volume $\bar{V}$ Steam Cu. ft per lb
600.0	585.3	486.20	471.7	732.0	1203.7	0.02013	0.76975
620.0	605.3	489.74	475.8	727.5	1203.4	0.02021	0.74408
640.0	625.3	493.19	479.9	723.1	1203.0	0.02028	0.71995
660.0	645.3	496.57	483.9	718.8	1202.7	0.02036	0.69724
680.0	665.3	499.86	487.8	714.5	1202.3	0.02043	0.67581
700.0	685.3	503.08	491.6	710.2	1201.8	0.02050	0.65556
720.0	705.3	506.23	495.4	706.0	1201.4	0.02058	0.63639
740.0	725.3	509.32	499.1	701.9	1200.9	0.02065	0.61822
760.0	745.3	512.34	502.7	697.7	1200.4	0.02072	0.60097
780.0	765.3	515.30	506.3	693.6	1199.9	0.02080	0.58457
800.0	785.3	518.21	509.8	689.6	1199.4	0.02087	0.56896
820.0	805.3	521.06	513.3	685.5	1198.8	0.02094	0.55408
840.0	825.3	523.86	516.7	681.5	1198.2	0.02101	0.53988
860.0	845.3	526.60	520.1	677.6	1197.7	0.02109	0.52631
880.0	865.3	529.30	523.4	673.6	1197.0	0.02116	0.51333
900.0	885.3	531.95	526.7	669.7	1196.4	0.02123	0.50091
920.0	905.3	534.56	530.0	665.8	1195.7	0.02130	0.48901
940.0	925.3	537.13	533.2	661.9	1195.1	0.02137	0.47759
960.0	945.3	539.65	536.3	658.0	1194.4	0.02145	0.46662
980.0	965.3	542.14	539.5	654.2	1193.7	0.02152	0.45609
1000.0	985.3	544.58	542.6	650.4	1192.9	0.02159	0.44596
1050.0	1035.3	550.53	550.1	640.9	1191.0	0.02177	0.42224
1100.0	1085.3	556.28	557.5	631.5	1189.1	0.02195	0.40058
1150.0	1135.3	561.82	564.8	622.2	1187.0	0.02214	0.38073
1200.0	1185.3	567.19	571.9	613.0	1184.8	0.02232	0.36245
1250.0	1235.3	572.38	578.8	603.8	1182.6	0.02250	0.34556
1300.0	1285.3	577.42	585.6	594.6	1180.2	0.02269	0.32991
1350.0	1335.3	582.32	592.2	585.6	1177.8	0.02288	0.31536
1400.0	1385.3	587.07	598.8	567.5	1175.3	0.02307	0.30178
1450.0	1435.3	591.70	605.3	567.6	1172.9	0.02327	0.28909
1500.0	1485.3	596.20	611.7	558.4	1170.1	0.02346	0.27719
1600.0	1585.3	604.87	624.2	540.3	1164.5	0.02387	0.25545
1700.0	1685.3	613.13	636.5	522.2	1158.6	0.02428	0.23607
1800.0	1785.3	621.02	648.5	503.8	1152.3	0.02472	0.21861
1900.0	1885.3	628.56	660.4	485.2	1145.6	0.02517	0.20278
2000.0	1985.3	635.80	672.1	466.2	1138.3	0.02565	0.18831
2100.0	2085.3	642.76	683.8	446.7	1130.5	0.02615	0.17501
2200.0	2185.3	649.45	695.5	426.7	1122.2	0.02669	0.16272
2300.0	2285.3	655.89	707.2	406.0	1113.2	0.02727	0.15133
2400.0	2385.3	662.11	719.0	384.8	1103.7	0.02790	0.14076
2500.0	2485.3	668.11	731.7	361.6	1093.3	0.02859	0.13068
2600.0	2585.3	673.91	744.5	337.6	1082.0	0.02938	0.12110
2700.0	2685.3	679.53	757.3	312.3	1069.7	0.03029	0.11194
2800.0	2785.3	684.96	770.7	285.1	1055.8	0.03134	0.10305
2900.0	2885.3	690.22	785.1	254.7	1039.8	0.03262	0.09420
3000.0	2985.3	695.33	801.8	218.4	1020.3	0.03428	0.08500
3100.0	3085.3	700.28	824.0	169.3	993.3	0.03681	0.07452
3200.0	3185.3	705.08	875.5	56.1	931.6	0.04472	0.05663
3208.2	3193.5	705.47	906.0	0.0	906.0	0.05078	0.05078

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PROPERTIES OF SUPERHEATED STEAM

$\overline{V}$ = specific volume, cubic feet per pound
h_g = total heat of steam, Btu per pound

Pressure Lbs. per Sq. In. Abs. P'	Gage P	Sat. Temp. t		Total Temperature — Degrees Fahrenheit (t) 350°	400°	500°	600°	700°	800°	900°	1000°	1100°	1300°	1500°
15.0	0.3	213.03	$\overline{V}$	31.939	33.963	37.985	41.986	45.978	49.964	53.946	57.926	61.905	69.858	77.807
			h_g	1216.2	1239.9	1287.3	1335.2	1383.8	1433.2	1483.4	1534.5	1586.5	1693.2	1803.4
20.0	5.3	227.96	$\overline{V}$	23.900	25.428	28.457	31.466	34.465	37.458	40.447	43.435	46.420	52.388	58.352
			h_g	1215.4	1239.2	1286.9	1334.9	1383.5	1432.9	1483.2	1534.3	1586.3	1693.1	1803.3
30.0	15.3	250.34	$\overline{V}$	15.859	16.892	18.929	20.945	22.951	24.952	26.949	28.943	30.936	34.918	38.896
			h_g	1213.6	1237.8	1286.0	1334.2	1383.0	1432.5	1482.8	1534.0	1586.1	1692.9	1803.2
40.0	25.3	267.25	$\overline{V}$	11.838	12.624	14.165	15.685	17.195	18.699	20.199	21.697	23.194	26.183	29.168
			h_g	1211.7	1236.4	1285.0	1333.6	1382.5	1432.1	1482.5	1533.7	1585.8	1692.7	1803.0
50.0	35.3	281.02	$\overline{V}$	9.424	10.062	11.306	12.529	13.741	14.947	16.150	17.350	18.549	20.942	23.332
			h_g	1209.9	1234.9	1284.1	1332.9	1382.0	1431.7	1482.2	1533.4	1585.6	1692.5	1802.9
60.0	45.3	292.71	$\overline{V}$	7.815	8.354	9.400	10.425	11.438	12.446	13.450	14.452	15.452	17.448	19.441
			h_g	1208.0	1233.5	1283.2	1332.3	1381.5	1431.3	1481.8	1533.2	1585.3	1692.4	1802.8
70.0	55.3	302.93	$\overline{V}$	6.664	7.133	8.039	8.922	9.793	10.659	11.522	12.382	13.240	14.952	16.661
			h_g	1206.0	1232.0	1282.2	1331.6	1381.0	1430.9	1481.5	1532.9	1585.1	1692.2	1802.6
80.0	65.3	312.04	$\overline{V}$	5.801	6.218	7.018	7.794	8.560	9.319	10.075	10.829	11.581	13.081	14.577
			h_g	1204.0	1230.5	1281.3	1330.9	1380.5	1430.5	1481.1	1532.6	1584.9	1692.0	1802.5
90.0	75.3	320.28	$\overline{V}$	5.128	5.505	6.223	6.917	7.600	8.277	8.950	9.621	10.290	11.625	12.956
			h_g	1202.0	1228.9	1280.3	1330.2	1380.0	1430.1	1480.8	1532.3	1584.6	1691.8	1802.4
100.0	85.3	327.82	$\overline{V}$	4.590	4.935	5.588	6.216	6.833	7.443	8.050	8.655	9.258	10.460	11.659
			h_g	1199.9	1227.4	1279.3	1329.6	1379.5	1429.7	1480.4	1532.0	1584.4	1691.6	1802.2
120.0	105.3	341.27	$\overline{V}$	3.7815	4.0786	4.6341	5.1637	5.6813	6.1928	6.7006	7.2060	7.7096	8.7130	9.7130
			h_g	1195.6	1224.1	1277.4	1328.2	1378.4	1428.8	1479.8	1531.4	1583.9	1691.3	1802.0
140.0	125.3	353.04	$\overline{V}$	—	3.4661	3.9526	4.4119	4.8588	5.2995	5.7364	6.1709	6.6036	7.4652	8.3233
			h_g	—	1220.8	1275.3	1326.8	1377.4	1428.0	1479.1	1530.8	1583.4	1690.9	1801.7
160.0	145.3	363.55	$\overline{V}$	—	3.0060	3.4413	3.8480	4.2420	4.6295	5.0132	5.3945	5.7741	6.5293	7.2811
			h_g	—	1217.4	1273.3	1325.4	1376.4	1427.2	1478.4	1530.3	1582.9	1690.5	1801.4
180.0	165.3	373.08	$\overline{V}$	—	2.6474	3.0433	3.4093	3.7621	4.1084	4.4508	4.7907	5.1289	5.8014	6.4704
			h_g	—	1213.8	1271.2	1324.0	1375.3	1426.3	1477.7	1529.7	1582.4	1690.2	1801.2
200.0	185.3	381.80	$\overline{V}$	—	2.3598	2.7247	3.0583	3.3783	3.6915	4.0008	4.3077	4.6128	5.2191	5.8219
			h_g	—	1210.1	1269.0	1322.6	1374.3	1425.5	1477.0	1529.1	1581.9	1689.8	1800.9
220.0	205.3	389.88	$\overline{V}$	—	2.1240	2.4638	2.7710	3.0642	3.3504	3.6327	3.9125	4.1905	4.7426	5.2913
			h_g	—	1206.3	1266.9	1321.2	1373.2	1424.7	1476.3	1528.5	1581.4	1689.4	1800.6
240.0	225.3	397.39	$\overline{V}$	—	1.9268	2.2462	2.5316	2.8024	3.0661	3.3259	3.5831	3.8385	4.3456	4.8492
			h_g	—	1202.4	1264.6	1319.7	1372.1	1423.8	1475.6	1527.9	1580.9	1689.1	1800.4
260.0	245.3	404.44	$\overline{V}$	—	—	2.0619	2.3289	2.5808	2.8256	3.0663	3.3044	3.5408	4.0097	4.4750
			h_g	—	—	1262.4	1318.2	1371.1	1423.0	1474.9	1527.3	1580.4	1688.7	1800.1
280.0	265.3	411.07	$\overline{V}$	—	—	1.9037	2.1551	2.3909	2.6194	2.8437	3.0655	3.2855	3.7217	4.1543
			h_g	—	—	1260.0	1316.8	1370.0	1422.1	1474.2	1526.8	1579.9	1688.4	1799.8
300.0	285.3	417.35	$\overline{V}$	—	—	1.7665	2.0044	2.2263	2.4407	2.6509	2.8585	3.0643	3.4721	3.8764
			h_g	—	—	1257.7	1315.2	1368.9	1421.3	1473.6	1526.2	1579.4	1688.0	1799.6
320.0	305.3	423.31	$\overline{V}$	—	—	1.6462	1.8725	2.0823	2.2843	2.4821	2.6774	2.8708	3.2538	3.6332
			h_g	—	—	1255.2	1313.7	1367.8	1420.5	1472.9	1525.6	1578.9	1687.6	1799.3
340.0	325.3	428.99	$\overline{V}$	—	—	1.5399	1.7561	1.9552	2.1463	2.3333	2.5175	2.7000	3.0611	3.4186
			h_g	—	—	1252.8	1312.2	1366.7	1419.6	1472.2	1525.0	1578.4	1687.3	1799.0
360.0	345.3	434.41	$\overline{V}$	—	—	1.4454	1.6525	1.8421	2.0237	2.2009	2.3755	2.5482	2.8898	3.2279
			h_g	—	—	1250.3	1310.6	1365.6	1418.7	1471.5	1542.4	1577.9	1686.9	1798.8

DeZURIK

PROPERTIES OF SUPERHEATED STEAM

$\overline{V}$ = specific volume, cubic feet per pound
h_g = total heat of steam, Btu per pound

Pressure Lbs. per Sq. In. Abs. P'	Gage P	Sat. Temp. t		Total Temperature — Degrees Fahrenheit (t) 500°	600°	700°	800°	900°	1000°	1100°	1200°	1300°	1400°	1500°
380.0	365.3	439.61	$\overline{V}$	1.3606	1.5598	1.7410	1.9139	2.0825	2.2484	2.4124	2.5750	2.7366	2.8973	3.0572
			h_g	1247.7	1309.0	1364.5	1417.9	1470.8	1523.8	1577.4	1631.6	1686.5	1742.2	1798.5
400.0	385.3	444.60	$\overline{V}$	1.2841	1.4763	1.6499	1.8151	1.9759	2.1339	2.2901	2.4450	2.5987	2.7515	2.9037
			h_g	1245.1	1307.4	1363 4	1417.0	1470.1	1523.3	1576.9	1631.2	1686.2	1741.9	1798.2
420.0	405.3	449.40	$\overline{V}$	1.2148	1.4007	1.5676	1.7258	1.8795	2.0304	2.1795	2.3273	2.4739	2.6196	2.7647
			h_g	1242.4	1305.8	1362.3	1416.2	1469.4	1522.7	1576.4	1630.8	1685.8	1741.6	1798.0
440.0	425.3	454.03	$\overline{V}$	1.1517	1.3319	1.4926	1.6445	1.7918	1.9363	2.0790	2.2203	2.3605	2.4998	2.6384
			h_g	1239 7	1304.2	1361.1	1415.3	1468.7	1522.1	1575.9	1630.4	1685.5	1741.2	1797.7
460.0	445.3	458.50	$\overline{V}$	1.0939	1.2691	1.4242	1.5703	1.7117	1.8504	1.9872	2.1226	2.2569	2.3903	2 5230
			h_g	1236.9	1302.5	1360.0	1414.4	1468.0	1521.5	1575.4	1629.9	1685.1	1740.9	1797.4
480.0	465.3	462.82	$\overline{V}$	1.0409	1.2115	1.3615	1 5023	1.6384	1.7716	1.9030	2.0330	2.1619	2.2900	2.4173
			h_g	1234.1	1300.8	1358.8	1413.6	1467.3	1520.9	1574.9	1629.5	1684.7	1740 6	1797.2
500.0	485.3	467.01	$\overline{V}$	0.9919	1.1584	1.3037	1.4397	1.5708	1.6992	1.8256	1.9507	2.0746	2.1977	2.3200
			h_g	1231.2	1299.1	1357.7	1412.7	1466.6	1520.3	1574.4	1629.1	1684.4	1740.3	1796.9
520.0	505.3	471.07	$\overline{V}$	0.9466	1.1094	1.2504	1.3819	1.5085	1.6323	1.7542	1 8746	1.9940	2.1125	2.2302
			h_g	1228 3	1297.4	1356.5	1411.8	1465.9	1519.7	1573.9	1628.7	1684.0	1740.0	1796.7
540.0	525.3	475.01	$\overline{V}$	0.9045	1.0640	1.2010	1.3284	1.4508	1.5704	1.6880	1.8042	1.9193	2.0336	2.1471
			h_g	1225.3	1295.7	1355.3	1410.9	1465.1	1519.1	1573.4	1628.2	1683.6	1739.7	1796.4
560.0	545.3	478.84	$\overline{V}$	0.8653	1.0217	1.1552	1.2787	1.3972	1.5129	1.6266	1.7388	1.8500	1.9603	2.0699
			h_g	1222.2	1293.9	1354.2	1410.0	1464.4	1518.6	1572.9	1627.8	1683.3	1739.4	1796.1
580.0	565.3	482.57	$\overline{V}$	0.8287	0.9824	1.1125	1.2324	1.3473	1.4593	1.5693	1.6780	1.7855	1.8921	1.9980
			h_g	1219.1	1292.1	1353.0	1409.2	1463.7	1518.0	1572.4	1627.4	1682.9	1739.1	1795.9
600.0	585.3	486.20	$\overline{V}$	0.7944	0.9456	1.0726	1.1892	1.3008	1.4093	1.5160	1.6211	1.7252	1.8284	1.9309
			h_g	1215.9	1290.3	1351.8	1408.3	1463.0	1517.4	1571.9	1627.0	1682.6	1738.8	1795 6
650.0	635.3	494.89	$\overline{V}$	0.7173	0.8634	0.9835	1.0929	1.1969	1.2979	1.3969	1.4944	1.5909	1.6864	1.7813
			h_g	1207.6	1285.7	1348.7	1406.0	1461.2	1515.9	1570.7	1625.9	1681.6	1738.0	1794.9
700.0	685.3	503.08	$\overline{V}$	—	0.7928	0.9072	1.0102	1.1078	1.2023	1.2948	1.3858	1.4757	1.5647	1.6530
			h_g	—	1281.0	1345.6	1403.7	1459.4	1514.4	1569.4	1624.8	1680.7	1737.2	1794.3
750.0	735.3	510.84	$\overline{V}$	—	0.7313	0.8409	0.9386	1.0306	1.1195	1.2063	1.2916	1.3759	1.4592	1.5419
			h_g	—	1276.1	1342.5	1401.5	1457.6	1512.9	1568.2	1623.8	1679.8	1736.4	1793.6
800.0	785.3	518.21	$\overline{V}$	—	0.6774	0.7828	0.8759	0.9631	1.0470	1.1289	1.2093	1.2885	1.3669	1.4446
			h_g	—	1271.1	1339.3	1399.1	1455.8	1511.4	1566.9	1622.7	1678.9	1735.7	1792.9
850.0	835.3	525.24	$\overline{V}$	—	0.6296	0.7315	0.8205	0.9034	0.9830	1.0606	1.1366	1.2115	1.2855	1.3588
			h_g	—	1265.9	1336.0	1396.8	1454.0	1510.0	1565.7	1621.6	1678.0	1734.9	1792.3
900.0	885.3	531.95	$\overline{V}$	—	0.5869	0.6858	0.7713	0.8504	0.9262	0.9998	1.0720	1.1430	1.2131	1.2825
			h_g	—	1260.6	1332.7	1394.4	1452.2	1508.5	1564.4	1620.6	1677.1	1734.1	1791.6
950.0	935.3	538.39	$\overline{V}$	—	0.5485	0.6449	0.7272	0.8030	0.8753	0.9455	1.0142	1.0817	1.1484	1.2143
			h_g	—	1255.1	1329.3	1392.0	1450.3	1507.0	1563 2	1619.5	1676.2	1733.3	1791.0
1000.0	985.3	544.58	$\overline{V}$	—	0.5137	0.6080	0.6875	0.7603	0.8295	0.8966	0.9622	1.0266	1.0901	1.1529
			h_g	—	1249.3	1325.9	1389.6	1448.5	1505.4	1561.9	1618.4	1675.3	1732.5	1790.3
1050.0	1035.3	550.53	$\overline{V}$	—	0.4821	0.5745	0.6515	0.7216	0.7881	0.8524	0.9151	0.9767	1.0373	1.0973
			h_g	—	1243.4	1322.4	1387.2	1446.6	1503.9	1560.7	1617.4	1674.4	1731.8	1789.6
1100.0	1085.3	556 28	$\overline{V}$	—	0 4531	0.5440	0.6188	0.6865	0.7505	0.8121	0.8723	0.9313	0.9894	1 0468
			h_g	—	1237.3	1318.8	1384.7	1444.7	1502.4	1559.4	1616.3	1673.5	1731.0	1789.0
1150.0	1135 3	561.82	$\overline{V}$	—	0.4263	0.5162	0.5889	0.6544	0.7161	0.7754	0.8332	0.8899	0.9456	1.0007
			h_g	—	1230.9	1315.2	1382.2	1442.8	1500.9	1558.1	1615.2	1672.6	1730.2	1788.3

DeZURIK

PROPERTIES OF SUPERHEATED STEAM

$\overline{V}$ = specific volume, cubic feet per pound
h_g = total heat of steam, Btu per pound

Pressure Lbs. per Sq. In.		Sat. Temp.		Total Temperature — Degrees Fahrenheit (t)										
Abs. P'	Gage P	t		650°	700°	750°	800°	900°	1000°	1100°	1200°	1300°	1400°	1500°
1200.0	1185.3	567.19	$\overline{V}$	0.4497	0.4905	0.5273	0.5615	0.6250	0.6845	0.7418	0.7974	0.8519	0.9055	0.9584
			h_g	1271.8	1311.5	1346.9	1379.7	1440.9	1499.4	1556.9	1614.2	1671.6	1729.4	1787.6
1300.0	1285.3	577.42	$\overline{V}$	0.4052	0.4451	0.4804	0.5129	0.5729	0.6287	0.6822	0.7341	0.7847	0.8345	0.8836
			h_g	1261.9	1303.9	1340.8	1374.6	1437.1	1496.3	1554.3	1612.0	1669.8	1727.9	1786.3
1400.0	1385.3	587.07	$\overline{V}$	0.3667	0.4059	0.4400	0.4712	0.5282	0.5809	0.6311	0.6798	0.7272	0.7737	0.8195
			h_g	1251.4	1296.1	1334.5	1369.3	1433.2	1493.2	1551.8	1609.9	1668.0	1726.3	1785.0
1500.0	1485.3	596.20	$\overline{V}$	0.3328	0.3717	0.4049	0.4350	0.4894	0.5394	0.5869	0.6327	0.6773	0.7210	0.7639
			h_g	1240.2	1287.9	1328.0	1364.0	1429.2	1490.1	1549.2	1607.7	1666.2	1724.8	1783.7
1600.0	1585.3	604.87	$\overline{V}$	0.3026	0.3415	0.3741	0.4032	0.4555	0.5031	0.5482	0.5915	0.6336	0.6748	0.7153
			h_g	1228.3	1279.4	1321.4	1358.5	1425.2	1486.9	1546.6	1605.6	1664.3	1723.2	1782.3
1700.0	1685.3	613.13	$\overline{V}$	0.2754	0.3147	0.3468	0.3751	0.4255	0.4711	0.5140	0.5552	0.5951	0.6341	0.6724
			h_g	1215.3	1270.5	1314.5	1352.9	1421.2	1483.8	1544.0	1603.4	1662.5	1721.7	1781.0
1800.0	1785.3	621.02	$\overline{V}$	0.2505	0.2906	0.3223	0.3500	0.3988	0.4426	0.4836	0.5229	0.5609	0.5980	0.6343
			h_g	1201.2	1261.1	1307.4	1347.2	1417.1	1480.6	1541.4	1601.2	1660.7	1720.1	1779.7
1900.0	1885.3	628.56	$\overline{V}$	0.2274	0.2687	0.3004	0.3275	0.3749	0.4171	0.4565	0.4940	0.5303	0.5656	0.6002
			h_g	1185.7	1251.3	1300.2	1341.4	1412.9	1477.4	1538.8	1599.1	1658.8	1718.6	1778.4
2000.0	1985.3	635.80	$\overline{V}$	0.2056	0.2488	0.2805	0.3072	0.3534	0.3942	0.4320	0.4680	0.5027	0.5365	0.5695
			h_g	1168.3	1240.9	1292.6	1335.4	1408.7	1474.1	1536.2	1596.9	1657.0	1717.0	1777.1
2100.0	2085.3	642.76	$\overline{V}$	0.1847	0.2304	0.2624	0.2888	0.3339	0.3734	0.4099	0.4445	0.4778	0.5101	0.5418
			h_g	1148.5	1229.8	1284.9	1329.3	1404.4	1470.9	1533.6	1594.7	1655.2	1715.4	1775.7
2200.0	2185.3	649.45	$\overline{V}$	0.1636	0.2134	0.2458	0.2720	0.3161	0.3545	0.3897	0.4231	0.4551	0.4862	0.5165
			h_g	1123.9	1218.0	1276.8	1323.1	1400.0	1467.6	1530.9	1592.5	1653.3	1713.9	1774.4
2300.0	2285.3	655.89	$\overline{V}$	—	0.1975	0.2305	0.2566	0.2999	0.3372	0.3714	0.4035	0.4344	0.4643	0.4935
			h_g	—	1205.3	1268.4	1316.7	1395.7	1464.2	1528.3	1590.3	1651.5	1712.3	1773.1
2400.0	2385.3	662.11	$\overline{V}$	—	0.1824	0.2164	0.2424	0.2850	0.3214	0.3545	0.3856	0.4155	0.4443	0.4724
			h_g	—	1191.6	1259.7	1310.1	1391.2	1460.9	1525.6	1588.1	1649.6	1710.8	1771.8
2500.0	2485.3	668.11	$\overline{V}$	—	0.1681	0.2032	0.2293	0.2712	0.3068	0.3390	0.3692	0.3980	0.4259	0.4529
			h_g	—	1176.7	1250.6	1303.4	1386.7	1457.5	1522.9	1585.9	1647.8	1709.2	1770.4
2600.0	2585.3	673.91	$\overline{V}$	—	0.1544	0.1909	0.2171	0.2585	0.2933	0.3247	0.3540	0.3819	0.4088	0.4350
			h_g	—	1160.2	1241.1	1296.5	1382.1	1454.1	1520.2	1583.7	1646.0	1707.7	1769.1
2700.0	2685.3	679.53	$\overline{V}$	—	0.1411	0.1794	0.2058	0.2468	0.2809	0.3114	0.3399	0.3670	0.3931	0.4184
			h_g	—	1142.0	1231.1	1289.5	1377.5	1450.7	1517.5	1581.5	1644.1	1706.1	1767.8
2800.0	2785.3	684.96	$\overline{V}$	—	0.1278	0.1685	0.1952	0.2358	0.2693	0.2991	0.3268	0.3532	0.3785	0.4030
			h_g	—	1121.2	1220.6	1282.2	1372.8	1447.2	1514.8	1579.3	1642.2	1704.5	1766.5
2900.0	2885.3	690.22	$\overline{V}$	—	0.1138	0.1581	0.1853	0.2256	0.2585	0.2877	0.3147	0.3403	0.3649	0.3887
			h_g	—	1095.3	1209.6	1274.7	1368.0	1443.7	1512.1	1577.0	1640.4	1703.0	1765.2
3000.0	2985.3	695.33	$\overline{V}$	—	0.0982	0.1483	0.1759	0.2161	0.2484	0.2770	0.3033	0.3282	0.3522	0.3753
			h_g	—	1060.5	1197.9	1267.0	1363.2	1440.2	1509.4	1574.8	1638.5	1701.4	1763.8
3100.0	3085.3	700.28	$\overline{V}$	—	—	0.1389	0.1671	0.2071	0.2390	0.2670	0.2927	0.3170	0.3403	0.3628
			h_g	—	—	1185.4	1259.1	1358.4	1436.7	1506.6	1572.6	1636.7	1699.8	1762.5
3200.0	3185.3	705.08	$\overline{V}$	—		0.1300	0.1588	0.1987	0.2301	0.2576	0.2827	0.3065	0.3291	0.3510
			h_g	—		1172.3	1250.9	1353.4	1433.1	1503.8	1570.3	1634.8	1698.3	1761.2
3300.0	3285.3	—	$\overline{V}$	—	—	0.1213	0.1510	0.1908	0.2218	0.2488	0.2734	0.2966	0.3187	0.3400
			h_g	—	—	1158.2	1242.5	1348.4	1429.5	1501.0	1568.1	1623.9	1696.7	1759.9
3400.0	3385.3	—	$\overline{V}$	—	—	0.1129	0.1435	0.1834	0.2140	0.2405	0.2646	0.2872	0.3088	0.3296
			h_g	—	—	1143.2	1233.7	1343.4	1425.9	1498.3	1565.8	1631.1	1695.1	1758.5

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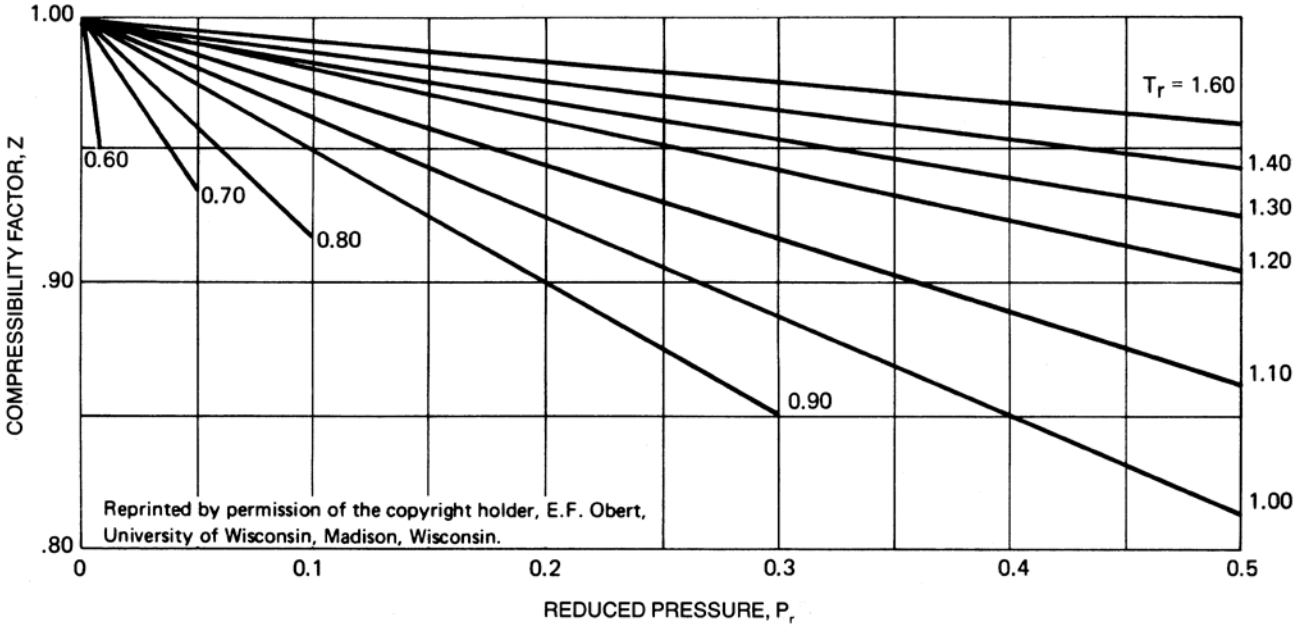
PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER

$\overline{V}$ = specific volume, cubic feet per pound
h_g = total heat of steam, Btu per pound

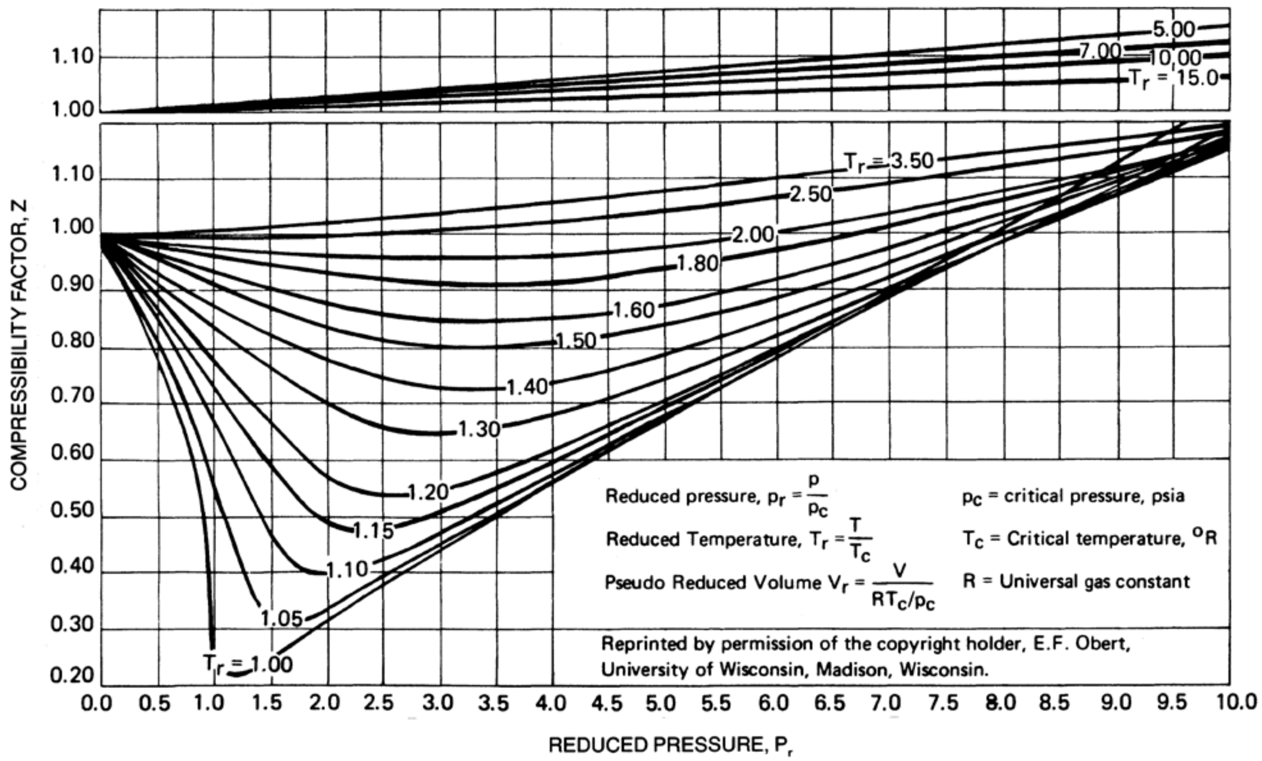
Absolute Pressure Lbs. per Sq. In.		Total Temperature — Degrees Fahrenheit (t) 200°	400°	500°	600°	700°	800°	900°	1000°	1100°	1200°	1300°	1400°	1500°
3500	$\overline{V}$	0.0164	0.0183	0.0199	0.0225	0.0307	0.1364	0.1764	0.2066	0.2326	0.2563	0.2784	0.2995	0.3198
	h_g	176.0	379.1	487.6	608.4	779.4	1224.6	1338.2	1422.2	1495.5	1563.6	1629.2	1693.6	1757.2
3600	$\overline{V}$	0.0164	0.0183	0.0198	0.0225	0.0302	0.1296	0.1697	0.1996	0.2252	0.2485	0.2702	0.2908	0.3106
	h_g	176.3	379.3	487.6	608.1	775.1	1215.3	1333.0	1418.6	1492.6	1561.3	1627.3	1692.0	1755.9
3800	$\overline{V}$	0.0164	0.0183	0.0198	0.0224	0.0294	0.1169	0.1574	0.1868	0.2116	0.2340	0.2549	0.2746	0.2936
	h_g	176.7	379.5	487.7	607.5	768.4	1195.5	1322.4	1411.2	1487.0	1556.8	1623.6	1688.9	1753.2
4000	$\overline{V}$	0.0164	0.0182	0.0198	0.0223	0.0287	0.1052	0.1463	0.1752	0.1994	0.2210	0.2411	0.2601	0.2783
	h_g	177.2	379.8	487.7	606.9	763.0	1174.3	1311.6	1403.6	1481.3	1552.2	1619.8	1685.7	1750.6
4200	$\overline{V}$	0.0164	0.0182	0.0197	0.0222	0.0282	0.0945	0.1362	0.1647	0.1883	0.2093	0.2287	0.2470	0.2645
	h_g	177.6	380.1	487.8	606.4	758.6	1151.6	1300.4	1396.0	1475.5	1547.6	1616.1	1682.6	1748.0
4400	$\overline{V}$	0.0164	0.0182	0.0197	0.0222	0.0278	0.0846	0.1270	0.1552	0.1782	0.1986	0.2174	0.2351	0.2519
	h_g	178.1	380.4	487.9	605.9	754.8	1127.3	1289.0	1388.3	1469.7	1543.0	1612.3	1679.4	1745.3
4600	$\overline{V}$	0.0164	0.0182	0.0197	0.0221	0.0274	0.0751	0.1186	0.1465	0.1691	0.1889	0.2071	0.2242	0.2404
	h_g	178.5	380.7	487.9	605.5	751.5	1100.0	1277.2	1380.5	1463.9	1538.4	1608.5	1676.3	1742.7
4800	$\overline{V}$	0.0164	0.0182	0.0196	0.0220	0.0271	0.0665	0.1109	0.1385	0.1606	0.1800	0.1977	0.2142	0.2299
	h_g	179.0	380.9	488.0	605.0	748.6	1071.2	1265.2	1372.6	1458.0	1533.8	1604.7	1673.1	1740.0
5200	$\overline{V}$	0.0164	0.0181	0.0196	0.0219	0.0265	0.0531	0.0973	0.1244	0.1458	0.1642	0.1810	0.1966	0.2114
	h_g	179.9	381.5	488.2	604.3	743.7	1016.9	1240.4	1356.6	1446.2	1524.5	1597.2	1666.8	1734.7
5600	$\overline{V}$	0.0163	0.0181	0.0195	0.0217	0.0260	0.0447	0.0856	0.1124	0.1331	0.1508	0.1667	0.1815	0.1954
	h_g	180.8	382.1	488.4	603.6	739.6	975.0	1214.8	1340.2	1434.3	1515.2	1589.6	1660.5	1729.5
6000	$\overline{V}$	0.0163	0.0180	0.0195	0.0216	0.0256	0.0397	0.0757	0.1020	0.1221	0.1391	0.1544	0.1684	0.1817
	h_g	181.7	382.7	488.6	602.9	736.1	945.1	1188.8	1323.6	1422.3	1505.9	1582.0	1654.2	1724.2
6500	$\overline{V}$	0.0163	0.0180	0.0194	0.0215	0.0252	0.0358	0.0655	0.0909	0.1104	0.1266	0.1411	0.1544	0.1669
	h_g	182.9	383.4	488.9	602.3	732.4	919.5	1156.3	1302.7	1407.3	1494.2	1572.5	1646.4	1717.6
7000	$\overline{V}$	0.0163	0.0180	0.0193	0.0213	0.0248	0.0334	0.0573	0.0816	0.1004	0.1160	0.1298	0.1424	0.1542
	h_g	184.0	384.2	489.3	601.7	729.3	901.8	1124.9	1281.7	1392.2	1482.6	1563.1	1638.6	1711.1
7500	$\overline{V}$	0.0163	0.0179	0.0193	0.0212	0.0245	0.0318	0.0512	0.0737	0.0918	0.1068	0.1200	0.1321	0.1433
	h_g	185.2	384.9	489.6	601.3	726.6	889.0	1097.7	1261.0	1377.2	1471.0	1553.7	1630.8	1704.6
8000	$\overline{V}$	0.0162	0.0179	0.0192	0.0211	0.0242	0.0306	0.0465	0.0671	0.0845	0.0989	0.1115	0.1230	0.1338
	h_g	186.3	385.7	490.0	600.9	724.3	879.1	1074.3	1241.0	1362.2	1459.6	1544.5	1623.1	1698.1
9000	$\overline{V}$	0.0162	0.0178	0.0191	0.0209	0.0237	0.0288	0.0402	0.0568	0.0724	0.0858	0.0975	0.1081	0.1179
	h_g	188.6	387.3	490.9	600.3	720.4	864.7	1037.6	1204.1	1333.0	1437.1	1526.3	1607.9	1685.3
10000	$\overline{V}$	0.0161	0.0177	0.0189	0.0207	0.0233	0.0276	0.0362	0.0495	0.0633	0.0757	0.0865	0.0963	0.1054
	h_g	190.9	388.9	491.8	600.0	717.5	854.5	1011.3	1172.6	1305.3	1415.3	1508.6	1593.1	1672.8
11000	$\overline{V}$	0.0161	0.0176	0.0188	0.0205	0.0229	0.0267	0.0335	0.0443	0.0562	0.0676	0.0776	0.0868	0.0952
	h_g	193.2	390.5	492.8	599.9	715.1	846.9	992.1	1146.3	1280.2	1394.4	1491.5	1578.7	1660.6
12000	$\overline{V}$	0.0161	0.0176	0.0187	0.0203	0.0226	0.0260	0.0317	0.0405	0.0508	0.0610	0.0704	0.0790	0.0869
	h_g	195.5	392.1	493.9	599.9	713.3	841.0	977.8	1124.5	1258.0	1374.7	1475.1	1564.9	1648.8
13000	$\overline{V}$	0.0160	0.0175	0.0186	0.0201	0.0223	0.0253	0.0302	0.0376	0.0466	0.0558	0.0645	0.0725	0.0799
	h_g	197.8	393.8	495.0	600.1	711.9	836.3	966.8	1106.7	1238.5	1356.5	1459.4	1551.6	1637.4
14000	$\overline{V}$	0.0160	0.0174	0.0185	0.0200	0.0220	0.0248	0.0291	0.0354	0.0432	0.0515	0.0595	0.0670	0.0740
	h_g	200.1	395.5	496.2	600.5	710.8	832.6	958.0	1092.3	1221.4	1340.2	1444.4	1538.8	1626.5
15000	$\overline{V}$	0.0159	0.0174	0.0184	0.0198	0.0218	0.0244	0.0282	0.0337	0.0405	0.0479	0.0552	0.0624	0.0690
	h_g	202.4	397.2	497.4	600.9	710.0	829.5	950.9	1080.6	1206.8	1326.0	1430.3	1526.4	1615.9
15500	$\overline{V}$	0.0159	0.0173	0.0184	0.0198	0.0217	0.0242	0.0278	0.0329	0.0393	0.0464	0.0534	0.0603	0.0668
	h_g	203.6	398.1	498.1	601.2	709.7	828.2	947.8	1075.7	1200.3	1319.6	1423.6	1520.4	1610.8

COMPRESSIBILITY FACTOR CHARTS

COMPRESSIBILITY FACTOR AT LOW PRESSURES, Z:P_r = 0 TO 0.5

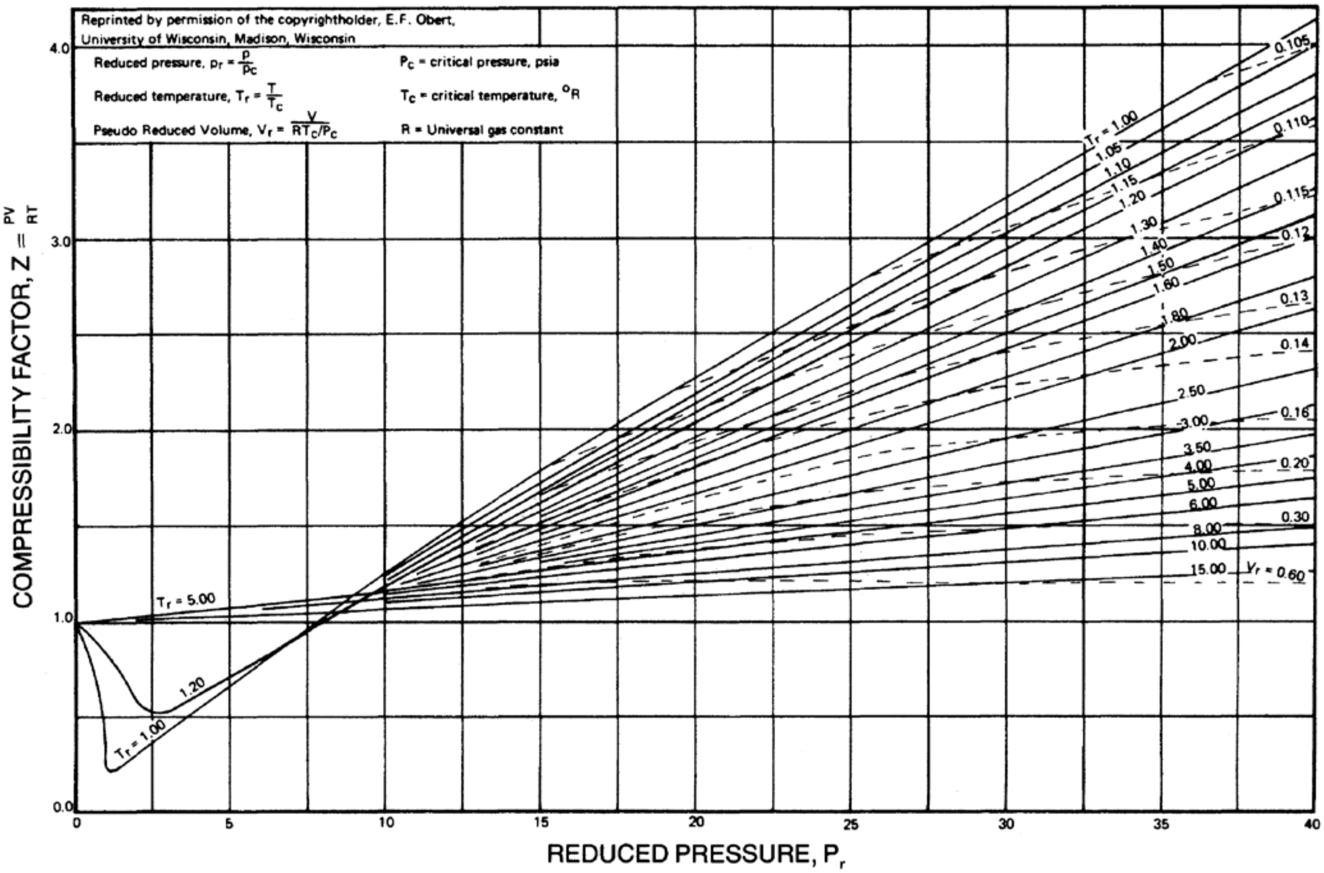


COMPRESSIBILITY FACTOR, Z:P_r = 0 TO 10



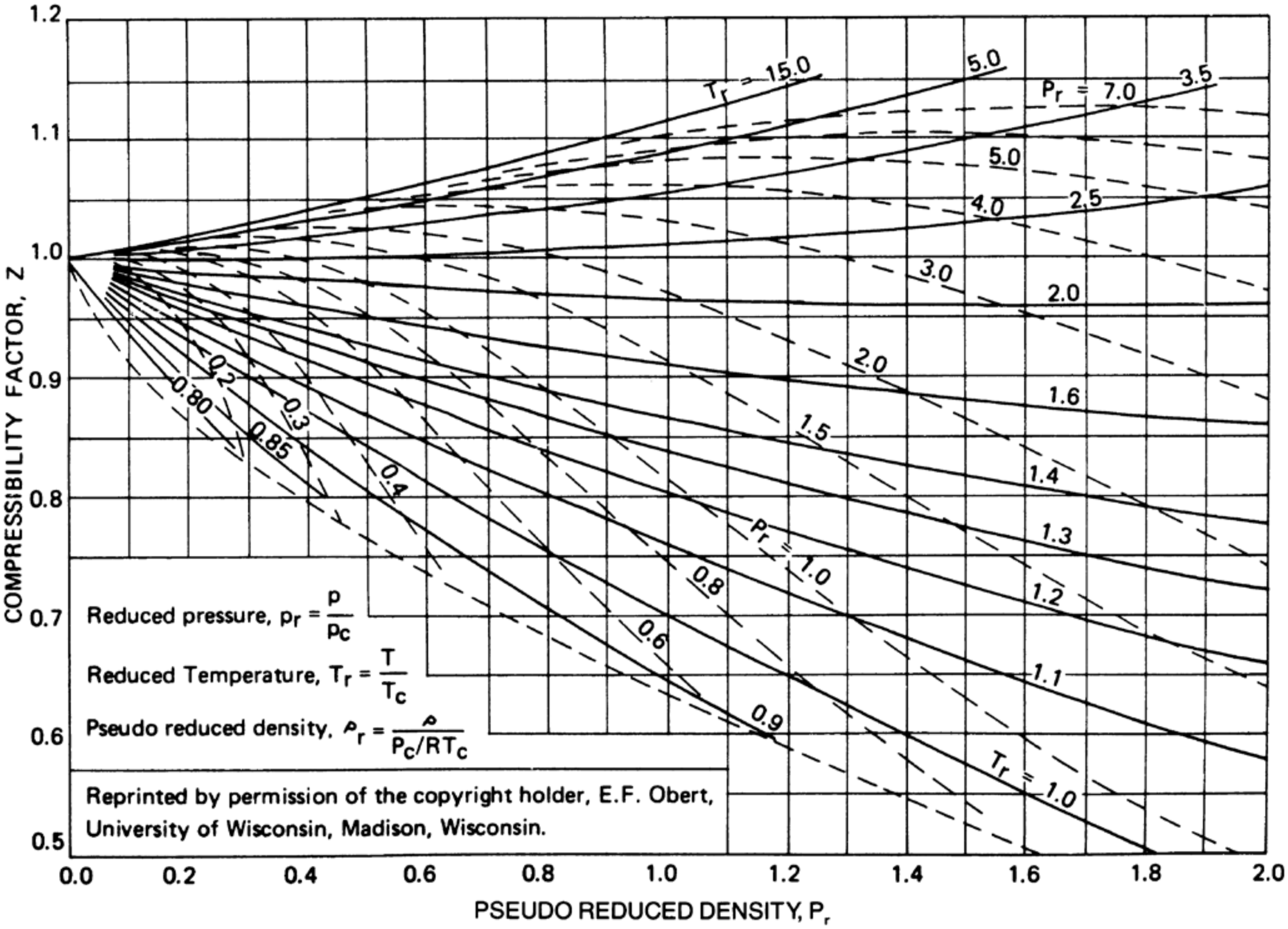
COMPRESSIBILITY FACTOR CHARTS (continued)

COMPRESSIBILITY FACTOR, Z:P_r = 0 TO 40



COMPRESSIBILITY FACTOR CHARTS (continued)

COMPRESSIBILITY FACTOR, Z:P_r = 0 TO 2.0



LIQUID SIZING

DETERMINING CRITICAL VS. SUBCRITICAL FLOW

Flow through a valve is classified as either critical or subcritical. A subcritical flowing condition exists so long as an increase in the pressure differential (ΔP) across the valve will produce an increase in the flow rate. A linear relationship exists between the flow rate and the square root of the pressure differential (ΔP) up to the point of incipient cavitation. (See Figure #1, Page 7.) At this point the relationship of flow to the square root of the pressure differential will begin to deviate from linear. The valve will continue to pass an increase in flow with an increase in pressure differential, however, there will be a loss in efficiency due to the cavitation effect.

As the pressure differential across the valve increases, a point is reached where an increase in the pressure differential no longer produces a change in the rate of flow. At this point a condition of critical flow (sometimes referred to as choked flow) exists. When this critical flow condition exists, the standard liquid sizing equations no longer apply and the critical flow equations found on page 8 must be used to determine the required valve size.

To determine whether a critical or subcritical flow condition exists the following equations are used.

If the vapor pressure is less than one-half the upstream pressure ($p_v < 0.5\, p_1$), then:

Subcritical flow exists when:

$$\Delta P < F_L^2 (p_1 - p_V)$$

Critical flow exists when:

$$\Delta P \geqq F_L^2 (p_1 - p_V)$$

If the vapor pressure is equal to or greater than ½ the upstream pressure ($p_V \geqq 0.5\, p_1$), then:

Subcritical flow exists when:

$$\Delta P < F_L^2 \left[p_1 - \left(0.96 - 0.28 \sqrt{\frac{p_V}{p_C}}\right) p_V \right]$$

Critical flow exists when:

$$\Delta P \geqq F_L^2 \left[p_1 - \left(0.96 - 0.28 \sqrt{\frac{p_V}{p_C}}\right) p_V \right]$$

Where:

- ΔP = Pressure drop across the valve in psi (metric; bar)
- F_L = Liquid pressure recovery factor, dimensionless (Ref. F_L data for valve style being considered)
- p_1 = Upstream static pressure, absolute psia (metric; bar absolute)
- p_V = Vapor pressure of liquid*, at inlet temperature, psia. (metric; bar absolute)
- p_C = Thermodynamic critical pressure, psia* (metric; bar absolute)

*Consult reference information found in last section of DeZURIK Control Valve Sizing handbook.

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LIQUID SIZING EQUATIONS FOR SUBCRITICAL FLOW (VOLUMETRIC)

ENGLISH FORMULA:

$$C_v = q_f \sqrt{\frac{G_f}{\Delta P}}$$

$$q_f = C_v \sqrt{\frac{\Delta P}{G_f}}$$

Where:

C_v = Valve flow coefficient
q_f = Volume rate of flow, U.S. gpm
G_f = Specific gravity, relative to water, std. temp.
ΔP = Pressure drop, psi

Sample Problem (Solve for C_v):

Where:

q_f = 4340 U.S. gpm (hot water)
P = 90 psig (upstream pressure)
ΔP = 15 psi
G_f = 0.96
p_v = 11.5 psia
F_L = 0.6 (determined by valve style)

Check for critical vs. subcritical condition:

p_v (11.5 psia) < 0.5 p_1 (105 psia)
$F_L^2 (p_1 - p_v) = 0.6^2 (105 - 11.5) =$
$0.36 (93.5) = 34.$

Subcritical flow exists since:

$\Delta P < F_L^2 (p_1 - p_v)$ or $15 < 34$

Hence:

$$C_v = q_f \sqrt{\frac{G_f}{\Delta P}} = 4340 \sqrt{\frac{0.96}{15}} =$$

$$4340 \sqrt{0.064} = 4340 (0.25) = 1100$$

$C_v = 1100$

METRIC FORMULA:

$$C_v = 1.16\, q_f \sqrt{\frac{G_f}{\Delta P}}$$

$$q_f = 0.86\, C_v \sqrt{\frac{\Delta P}{G_f}}$$

Where:

C_v = Valve flow coefficient
q_f = Volume rate of flow, m^3/hr.
G_f = Specific gravity, relative to water @ std. temp.
ΔP = Pressure drop, bar

Sample Problem (Solve for C_v):

Where:

q_f = 986 m^3/hr. (hot water)
P = 6.2 bar (upstream pressure)
ΔP = 1.03 bar
G_f = 0.96
p_v = 0.79 bar absolute
F_L = 0.6 (determined by valve style)

Check for critical vs. subcritical condition:

$p_v < 0.5 p_1$; $0.79 < 0.5 (7.2)$
$F_L^2 (p_1 - p_v) = 0.6^2 (7.2 - 0.79) =$
$0.36 (6.4) = 2.3$

Subcritical flow exists since:

$\Delta P < F_L^2 (p_1 - p_v)$ or $0.79 < 2.3$

Hence:

$$C_v = 1.16\, q_f \sqrt{\frac{G_f}{\Delta P}} = (1.16)(986) \sqrt{\frac{0.96}{1.03}}$$

$$= 1144 \sqrt{0.93} = 1144 (0.97) = 1100$$

$C_v = 1100$

LIQUID SIZING EQUATION FOR SUBCRITICAL FLOW (WEIGHT – WHERE SPECIFIC WEIGHT IS KNOWN)

ENGLISH FORMULA:

$$C_v = \frac{w}{63.3\sqrt{\Delta P \gamma}}$$

$$w = 63.3\, C_v \sqrt{\Delta P \gamma}$$

Where:

- w = Weight rate of flow, lbs/hr
- γ = Specific weight, lbs/ft³
- C_v = Valve flow coefficient
- ΔP = Pressure drop, psi

Sample Problem (Solve for C_v):

Where:

- w = 2,080,000 lbs/hr.
- γ = 60 lbs/ft³
- ΔP = 15 psi

(Assume subcritical condition)

Hence:

$$C_v = \frac{w}{63.3\sqrt{\Delta P \gamma}} = \frac{2{,}080{,}000}{63.3\sqrt{(15)\,(60)}} =$$

$$\frac{2{,}080{,}000}{63.3\sqrt{900}} = \frac{2{,}080{,}000}{(63.3)\,30} = \frac{2{,}080{,}000}{1899}$$

$$= 1100$$

$$C_v = 1100$$

METRIC FORMULA:

$$C_v = \frac{w}{27.3\sqrt{\Delta P \gamma}}$$

$$w = 27.3\, C_v \sqrt{\Delta P \gamma}$$

Where:

- w = Weight rate of flow, kg/hr
- γ = Specific weight, kg/m³
- C_v = Valve flow coefficient
- ΔP = Pressure drop, bar

Sample Problem (Solve for C_v):

Where:

- w = 946,000 kg/hr
- γ = 963 kg/m³
- ΔP = 1.03 bar

(Assume subcritical condition)

Hence:

$$C_v = \frac{w}{27.3\sqrt{\Delta P \gamma}} = \frac{946{,}000}{27.3\sqrt{(1.03)\,(963)}}$$

$$= \frac{946{,}000}{27.3\sqrt{992}} = \frac{946{,}000}{(27.3)\,31.5} = \frac{946{,}000}{860}$$

$$= 1100$$

$$C_v = 1100$$

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LIQUID SIZING EQUATION FOR SUBCRITICAL FLOW (WEIGHT – WHERE SPECIFIC GRAVITY IS KNOWN)

ENGLISH FORMULA:

$$C_v = \frac{w}{500\sqrt{\Delta P\, G_f}}$$

$$w = 500\, C_v \sqrt{\Delta P\, G_f}$$

Where:

- w = Weight rate of flow, lbs/hr
- C_v = Valve flow coefficient
- G_f = Specific gravity, relative to water @ std. temp.
- ΔP = Pressure drop, psi

Sample Problem (Solve for C_v):

Where:

- w = 2,080,000 lbs/hr
- G_f = 0.96
- ΔP = 15 psi

(Assume subcritical condition)

Hence:

$$C_v = \frac{w}{500\sqrt{\Delta P\, G_f}} = \frac{2{,}080{,}000}{500\sqrt{(15)\,(0.96)}}$$

$$= \frac{2{,}080{,}000}{500\sqrt{14.4}} = \frac{2{,}080{,}000}{(500)\; 3.79} =$$

$$\frac{2{,}080{,}000}{1895} = 1100$$

$C_v = 1100$

METRIC FORMULA:

$$C_v = \frac{w}{865\sqrt{\Delta P\, G_f}}$$

$$w = 865\, C_v \sqrt{\Delta P\, G_f}$$

Where:

- w = Weight rate of flow, kg/hr
- C_v = Valve flow coefficient
- G_f = Specific gravity, relative to water @ std. temp.
- ΔP = Pressure drop, bar

Sample Problem (Solve for C_v):

Where:

- w = 946,000 kg/hr
- G_f = 0.96
- ΔP = 1.03 bar

(Assume subcritical condition)

Hence:

$$C_v = \frac{w}{865\sqrt{\Delta P\, G_f}} = \frac{946{,}000}{865\sqrt{(1.03)\,(0.96)}}$$

$$= \frac{946{,}000}{865\sqrt{0.989}} = \frac{946{,}000}{(865)\,(0.99)} =$$

$$\frac{946{,}000}{860} = 1100$$

$C_v = 1100$

CAVITATION

Cavitation is a condition in which a part of the liquid passing through a valve is first transformed into vapor bubbles and subsequently back to liquids. As the liquid passes through the flow restriction caused by the valve, there is a rapid increase in liquid flow velocity accompanied by a reduction in pressure. This area of increased velocity and reduced pressure occurs immediately downstream from the internal valve restriction and is referred to as the vena contracta. If the pressure in the area of the vena contracta falls below the vapor pressure of the flowing liquid, vapor bubbles will develop.

Immediately downstream from the vena contracta there is a rapid decrease of flow velocity accompanied by an increase in pressure. This increase in pressure causes the vapor bubbles to collapse. The continuous formation and subsequent collapse of these vapor bubbles causes localized pressure impulses which in turn may result in vibration and noise. Evidence of cavitation is often detected by the characteristic noise of the collapsing bubbles which sounds like gravel flowing through the pipe. Severe cavitation may also cause mechanical damage and eventual failure of the valve and downstream piping.

As vapor bubbles begin to form, they displace the liquid, thereby choking the flow and reducing the efficiency of the valve. The early stage of bubble formation is called incipient cavitation (K_c) and is represented by the area of inscribed arc at the intersection of the two lines

As the pressure differential increases, a point will be reached where an increase in pressure differential (ΔP) across the valve will no longer produce an increase in the rate of flow. At this point the condition is referred to as critical or choked flow (F_L^2) and the design engineer must resort to some other solution for flow control. Typical solutions to this problem include:

1) Selection of a larger valve size.
2) Select a valve design having a greater K_c factor.
3) Reduce the individual valve pressure drop by installing two valves in series.
4) Lower the elevation of the valve in the system, thereby increasing the system pressure nearer to or above the vapor pressure of the liquid.
5) Introduce air into the low pressure area.

Each valve style will produce cavitation at a different ratio of pressure differential to upstream absolute pressure less vapor pressure.

$\left(\dfrac{\Delta P}{p_1 - p_v}\right)$ This ratio is expressed as a K_c factor which must be determined by test for any given valve style by the valve manufacturer. With this K_c factor the design engineer can determine the pressure differential at which cavitation will begin to occur.

$$\Delta P \text{ (Allowable)} = K_c (p_1 - p_v)$$

Sample Problem:

Where:

$K_c = 0.24$ (Valve fully open)

$p_1 = 105$ psia

$\Delta P = 15$ psi

$p_v = 11.5$ psia

$\Delta P \text{ (Allowable)} = K_c (p_1 - p_v)$

$0.24 (105 - 11.5) = (0.24)(93.5) = 22$

Hence:

Actual ΔP (15 psi) $<$ Allowable ΔP (22 psi)

Therefore: Cavitation will not occur in this instance:

If the actual differential pressure is found to be greater than the allowable differential pressure, cavitation will occur. If this cannot be tolerated, then the design engineer can easily determine what valve size is required to avoid cavitation by substituting the allowable pressure differential for the actual differential pressure in the standard liquid sizing formula.

Example:

Where:

K_c = 0.24 (Valve fully open)
p_1 = 105 psia
ΔP (Allowable) = 22 psi
ΔP (Actual) = 25 psi
p_v = 11.5 psia
G_f = 0.96
q_f = 4340

$$C_v = q_f \sqrt{\frac{G_f}{\Delta P \text{ (Allowable)}}}$$

$$C_v = 4340 \sqrt{\frac{0.96}{22}}$$

$$C_v = 4340 \sqrt{.044}$$

$$C_v = (4340)\ (.210)$$

$$C_v = 911$$

This C_v value of 911 compares with a C_v of 851 if the actual pressure differential of 25 psi had been used to size the valve. By substituting the 22 psi allowable pressure differential for the 25 psi actual pressure differential, the engineer has increased the valve size and has avoided the cavitation condition which would occur at the 25 psi differential pressure.

As outlined above, when the ratio of pressure differential to the upstream absolute pressure less vapor pressure $\left(\frac{\Delta P}{p_1 - p_v}\right)$ increases beyond the stage of incipient cavitation, a choked flow condition will develop. The point at which choked flow occurs is also a function of the valve style and is described by the equation:

$$\Delta P \text{ (At Choked Flow)} = F_L^2 (p_1 - p_v)$$

This choked flow equation determines the maximum pressure differential which will produce an increase in flow rate. The valve size can be increased to compensate for choked flow by substituting the maximum choked flow pressure differential from the equation above for the pressure differential in the standard liquid size equation. However, the preferred method of valve sizing for liquid critical flow is outlined on the following pages.

(Note: Presented as an example only. Additional data must be obtained for the valve style being considered.)

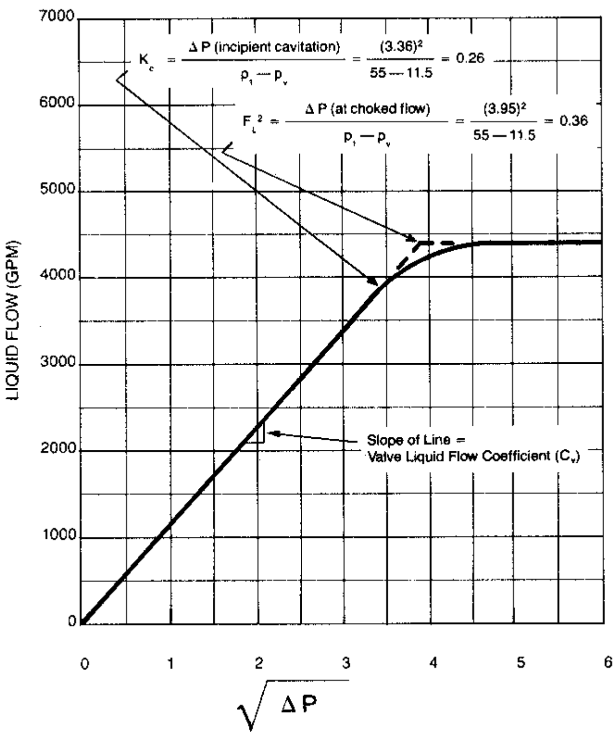

Figure 1. TYPICAL K_C AND F_L^2 DATA.

LIQUID SIZING EQUATIONS FOR CRITICAL FLOW (VOLUMETRIC*)

ENGLISH FORMULA:

$$C_v = \frac{q_f}{F_L}\sqrt{\frac{G_f}{p_1 - F_F\, p_v}}$$

$$q_f = C_v F_L \sqrt{\frac{p_1 - F_F\, p_v}{G_f}}$$

Where:

- C_v = Valve Flow Coefficient
- q_f = Volume Flow Rate, U.S. gpm
- F_L = Pressure Recovery Factor of Valve
- G_f = Specific gravity, relative to water @ std. temp.
- p_1 = Upstream static pressure, psia
- p_v = Vapor pressure of liquid, psia

$$F_F = 0.96 - 0.28\sqrt{\frac{p_v}{p_c}}$$

Where:

- p_c = Thermodynamic Critical Press (psia)

Sample Problem (Solve for C_v):

Where:

- q_f = 4000 U.S. gpm
- p_1 = Upstream pressure 40 psi
- ΔP = 24 psi
- p_v = 11.5 psia
- G_f = 0.96
- F_L = 0.6 (determined by valve style)
- p_c = 3206 psia

METRIC FORMULA:

$$C_v = 1.16\,\frac{q_f}{F_L}\sqrt{\frac{G_f}{p_1 - F_F\, p_v}}$$

$$q_f = 0.86\, C_v F_L \sqrt{\frac{p_1 - F_F\, p_v}{G_f}}$$

Where:

- C_v = Valve Flow Coefficient
- q_f = Volume Flow Rate, m^3/hr
- F_L = Pressure Recovery Factor of Valve
- G_f = Specific gravity, relative to water @ std. temp.
- p_1 = Upstream static pressure, bar absolute
- p_v = Vapor pressure of liquid, bar absolute

$$F_F = 0.96 - 0.28\sqrt{\frac{p_v}{p_c}}$$

Where:

- p_c = Thermodynamic Critical Press (psia)

Sample Problem (Solve for C_v):

Where:

- q_f = 910 m^3/hr.
- p_1 = Upstream pressure 2.76 bar
- ΔP = 1.66 bar
- p_v = 0.79 bar absolute
- G_f = 0.96
- F_L = 0.6 (determined by valve style)
- p_c = 221 bar absolute

*Use conversion factor if rate of flow by weight is required.

Check for critical vs. subcritical condition.

Is $p_v < 0.5\, p_1$?

$(0.5)\,(55 \text{ psia}) = 27.5$

Therefore p_v (11.5 psia) $< 0.5\, p_1$ (27.5)

$\Delta P\,(\text{Critical}) = F_L^2\,(p_1 - p_v) =$

$0.6^2\,(55 - 11.5) = (0.36)\,(43.5) =$

15.7 psi

$\Delta P\,(\text{Actual}) > \Delta P\,(\text{Critical})$

Therefore critical condition equation must be used.

Hence:

$$C_v = \frac{q_f}{F_L}\sqrt{\frac{G_f}{(p_1 - F_F p_v)}}$$

$$F_F = 0.96 - 0.28\sqrt{\frac{11.5}{3206}} = 0.94$$

$$C_v = \frac{4000}{0.6}\sqrt{\frac{0.96}{55 - (0.94)\,(11.5)}} =$$

$$6667\sqrt{\frac{0.96}{44.2}} =$$

$$6667\sqrt{0.022} =$$

$(6667)\,(0.148) = 990$

$C_v = 990$

METRIC FORMULA:

Note: Assume critical flow conditions.

Hence:

$$C_v = 1.16\,\frac{q_f}{F_L}\sqrt{\frac{G_f}{(p_1 - F_F p_v)}}$$

$$F_F = 0.96 - 0.28\sqrt{\frac{0.79}{221}} = 0.94$$

$$C_v = (116)\left(\frac{910}{0.6}\right)\sqrt{\frac{0.96}{3.77 - (0.94)\,(0.79)}} =$$

$$1760\sqrt{\frac{0.96}{3.77 - 0.74}} =$$

$$1760\sqrt{0.317} =$$

$(1760)\,(0.563) = 990$

$C_v = 990$

LIQUID SIZING EQUATIONS FOR VISCOUS LIQUIDS

Liquid viscosity produces a resistance to flow through pipelines and fittings. The following formulas may be used to size valves for viscous (non-turbulent) Newtonian fluid applications. (Note: This is a simplified formula to be used only on high viscosity fluids which exceed 6500* centipoise.)

ENGLISH FORMULA:

$$C_v = 0.07 \left(\frac{q_f\,\mu}{\Delta P}\right)^{2/3} \text{ or}$$

$$C_v = 0.07 \sqrt[3]{\left(\frac{q_f\,\mu}{\Delta P}\right)^2}$$

Where:

- μ = Viscosity, centipoise
- ΔP = Pressure drop, psi
- q_f = Flow rate, U.S. gpm
- C_v = Valve flow coefficient

Sample Problem (Solve for C_v):

Where:

- q_f = 4340 U.S. gpm
- ΔP = 15 psi
- μ = 9000 centipoise

Hence:

$$C_v = 0.07 \sqrt[3]{\left(\frac{q_f\,\mu}{\Delta P}\right)^2} =$$

$$0.07 \sqrt[3]{\left(\frac{(4340)\,(9000)}{15}\right)^2} =$$

$$0.07 \sqrt[3]{\left(\frac{39{,}060{,}000}{15}\right)^2} =$$

$$0.07 \sqrt[3]{(2{,}604{,}000)^2} =$$

$$(0.07)\,(18{,}900) = 1323$$

$$C_v = 1323$$

METRIC FORMULA:

$$C_v = 0.032 \left(\frac{q_f\,\mu}{\Delta P}\right)^{2/3} \text{ or}$$

$$C_v = 0.032 \sqrt[3]{\left(\frac{q_f\,\mu}{\Delta P}\right)^2}$$

Where:

- μ = Viscosity, centipoise
- ΔP = Pressure drop, bar
- q_f = Flow rate, m^3/hr
- C_v = Valve flow coefficient

Sample Problem (Solve for C_v):

Where:

- q_f = 986 m^3/hr
- ΔP = 1.03 bar
- μ = 9000 centipoise

Hence:

$$C_v = 0.032 \sqrt[3]{\left(\frac{q_f\,\mu}{\Delta P}\right)^2} =$$

$$0.032 \sqrt[3]{\left(\frac{(986)\,(9000)}{1.03}\right)^2} =$$

$$0.032 \sqrt[3]{\left(\frac{8{,}874{,}000}{1.03}\right)^2} =$$

$$0.032 \sqrt[3]{(8{,}620{,}000)^2} =$$

$$(0.032)\,(42{,}000) = 1344$$

$$C_v = 1340$$

*6500 equals printers ink at 80° F.

A more general formula which may be applied to the full viscosity range may also be used. This formula incorporates a correction factor (F_R) for the fluid Reynolds Number (R_c). In addition to the F_R value, a factor (F_d), which correlates the valve flow coefficient to the Reynolds Number for the valve style being considered, must be used in the calculation. This F_d factor is supplied by the valve manufacturer.

The first step in correcting C_v due to viscosity is to solve the theta (Θ) which is the viscosity correction factor. The viscosity correction factor is used to find the Reynolds Number correction factor (F_R) on the Reynolds Number graph (Figure 2, Page 12). The corrected C_v is then found by dividing the standard uncorrected flow coefficient [$(C_v)_u$] by the F_R factor.

$$C_v = \frac{(C_v)_u}{F_R}$$

ENGLISH FORMULA:

$$\Theta = \frac{\mu F_d}{\sqrt{\Delta P \, G_f \, (C_v)_u}}$$

Where:

- Θ = Viscosity Correction Index
- μ = Viscosity, centipoise
- F_d = Reynolds Number Factor for valve style being considered
- ΔP = Pressure drop, psi
- G_f = Specific gravity
- $(C_v)_u$ = Uncorrected C_v (from standard equation)

Sample Problem (Solve for Corrected C_v):

Where:

- q_f = 4340 U.S. gpm
- G_f = 0.96
- ΔP = 15 psi
- μ = 9000 centipoise
- F_d = 1.0 (determined by valve style)

Hence:

First solve for uncorrected flow coefficient $(C_v)_u$:

$$(C_v)_u = q_f \sqrt{\frac{G_f}{\Delta P}} =$$

$$4340 \sqrt{\frac{0.96}{15}} = 1100$$

METRIC FORMULA:

$$\Theta = \frac{0.262 \, \mu F_d}{\sqrt{\Delta P \, G_f \, (C_v)_u}}$$

Where:

- Θ = Viscosity Correction Index
- μ = Viscosity, centipoise
- F_d = Reynolds Number Factor for valve style being considered
- ΔP = Pressure drop, bar
- G_f = Specific gravity
- $(C_v)_u$ = Uncorrected C_v (from standard equation)

Sample Problem (Solve for Corrected C_v):

Where:

- q_f = 986 m^3/hr
- G_f = 0.96
- ΔP = 1.03 bar
- μ = 9000 centipoise
- F_d = 1.0 (determined by valve style)

Hence:

First solve for uncorrected flow coefficient $(C_v)_u$:

$$(C_v)_u = 1.16 \, q_f \sqrt{\frac{G_f}{\Delta P}} =$$

$$(1.16)\,(986) \sqrt{\frac{0.96}{1.03}} = 1100$$

Then solve for Θ, Where:

$$\Theta = \frac{\mu F_d}{\sqrt{\Delta P\, G_f\, (C_v)_u}} =$$

$$\frac{(9000)\,(1.0)}{\sqrt{(15)\,(0.96)\,(1100)}} =$$

$$\frac{9000}{\sqrt{15{,}840}} = \frac{9000}{126} = 71.5$$

Then from the graph (Figure 2 below) find Reynolds Number correction factor (F_R) for Θ of 71.5:

F_R for Θ of 71.5 = 0.62

Therefore:

$$C_v = \frac{(C_v)_u}{F_R} = \frac{1100}{0.62} = 1780$$

Corrected C_v = 1780

METRIC FORMULA:

Then solve for Θ, Where:

$$\Theta = \frac{0.262\, \mu F_d}{\sqrt{\Delta P\, G_f\, (C_v)_u}} =$$

$$\frac{(0.262)\,(9000)\,(1.0)}{\sqrt{(1.03)\,(0.96)\,(1100)}} =$$

$$\frac{2358}{\sqrt{1088}} = \frac{2358}{32.98} = 71.5$$

Then from the graph (Figure 2 below) find Reynolds Number correction factor (F_R) for Θ of 71.5:

F_R for Θ of 71.5 = 0.62

Therefore:

$$C_v = \frac{(C_v)_u}{F_R} = \frac{1100}{0.62} = 1780$$

Corrected C_v = 1780

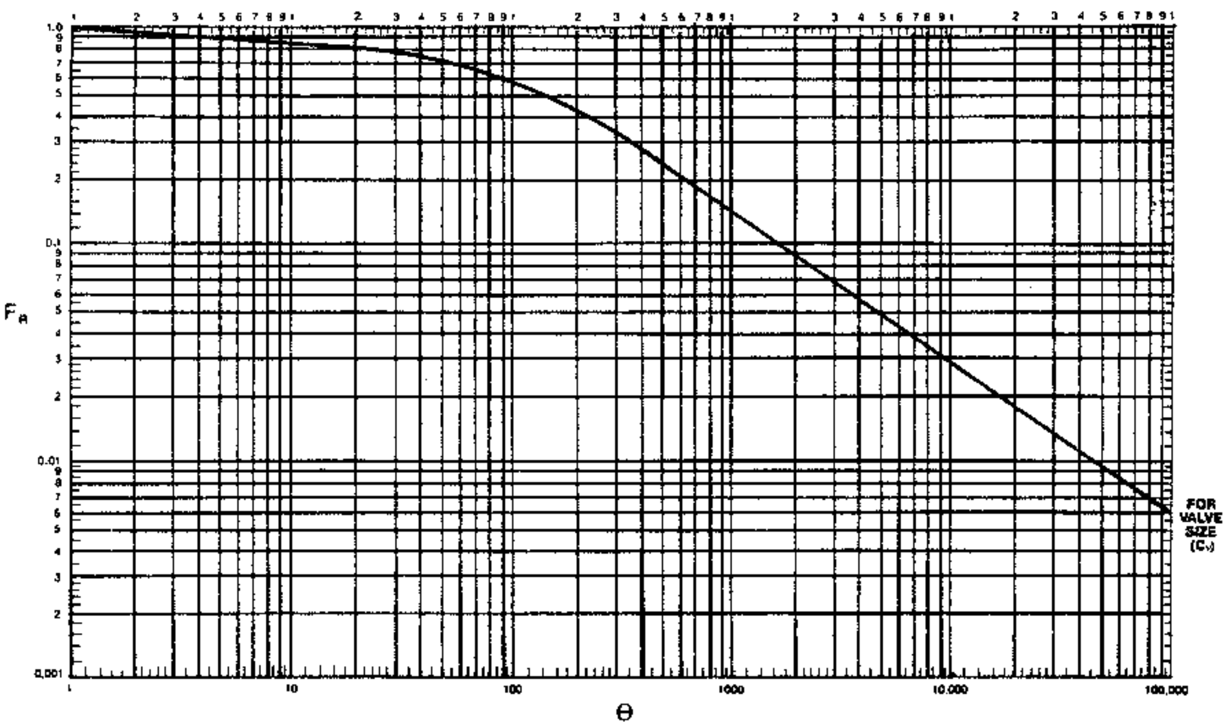

Figure 2. THE VALVE RATED C_v MUST BE MULTIPLIED BY THE FACTOR F_R WHEN THE STREAM REYNOLDS NUMBER IS LOW. HIGH VISCOSITY, LOW ΔP AND SMALL C_v ALL CONTRIBUTE TO LOWERING OF REYNOLDS CRITERION.

LIQUID SIZING CORRECTION EQUATIONS FOR CONSISTENCY

The consistency level of fiber (pulp stock) suspensions contributes to flow resistance through pipes and fittings. A pulp stock correction factor F_c is used in liquid sizing equations to compensate for these frictional losses. While this F_c factor is used primarily in pulp and paper suspensions of wood fiber and water, it may also be used to correct for the flow calculations on other fibrous slurries such as sewage sludge.

Pulp Stock Correction Factor (F_c)

% Consistency	Chemical Stock	Mechanical (Groundwood) Stock
1%	1.0	1.0
2%	0.97	0.99
3%	0.90	0.95
4%	0.84	0.92
5%	0.80	0.90

To determine the effective corrected C_v of an existing valve, multiply the standard published C_v by the F_c factor.

To solve for flow rate use the formula:

$$q_f = F_c C_v \sqrt{\frac{\Delta P}{G_f}}$$

To solve for flow coefficient (C_v) use the formula:

$$C_v \quad \frac{q_f \sqrt{\frac{G_f}{\Delta P}}}{F_c}$$

Where:

C_v = Valve flow coefficient
q_f = Volume rate of flow, U.S. gpm
G_f = Specific Gravity, relative to water, std. temp.
ΔP = Pressure drop, psi
F_c = Pulp stock correction factor

GAS AND STEAM SIZING

Sizing valves for compressible fluid applications is more complicated than liquid sizing because of the increased number of physical variables. Two series of compressible fluid sizing formulas are presented on the following pages. The first series of formulas are simplified for general use and are limited in accuracy.

These simplified compressible fluid sizing equations may be used if the ratio of the pressure differential to the upstream pressure (absolute) is less than 0.1.

$x < 0.10$

Where:

$$x = \frac{\Delta P \text{ (Pressure Differential)}}{p_1 \text{ (Upstream Pressure Absolute, psia)}}$$

Under this condition the error should not exceed 10%. If the "X" value is greater than .1 or greater accuracy is required, the universal sizing equations for compressible fluids beginning on page 19 should be used.

SIMPLIFIED SIZING EQUATIONS FOR COMPRESSIBLE FLUIDS (VOLUMETRIC GAS FLOW)

ENGLISH FORMULA:

$$C_v = \frac{q_g}{963}\sqrt{\frac{G_g T_1}{\Delta P (p_1 + p_2)}}$$

$$q_g = 963\, C_v \sqrt{\frac{\Delta P (p_1 + p_2)}{G_g T_1}}$$

Where:

- q_g = Volume rate of flow, SCFH
- C_v = Valve flow coefficient
- G_g = Specific gravity, Air = 1.0 @ std. temp.
- T_1 = Upstream temp. (° F + 460)
- ΔP = Pressure drop, psi
- p_1 = Upstream pressure, psia
- p_2 = Downstream pressure, psia

METRIC FORMULA:

$$C_v = \frac{q_g}{298}\sqrt{\frac{G_g T_1}{\Delta P (p_1 + p_2)}}$$

$$q_g = 298\, C_v \sqrt{\frac{\Delta P (p_1 + p_2)}{G_g T_1}}$$

Where:

- q_g = Volume rate of flow, m^3/hr
- C_v = Valve flow coefficient
- G_g = Specific gravity, Air 1.0 @ std. temp.
- T_1 = Upstream temp. °K (° C + 273)
- ΔP = Pressure drop, bar
- p_1 = Upstream pressure, bar absolute
- p_2 = Downstream pressure, bar absolute

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Sample Problem (Solve for C_v):

Where:

q_g = 873,000 SCFH
G_g = 1.0
T_1 = 60° + 460 = 519° R
p_1 = 65 psia
p_2 = 60 psia

Hence:

$$C_v = \frac{q_g}{963}\sqrt{\frac{G_g T_1}{\Delta P (p_1 + p_2)}} =$$

$$\frac{873{,}000}{963}\sqrt{\frac{(1)(519)}{(5)(65+60)}}$$

$$906.5\sqrt{\frac{519}{625}} = (906.5)(0.912) = 827$$

C_v = 825

METRIC FORMULA:

Sample Problem (Solve for C_v):

Where:

q_g = 24,721 m^3/hr
G_g = 1.0
T_1 = 15°C + 273 = 288.5° K
p_1 = 4.48 bar absolute
p_2 = 4.14 bar absolute

Hence:

$$C_v = \frac{q_g}{298}\sqrt{\frac{G_g T_1}{\Delta P (p_1 - p_2)}} =$$

$$\frac{24{,}721}{298}\sqrt{\frac{(1)(288.5)}{(0.34)(4.48+4.14)}} =$$

$$8356\sqrt{\frac{288.5}{2.93}} = (83.56)(9.914) = 828$$

C_v = 825

Note: Conversion of 1 $ft.^3$ x .028317 = m^3 from ANSI Z210.1

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SIMPLIFIED SIZING EQUATIONS FOR COMPRESSIBLE FLUIDS (WEIGHT RATE OF FLOW)

ENGLISH FORMULA:

$$C_v = \frac{w}{3.22 \sqrt{\Delta P (p_1 + p_2) G_g}}$$

$$w = 3.22\, C_v \sqrt{\Delta P (p_1 + p_2) G_g}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, lbs/hr
- ΔP = Pressure drop, psi
- p_1 = Upstream pressure, psia
- p_2 = Downstream pressure, psia
- G_g = Specific gravity, Air = 1.0 @ std. temp.

Sample Problem (Solve for C_v):

Where:

- w = 70,450 lbs/hr
- G_g = 1.0
- T_1 = 60° + 460° = 520° R.
- p_1 = 65 psia
- p_2 = 60 psia

Hence:

$$C_v = \frac{w}{3.22 \sqrt{\Delta P (p_1 + p_2) G_g}} =$$

$$\frac{70{,}450}{3.22 \sqrt{(5)\,(65 + 60)\,(1)}} =$$

$$\frac{70{,}450}{3.22 \sqrt{625}} = \frac{70{,}450}{(3.22)\,(25)} =$$

$$\frac{70{,}450}{80.5} = 875$$

C_v = 875

METRIC FORMULA:

$$C_v = \frac{w}{21.4 \sqrt{\Delta P (p_1 + p_2) G_g}}$$

$$w = 21.4\, C_v \sqrt{\Delta P (p_1 + p_2) G_g}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, kg/hr
- ΔP = Pressure drop, bar
- p_1 = Upstream pressure, bar absolute
- p_2 = Downstream pressure, bar absolute
- G_g = Specific gravity, Air = 1.0 @ std. temp.

Sample Problem (Solve for C_v):

Where:

- w = 32,020 kg/hr
- G_g = 1.0
- T_1 = 15°C + 273° = 288° K
- p_1 = 4.48 bar
- p_2 = 4.14 bar

Hence:

$$C_v = \frac{w}{21.4 \sqrt{\Delta P (p_1 + p_2) G_g}} =$$

$$\frac{32{,}020}{21.4 \sqrt{(0.34)\,(4.48 + 0.14)\,(1.0)}} =$$

$$\frac{32{,}020}{21.4 \sqrt{2.93}} = \frac{32{,}020}{(21.4)\,(1.712)} =$$

$$\frac{32{,}020}{36.64} = 874$$

C_v = 874

SIMPLIFIED SIZING EQUATIONS FOR COMPRESSIBLE FLUIDS (STEAM FLOW)

ENGLISH FORMULA:

$$C_v = \frac{w}{2.1\sqrt{\Delta P\,(p_1 + p_2)}}$$

$$w = 2.1\,C_v\sqrt{\Delta P\,(p_1 + p_2)}$$

Where:

C_v = Valve flow coefficient
w = Weight rate of flow, lb/hr
ΔP = Pressure drop, psi
p_1 = Upstream pressure, psia
p_2 = Downstream pressure, psia

Sample Problem (Solve for C_v):

Where:

w = 90,000 lbs/hr
p_1 = 75 psia
p_2 = 70 psia
SATURATED STEAM

Hence:

$$C_v = \frac{w}{2.1\sqrt{\Delta P\,(p_1 + p_2)}} =$$

$$\frac{90{,}000}{2.1\sqrt{(5)\,(75 + 70)}} =$$

$$\frac{90{,}000}{2.1\sqrt{725}} = \frac{90{,}000}{(2.1)\,(26.9)} = 1590$$

$$C_v = 1590$$

METRIC FORMULA:

$$C_v = \frac{w}{14\sqrt{\Delta P\,(p_1 + p_2)}}$$

$$w = 14\,C_v\sqrt{\Delta P\,(p_1 + p_2)}$$

Where:

C_v = Valve flow coefficient
w = Weight rate of flow, kg/hr
ΔP = Pressure drop, bar
p_1 = Upstream pressure, bar absolute
p_2 = Downstream pressure, bar absolute

Sample Problem (Solve for C_v):

Where:

w = 40,900 kg/hr
p_1 = 5.17 bar absolute
p_2 = 4.83 bar absolute
SATURATED STEAM

Hence:

$$C_v = \frac{w}{14\sqrt{\Delta P\,(p_1 + p_2)}} =$$

$$\frac{40{,}900}{14\sqrt{(0.34)\,(5.17 + 4.83)}} = \frac{40{,}900}{(14)\sqrt{3.4}} =$$

$$\frac{40{,}900}{(14)\,(1.84)} = \frac{40{,}900}{25.8} = 1580$$

$$C_v = 1580$$

SIMPLIFIED SIZING EQUATIONS FOR COMPRESSIBLE FLUIDS (SUPERHEATED STEAM FLOW)

ENGLISH FORMULA:

$$C_v = \frac{w\,(1 + 0.0007\,T_{SH})}{2.1\sqrt{\Delta P\,(p_1 + p_2)}}$$

$$w = \frac{2.1\,C_v\sqrt{\Delta P\,(p_1 + p_2)}}{1 + 0.0007\,T_{SH}}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, lbs/hr
- T_{SH} = Steam superheat, °F
- ΔP = Pressure drop, psi
- p_1 = Upstream pressure, psia
- p_2 = Downstream pressure, psia

Sample Problem (Solve for C_v):

Where:

- w = 90,000 lbs/hr
- T_{SH} = 350°F
- p_1 = 75 psia
- p_2 = 70 psia

Hence:

$$C_v = \frac{w\,(1 + 0.0007\,T_{SH})}{2.1\sqrt{\Delta P\,(p_1 + p_2)}} =$$

$$\frac{90{,}000\,[1 + (0.0007)\,(350°)\,]}{2.1\sqrt{(5)\,(75 + 70)}} =$$

$$\frac{(90{,}000)\,(1 + 0.245)}{(2.1)\sqrt{725}} =$$

$$\frac{(90{,}000)\,(1.245)}{56.54} = \frac{112{,}050}{56.54} = 1980$$

$$C_v = 1980$$

METRIC FORMULA:

$$C_v = \frac{w\,(1 + 0.0007\,T_{SH})}{12.6\sqrt{\Delta P\,(p_1 + p_2)}}$$

$$w = \frac{12.6\,C_v\sqrt{\Delta P\,(p_1 + p_2)}}{1 + 0.0007\,T_{SH}}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, kg/hr
- T_{SH} = Steam superheat, °C
- ΔP = Pressure drop, bar
- p_1 = Upstream pressure, bar absolute
- p_2 = Downstream pressure, bar absolute

Sample Problem (Solve for C_v):

Where:

- w = 40,900
- T_{SH} = 177°C
- p_1 = 5.17 bar
- p_2 = 4.83 bar

Hence:

$$C_v = \frac{w\,(1 + 0.0007\,T_{SH})}{12.6\sqrt{\Delta P\,(p_1 + p_2)}} =$$

$$\frac{(40{,}900)\;[1 + (0.0007)\,(177)\,]}{12.6\sqrt{(0.34)\,(5.17 + 4.83)}} =$$

$$\frac{(40{,}900)\,(1.124)}{(12.6)\,(1.844)} =$$

$$\frac{45{,}970}{23.2} = 1980$$

$$C_v = 1980$$

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UNIVERSAL SIZING EQUATIONS FOR COMPRESSIBLE FLUIDS (VOLUMETRIC FLOW – WHEN SPECIFIC GRAVITY IS KNOWN)

NOTE: See Notes Regarding Universal Sizing Equations below.

ENGLISH FORMULA:

$$C_v = \frac{q_g}{1360\, p_1\, Y}\sqrt{\frac{G_g T_1 Z}{x}}$$

$$q_g = 1360\, C_v\, p_1\, Y \sqrt{\frac{x}{G_g T_1 Z}}$$

Where:

- C_v = Valve flow coefficient
- q_g = Volume rate of flow, SCFH
- p_1 = Upstream pressure, psia
- G_g = Specific gravity, Air = 1.0 @ std. temp.
- T_1 = Temp., °R (°F + 460)
- Z = Compressibility factor
- Y = Expansion factor, $Y = 1 - \frac{x}{3\, x_T}$

METRIC FORMULA:

$$C_v = \frac{q_g}{417\, p_1\, Y}\sqrt{\frac{G_g T_1 Z}{x}}$$

$$q_g = 417\, C_v\, p_1\, Y \sqrt{\frac{x}{G_g T_1 Z}}$$

Where:

- C_v = Valve flow coefficient
- q_g = Volume rate of flow, m^3/hr
- p_1 = Upstream pressure, bar absolute
- G_g = Specific gravity, Air = 1.0 @ std. temp.
- T_1 = Temp., °K (°C + 273)
- Z = Compressibility factor
- Y = Expansion factor, $Y = 1 - \frac{x}{3\, x_T}$

NOTES REGARDING UNIVERSAL SIZING EQUATIONS

The Universal Sizing Equations presented in this section for compressible fluids are applicable to all DeZURIK valves and are based on Instrument Society of America Standard ISA—S39.3.

These equations include a fluid expansion (Y) factor and compressibility (Z) factor. The compressibility (Z) factor can be found in the Reference Information section in the back of the handbook. The fluid expansion (Y) factor is determined by the calculation:

$$Y = 1 - \frac{x}{3\, x_T}$$

Where:

$$x = \frac{\Delta P}{p_1}$$

$$x_T = 0.85\, F_L^2$$

Where:

- ΔP = Pressure differential, psi or bar
- p_1 = Upstream pressure, psia or bar absolute
- x_T = Terminal pressure differential factor (Determined by valve style)
- F_L^2 = Critical flow factor (Determined by valve style)

The fluid expansion (Y) factor ranges from 1.0 to 0.667. If the calculated value is lower than 0.667, then substitute 0.667 for the calculated (Y) factor. Check to be sure that the (x) factor does not exceed (x_T). If by calculation, (x) is found to exceed (x_T) then the (x_T) value should be used to replace (x).

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ENGLISH FORMULA:

Sample Problem (Solve for C_v):

Where:

Air @ 60° F
q_g = 900,000 SCFH
p_1 = 85 psia
ΔP = 10 psi
G_g = 1.0
T_1 = 519° R
Z = 1.0
F_L = 0.6
$x_T = 0.85\, F_L^2 = 0.31$

Hence:

$$x = \frac{\Delta P}{p_1} = \frac{10}{85} = 0.118; \quad x = 0.118$$

$$Y = 1 - \frac{x}{3\,x_T} = 1 - \frac{0.118}{(3)\,(0.31)} =$$

$$1 - \frac{0.118}{0.93} = 1 - 0.127 = 0.873; \quad Y = 0.873.$$

$$C_v = \frac{q_g}{1360\, p_1\, Y}\sqrt{\frac{G_g T_1 Z}{x}} =$$

$$\frac{900{,}000}{(1360)\,(85)\,(0.873)}\sqrt{\frac{(1)\,(520)\,(1)}{0.118}} =$$

$$\frac{900{,}000}{100{,}919}\sqrt{\frac{(520)}{0.118}} =$$

$$8.92\sqrt{4410} = (8.92)\,(66.4) = 592.2$$

C_v = 591

METRIC FORMULA:

Sample Problem (Solve for C_v):

Where:

Air @ 15° C
q_g = 25,485 m^3/hr
p_1 = 5.86 bar absolute
ΔP = 0.69 bar
G_g = 1.0
T_1 = 288.5° K
Z = 1.0
F_L = 0.6
$x_T = 0.85\, F_L^2 = 0.31$

Hence:

$$x = \frac{\Delta P}{p_1} = \frac{0.69}{5.86} = 0.118; \quad x = 0.118$$

$$Y = 1 - \frac{x}{3\,x_T} = 1 - \frac{0.118}{(3)\,(0.31)} =$$

$$1 - \frac{0.118}{0.93} = 1 - 0.127 = 0.873; \quad Y = 0.873$$

$$C_v = \frac{q_g}{417\, p_1\, Y}\sqrt{\frac{G_g T_1 Z}{x}} =$$

$$\frac{25{,}485}{(417)\,(5.86)\,(0.873)}\sqrt{\frac{(1)\,(288)\,(1)}{0.118}} =$$

$$\frac{25{,}485}{2{,}133}\sqrt{\frac{288}{0.118}} =$$

$$(12.02)\,(49.4) = 593$$

C_v = 591

Note: Conversion of 1 ft.^{3} x .028317 = m^3 from ANSI Z210.1

UNIVERSAL SIZING EQUATION FOR COMPRESSIBLE FLUIDS (WEIGHT RATE OF FLOW—WHEN SPECIFIC WEIGHT IS KNOWN)

NOTE: See Notes Regarding Universal Sizing Equations **ALPHA-1 SIZING 6.2.5** Page **1**

ENGLISH FORMULA:

$$C_v = \frac{0.0158\,w}{Y\sqrt{x\,p_1\,\gamma_1}}$$

$$w = 63.3\,C_v\,Y\sqrt{x\,p_1\,\gamma_1}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, lb/hr
- Y = Expansion factor, $Y = 1 - \frac{x}{3\,x_T}$
- x = Pressure drop ratio, $\frac{\Delta P}{p_1}$
- p_1 = Upstream pressure, psia
- γ_1 = Specific weight, lb/ft³

Sample Problem (Solve for C_v):

Where:

- Air @ 60°F.
- w = 72,630 lb/hr
- p_1 = 85 psia
- ΔP = 10 psi
- γ_1 = 0.4666 @ 85 psia
- F_L = 0.6
- $x_T = 0.85\,F_L^2 = 0.31$

Hence:

$$x = \frac{\Delta P}{p_1} = \frac{10}{85} = 0.118; \quad x = 0.118$$

$$Y = 1 - \frac{x}{3\,x_T} = 1 - \frac{0.118}{(3)\,(0.31)} = 1 - \frac{0.118}{0.93}$$

$$= 1 - 0.127 = 0.873$$

$$Y = 0.873$$

$$C_v = \frac{0.0158w}{Y\sqrt{x\,p_1\,\gamma_1}} = \frac{(0.0158)\,(72{,}630)}{0.873\sqrt{(0.118)(85)(0.4666)}}$$

$$= \frac{1148}{0.873\sqrt{4.680}} = \frac{1148}{(0.873)\,(2.16)} =$$

$$\frac{1148}{1.89} = 608$$

$$C_v = 608$$

METRIC FORMULA:

$$C_v = \frac{0.0366\,w}{Y\sqrt{x\,p_1\,\gamma_1}}$$

$$w = 27.3\,C_v\,Y\sqrt{x\,p_1\,\gamma_1}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, kg/hr
- Y = Expansion factor, $Y = 1 - \frac{x}{3\,x_T}$
- x = Pressure drop ratio, $\frac{\Delta P}{p_1}$
- p_1 = Upstream pressure, bar absolute
- γ_1 = Specific weight, kg/m³

Sample Problem (Solve for C_v):

Where:

- Air @ 15°C.
- w = 33,010 kg/hr
- p_1 = 5.86 bar absolute
- ΔP = 0.69 bar
- γ_1 = 7.448 kg/m³ @ 5.86 bar absolute
- F_L = 0.6
- $x_T = 0.85\,F_L^2 = 0.31$

Hence:

$$x = \frac{\Delta P}{p_1} = \frac{0.69}{5.86} = 0.118; \quad x = 0.118$$

$$Y = 1 - \frac{x}{3\,x_T} = 1 - \frac{0.118}{(3)\,(0.31)} = 1 - \frac{0.118}{0.93}$$

$$= 1 - 0.127 = 0.873$$

$$Y = 0.873$$

$$C_v = \frac{0.0366w}{Y\sqrt{x\,p_1\,\gamma_1}} = \frac{(0.0366)\,(33{,}010)}{0.873\sqrt{(0.118)(5.86)(7.448)}}$$

$$= \frac{1208}{0.873\sqrt{5.15}} = \frac{1208}{(0.873)\,(2.27)} =$$

$$\frac{1208}{1.98} = 609$$

$$C_v = 609$$

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UNIVERSAL SIZING EQUATION FOR COMPRESSIBLE FLUIDS (VOLUMETRIC FLOW—WHEN MOLECULAR WEIGHT IS KNOWN)

Note: See Notes Regarding Universal Sizing Equations on **ALPHA-1 SIZING 6.2.5** Page 1

ENGLISH FORMULA:

$$C_v = \frac{q_g}{7320\, p_1 Y} \sqrt{\frac{M T_1 Z}{x}}$$

$$q_g = 7320\, C_v\, p_1 Y \sqrt{\frac{x}{M T_1 Z}}$$

Where:

- C_v = Valve flow coefficient
- q_g = Volume rate of flow, SCFH
- p_1 = Upstream pressure, psia
- Y = Expansion factor, $Y = 1 - \frac{x}{3\, x_T}$
- x = *Pressure drop ratio* $= \frac{\Delta P}{p_1}$
- M = Molecular weight of fluid
- T_1 = Temp of fluid, °R
- Z = Compressibility factor

Sample Problem (Solve for C_v):

Air @ 60°F

- q_g = 900,000 SCFH
- p_1 = 85 psia
- ΔP = 10 psi
- T_1 = 60° + 460° = 520°R
- Z = 1.0
- F_L = 0.6
- x_T = $0.85\, F_L^2 = 0.31$
- M = 28.97

METRIC FORMULA:

$$C_v = \frac{q_g}{2240\, p_1 Y} \sqrt{\frac{M T_1 Z}{x}}$$

$$q_g = 2240\, C_v\, p_1 Y \sqrt{\frac{x}{M T_1 Z}}$$

Where:

- C_v = Valve flow coefficient
- q_g = Volume rate of flow, m^3/hr
- p_1 = Upstream pressure, bar absolute
- Y = Expansion factor, $Y = 1 - \frac{x}{3\, x_T}$
- x = Pressure drop ratio $= \frac{\Delta P}{p_1}$
- M = Molecular weight of fluid
- T_1 = Temp of fluid, °K
- Z = Compressibility factor

Sample Problem (Solve for C_v):

Air @ 15°C

- q_g = 25,640 m^3/hr
- p_1 = 5.86
- ΔP = 0.69
- T_1 = 15°C + 273° = 288°K
- Z = 1.0
- F_L = 0.6
- x_T = $0.85\, F_L^2 = 0.31$
- M = 28.97

Hence:

$$x = \frac{\Delta P}{p_1} = \frac{10}{85} = 0.118; \quad x = 0.118$$

$$Y = 1 - \frac{x}{3\,x_T} = 1 - \frac{0.118}{(3)\,(0.31)} =$$

$$1 - \frac{0.118}{0.93} = 1 - 0.127 = 0.873$$

$$Y = 0.873$$

$$C_v = \frac{q_g}{7320\,p_1\,Y}\sqrt{\frac{MT_1\,Z}{x}} =$$

$$\frac{900{,}000}{(7320)\,(85)\,(0.873)}\sqrt{\frac{(28.97)\,(520)\,(1.0)}{0.118}} =$$

$$\frac{900{,}000}{543{,}180}\sqrt{\frac{15{,}064}{0.118}} =$$

$$1.657\sqrt{127{,}661} = (1.657)\,(357.3) = 592$$

$$C_v = 592$$

METRIC FORMULA:

Hence:

$$x = \frac{\Delta P}{p_1} = \frac{0.69}{5.86} = 0.118; \quad x = 0.118$$

$$Y = 1 - \frac{x}{3\,x_T} = 1 - \frac{0.118}{(3)\,(0.31)} =$$

$$1 - \frac{0.118}{0.93} = 1 - 0.127 = 0.873$$

$$Y = 0.873$$

$$C_v = \frac{q_g}{2240\,p_1\,Y}\sqrt{\frac{MT_1\,Z}{x}} =$$

$$\frac{25{,}640}{(2240)\,(5.86)\,(0.873)}\sqrt{\frac{(28.97)\,(288)\,(1.0)}{0.118}} =$$

$$\frac{25{,}640}{11{,}460}\sqrt{\frac{8340}{0.118}} =$$

$$(2.24)\sqrt{70{,}680} = (2.24)\,(265.9) = 595$$

$$C_v = 595$$

UNIVERSAL SIZING EQUATIONS FOR COMPRESSIBLE FLUIDS (WEIGHT RATE OF FLOW–WHEN MOLECULAR WEIGHT IS KNOWN)

Note: See Notes Regarding Universal Sizing Equations on **ALPHA-1 SIZING 6.2.5** Page 1

ENGLISH FORMULA:

$$C_v = \frac{0.0518w}{p_1 Y}\sqrt{\frac{T_1 Z}{xM}}$$

$$w = 19.3\, C_v\, p_1\, Y \sqrt{\frac{xM}{T_1 Z}}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, lbs/hr
- p_1 = Upstream pressure, psia
- Y = Expansion factor, $Y = 1 - \frac{x}{3\,x_T}$
- x = Pressure drop ratio $= \frac{\Delta P}{p_1}$
- M = Molecular Weight of Fluid
- T_1 = Temperature of Fluid, °R
- Z = Compressibility Factor

Sample Problem (Solve for C_v):

Where:

Air @ 60°F

- w = 72,630 lbs/hr
- p_1 = 85 psia
- ΔP = 10 psi
- T_1 = 60° + 460° = 520°R
- Z = 1.0
- F_L = 0.6
- x_T = $0.85\, F_L^2 = 0.31$
- M = 28.97

METRIC FORMULA:

$$C_v = \frac{0.0105w}{p_1 Y}\sqrt{\frac{T_1 Z}{xM}}$$

$$w = 94.8\, C_v\, p_1\, Y \sqrt{\frac{xM}{T_1 Z}}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, kg/hr
- p_1 = Upstream pressure, bar absolute
- Y = Expansion factor, $Y = 1 - \frac{x}{3\,x_T}$
- x = Pressure drop ratio $= \frac{\Delta P}{p_1}$
- M = Molecular Weight of Fluid
- T_1 = Temperature of Fluid, °K
- Z = Compressibility Factor

Sample Problem (Solve for C_v):

Where:

Air @ 15°C

- w = 33,010 kg/hr
- p_1 = 5.86 bar absolute
- ΔP = 0.69 bar
- T_1 = 15° + 273 = 288°K
- Z = 1.0
- F_L = 0.6
- x_T = $0.85\, F_L^2 = 0.31$
- M = 28.97

Hence:

$$x = \frac{\Delta P}{p_1} = \frac{10}{85} = 0.118; \quad x = 0.118$$

$$Y = 1 - \frac{x}{3\,x_T} = 1 - \frac{0.118}{(3)\,(0.31)} =$$

$$1 - \frac{0.118}{0.93} = 1 - 0.127 = 0.873$$

$$Y = 0.873$$

$$C_v = \frac{0.0518\,w}{P_1\,Y}\sqrt{\frac{T_1\,Z}{x\,M}} =$$

$$\frac{(0.0518)\,(72{,}630)}{(85)\,(0.873)}\sqrt{\frac{(520)\,(1.0)}{(0.118)\,(28.97)}} =$$

$$\frac{3762}{74.2}\sqrt{\frac{520}{3.418}} =$$

$$50.7\sqrt{152} = (50.7)\,(12.3) = 625$$

$$C_v = 625$$

METRIC FORMULA:

Hence:

$$x = \frac{\Delta P}{p_1} = \frac{0.69}{5.86} = 0.118; \quad x = 0.118$$

$$Y = 1 - \frac{x}{3\,x_T} = 1 - \frac{0.118}{(3)\,(0.31)} =$$

$$1 - \frac{0.118}{0.93} = 1 - 0.127 = 0.873$$

$$Y = 0.873$$

$$C_v = \frac{0.0105\,w}{P_1\,Y}\sqrt{\frac{T_1\,Z}{x\,M}} =$$

$$\frac{(0.0105)\,(33{,}010)}{(5.86)\,(0.873)}\sqrt{\frac{(288)\,(1.0)}{(0.118)\,(28.97)}} =$$

$$\frac{346.6}{5.12}\sqrt{\frac{288}{3.42}} =$$

$$67.7\sqrt{84.2} = (67.7)\,(9.18) = 621$$

$$C_v = 621$$

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COMPRESSIBLE FLUIDS SONIC VELOCITY EQUATIONS

As in the case of liquids, there is a maximum rate of flow for compressible fluids which will result in choked flow. For compressible fluids this maximum rate of flow occurs at sonic velocity. Sonic velocity may be reached when the ratio of pressure differential to the upstream absolute pressure $\frac{\Delta P}{p_1}$ exceeds the terminal pressure drop ratio factor (x_T) for the valve style selected.

Sonic velocity may produce shock waves, pipeline vibration, and considerable noise. Ultimately, sonic velocity will cause valve and/or pipeline damage and should therefore be avoided.

Sonic velocity is a function of both the fluid characteristic and the downstream pressure. The following equation can be used to determine the minimum valve outlet diameter required to avoid sonic velocity. To avoid sonic velocity the outlet diameter (d) must be greater than the calculated value.

ENGLISH FORMULA (FOR GASES):

For Volume:

$$d > 0.0024 \sqrt{\frac{q_g}{p_2}\left(\frac{T_1 M}{k}\right)^{1/2}}$$

For Weight:

$$d > 0.047 \sqrt{\frac{w}{p_2}\left(\frac{T_1}{Mk}\right)^{1/2}}$$

Where:

- d = Valve outlet diameter, inches
- q_g = Volume rate of flow, SCFH
- p_2 = Downstream pressure, psia
- T_1 = Upstream temperature, °R
- M = Molecular weight
- k = Gas specific heat ratio
  See Specific Heat of Gases Chart (Air = 1.40) on page 80-34 of the Reference Information section.
- w = Weight rate of flow, lbs/hr

ENGLISH FORMULA (FOR STEAM):

$$d > 0.12 \sqrt{\frac{w}{p_2}}$$

Where:

- d = Valve outlet diameter, inches
- w = Weight rate of flow, lbs/hr
- p_2 = Downstream pressure, psia

METRIC FORMULA (FOR GASES):

For Volume:

$$d > 0.110 \sqrt{\frac{q_g}{p_2}\left(\frac{T_1 M}{k}\right)^{1/2}}$$

For Weight:

$$d > 0.539 \sqrt{\frac{w}{p_2}\left(\frac{T_1}{Mk}\right)^{1/2}}$$

Where:

- d = Valve outlet diameter, mm
- q_g = Volume rate of flow, m³/hr
- p_2 = Downstream pressure, bar absolute
- T_1 = Upstream temperature, °K
- M = Molecular weight
- k = Gas specific heat ratio
  See Specific Heat of Gases Chart (Air = 1.40) on page 80-34 of the Reference Information section.
- w = Weight rate of flow, kg/hr

METRIC FORMULA (FOR STEAM):

$$d > 1.188 \sqrt{\frac{w}{p_2}}$$

Where:

- d = Valve outlet diameter, mm
- w = Weight rate of flow, kg/hr
- p_2 = Downstream pressure, bar absolute

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SIZING EQUATIONS FOR MIXED PHASE FLUIDS (LIQUID/VAPOR)

Sizing valves for mixed phase fluids is similar to sizing for liquid subcritical flow (by weight). The variation is that the specific weight factor must be modified to adjust for the percentage of each fluid in the process flow.

ENGLISH FORMULA:

$$C_v = \frac{w}{63.3\sqrt{\Delta P \gamma_e}}$$

$$w = 63.3\ C_v \sqrt{\Delta P \gamma_e}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, lbs/hr
- ΔP = Pressure drop, psi
- γ_e = Effective specific weight of mixture, lbs/ft³

$$\gamma_e = \frac{w}{V_{ge} + V_f}$$

Where:

- w = Weight rate of flow, lbs/hr
- V_{ge} = Effective volume rate of flow of gas, CFH
- V_f = Volume rate of flow of liquid, CFH

$$V_{ge} = \frac{10.7\ T_1\ w_g}{M\ p_1\ Y^2}$$

Where:

- T_1 = Upstream temperature, °R
- w_g = Weight rate of flow of the gas phase, lbs/hr
- M = Molecular weight
- p_1 = Upstream pressure, psia
- Y = Expansion factor

$$V_f = \frac{w_f}{\gamma_f}$$

Where:

- w_f = Weight rate of flow of liquid, lbs/hr
- γ_f = Specific weight, lbs/ft³

METRIC FORMULA:

$$C_v = \frac{w}{27.3\sqrt{\Delta P \gamma_e}}$$

$$w = 27.3\ C_v \sqrt{\Delta P \gamma_e}$$

Where:

- C_v = Valve flow coefficient
- w = Weight rate of flow, kg/hr
- ΔP = Pressure drop, bar
- γ_e = Effective specific weight of mixture, kg/m³

$$\gamma_e = \frac{w}{V_{ge} + V_f}$$

Where:

- w = Weight rate of flow, kg/hr
- V_{ge} = Effective volume rate of flow of gas, m³/hr
- V_f = Volume rate of flow of liquid, m³/hr

$$V_{ge} = \frac{0.0836\ T_1\ w_g}{M\ p_1\ Y^2}$$

Where:

- T_1 = Upstream temperature, °K
- w_g = Weight rate of flow, gas, kg/hr
- M = Molecular weight
- p_1 = Upstream pressure, bar absolute
- Y = Expansion factor

$$V = \frac{w_f}{\gamma_f}$$

Where:

- w_f = Weight rate of flow of liquid, kg/hr
- γ_f = Specific weight, kg/m³

Sample Problem (Solve for C_v):

Where:

w_g = 7800 lbs/hr
w_f = 350,000 lbs/hr
p_1 = 140 psia
ΔP = 25 psi
T_1 = 60°F
F_L = 0.6 (determined by valve style)

Hence:

(Step 1 — Solve for x_T)

$$x_T = 0.85\,F_L^2 = 0.31$$

(Step 2 — Solve for x)

$$x = \frac{\Delta P}{p_1} = \frac{25}{140} = 0.179$$

(Step 3 — Solve for Y)

$$Y = 1 - \frac{x}{3x_T} = 1 - \frac{0.179}{(3)(0.31)} =$$

$$1 - \frac{0.179}{0.93} = 1 - 0.192 = 0.808$$

(Step 4 — Solve for V_{ge})

$$V_{ge} = \frac{10.7\,T_1\,w_g}{M\,p_1\,Y^2} =$$

$$\frac{(10.7)(520)(7800)}{(28.97)(140)(0.808)^2} =$$

$$\frac{43{,}399{,}200}{(4056)(0.653)} = \frac{43{,}399{,}200}{2649} = 16{,}380 \text{ CFH}$$

(Step 5 — Solve for V_f)

$$V_f = \frac{w_f}{\gamma_f} = \frac{350{,}000}{62.4} = 5610 \text{ CFH}$$

(Step 6 — Solve for Total Volume Effective)

$V_e = V_{ge} + V_f = 16{,}380 + 5609 =$
21,990 CFH

(Step 7 — Solve for w)

$w = w_g + w_f = 7800 + 350{,}000 =$
357,800 lbs/hr

METRIC FORMULA:

Sample Problem (Solve for C_v):

Where:

w_g = 3550 kg/hr
w_f = 159,000 kg/hr
p_1 = 9.66 bar absolute
ΔP = 1.72 bar
T_1 = 15°C
F_L = 0.6 (determined by valve style)

Hence:

(Step 1 — Solve for x_T)

$$x_T = 0.85\,F_L^2 = 0.31$$

(Step 2 — Solve for x)

$$x = \frac{\Delta P}{p_1} = \frac{1.72}{9.66} = 0.178$$

(Step 3 — Solve for Y)

$$Y = 1 - \frac{x}{3x_T} = 1 - \frac{0.178}{(3)(0.31)} =$$

$$1 - \frac{0.178}{0.93} = 1 - 0.191 = 0.809$$

(Step 4 — Solve for V_{ge})

$$V_{ge} = \frac{0.084\,T_1\,w_g}{M\,p_1\,Y^2} =$$

$$\frac{(0.084)(288)(3550)}{(28.97)(9.66)(0.809)^2} =$$

$$\frac{85{,}880}{(279.9)(0.654)} = \frac{85{,}880}{183.2} = 469 \text{ m}^3\text{/hr}$$

(Step 5 — Solve for V_f)

$$V_f = \frac{w_f}{\gamma_f} = \frac{159{,}000}{996} = 159.7 \text{ m}^3\text{/hr}$$

(Step 6 — Solve for Total Volume Effective)

$V_e = V_{ge} + V_f = 469 + 159.7 =$
628.7 m³/hr

(Step 7 — Solve for w)

$w = w_g + w_f = 3550 + 159{,}000 =$
162,550 kg/hr

(Step 8 — Solve for γ_e)

$$\gamma_e = \frac{w}{V_e} = \frac{357{,}800}{21{,}990} =$$

16.30 lbs/ft^3

(Step 9 — Solve for C_v)

$$C_v = \frac{w}{63.3 \sqrt{\Delta P \gamma_e}} =$$

$$\frac{357{,}800}{63.3 \sqrt{(25)(16.3)}} =$$

$$\frac{357{,}800}{63.3 \sqrt{407}} = \frac{357{,}800}{(63.3)(20.17)} =$$

$$\frac{357{,}800}{1277} = 280$$

$C_v = 280$

METRIC FORMULA:

(Step 8 — Solve for γ_e)

$$\gamma_e = \frac{w}{V_e} = \frac{162{,}550}{628.7} =$$

258.5 kg/m^3

(Step 9 — Solve for C_v)

$$C_v = \frac{w}{27.3 \sqrt{\Delta P \gamma_e}} =$$

$$\frac{162{,}550}{27.3 \sqrt{(1.72)(258.5)}} =$$

$$\frac{162{,}550}{27.3 \sqrt{445}} = \frac{162{,}550}{(27.3)(21.1)} =$$

$$\frac{162{,}550}{576} = 282$$

$C_v = 282$

PIPE REDUCER EFFECTS

The installation of pipe reducers or expanders in a pipeline create added flow resistance in a pipeline. When installing a control valve between reducers, it is general practice to consider the total effect of the combined parts in calculating the required valve flow coefficient (C_v).

In valve sizing equations, the effect of adjacent reducers on liquid or gas flow is the factor F_p. The F_p factor is a function of the valve C_v and the pipe diameter and can be calculated for any given valve and pipe size combination. F_p factors are dimensionless. Once the F_p has been calculated it is multiplied by the selected valve C_v to determine the effective C_v of the combined valve and adjacent reducers.

F_p is determined by the equation:

ENGLISH FORMULA:

$$F_p = \frac{1}{\sqrt{1 + \frac{[\Sigma K] C_d^2}{890}}}$$

METRIC FORMULA:

$$F_p = \frac{1}{\sqrt{1 + \frac{[\Sigma K] C_d^2}{0.00214}}}$$

Where:

F_p = Piping effects correction factor

$$C_d = \frac{C_v}{d^2}$$

Where:

C_v = Valve flow coefficient

d = Valve size expressed in inches (mm in the case of metric)

ΣK = The algebraic sum of the velocity head coefficient of the reducers and/or expanders ($\Sigma K = K_1 + K_2 + K_{B1} - K_{B2}$)

Where:

K_1 = Coefficient for upstream pipe reducer (See reference information)

K_2 = Coefficient for downstream pipe reducer (See reference information)

K_{B1} = Inlet Bernoulli Coefficient

K_{B2} = Outlet Bernoulli Coefficient

(Note: Where the inlet and outlet fittings are identical, K_{B1} and K_{B2} are eliminated from the equation.)

When the inlet and outlet fittings are of different sizes K_{B1} and K_{B2} are calculated:

$$K_{B1} = 1 - \left(\frac{d}{D}\right)^4$$

$$K_{B2} = 1 - \left(\frac{d}{D}\right)^4$$

Where:

d = Valve size in inches (mm in the case of metric)

D = Pipe size in inches (mm in the case of metric)

Note: If charted values for K_1 and K_2 are not available, then they may be calculated:

$$K_1 + K_2 = 1.5 \left(1 - \frac{d^2}{D^2}\right)^2$$

(Where the inlet and outlet reducers are the same size.)

$$K_1 = 0.5 \left(1 - \frac{d^2}{D^2}\right)^2 \quad \text{(Inlet reducer only)}$$

$$K_2 = 1.0 \left(1 - \frac{d^2}{D^2}\right)^2 \quad \text{(Outlet reducer only)}$$

Sample Problem (Solve for effective C_v):

Where:

q_f = 4340 U.S. gpm
ΔP = 15 psi
G_f = 0.96
Fluid = Water
Pipe Diameter = 8 inches
Valve Size = 6 inches (C_v = 1310)

(Step 1 — Solve for ΣK)

$$\Sigma K = 1.5\left(1-\frac{d^2}{D^2}\right)^2 = 1.5\left(1-\frac{6^2}{8^2}\right)^2 =$$

$$1.5\left(1-\frac{36}{64}\right)^2 = 1.5\,(0.432)^2 =$$

$$(1.5)\,(0.191) = 0.287$$

$$\Sigma K = 0.287$$

(Step 2 — Solve for C_d)

$$C_d = \frac{C_v}{d^2} = \frac{1310}{6^2} = \frac{1310}{36} = 36.4$$

$$C_d = 36.4$$

(Step 3 — Solve For F_p)

$$F_p = \frac{1}{\sqrt{1+\dfrac{[\Sigma K]C_d{}^2}{890}}} =$$

$$\frac{1}{\sqrt{1+\dfrac{(0.287)\,(1324)}{890}}} =$$

$$\frac{1}{\sqrt{1+0.427}} = \frac{1}{\sqrt{1.427}} =$$

$$\frac{1}{1.195} = 0.84$$

$$F_p = 0.84$$

(Step 4 — Determine effective C_v)

Effective C_v = (Valve C_v) (F_p)
Effective C_v = (1310) (0.84)
Effective C_v = 1100

METRIC FORMULA:

Sample Problem (Solve for effective C_v):

Where:

q_f = 986 m^3/hr
ΔP = 1.03 bar
G_f = 0.96
Fluid = Water
Pipe Diameter = 200 mm
Valve Size = 150 mm (C_v = 1310)

(Step 1 — Solve for ΣK)

$$\Sigma K = 1.5\left(1-\frac{d^2}{D^2}\right)^2 = 1.5\left(1-\frac{6^2}{8^2}\right)^2 =$$

$$1.5\left(1-\frac{36}{64}\right)^2 = 1.5\,(0.432)^2 =$$

$$(1.5)\,(0.191) = 0.287$$

$$\Sigma K = 0.287$$

(Step 2 — Solve for C_d)

$$C_d = \frac{C_v}{d^2} = \frac{1310}{22{,}500} = 0.058$$

$$C_d = 0.058$$

(Step 3 — Solve for F_p)

$$F_p = \frac{1}{\sqrt{1+\dfrac{[\Sigma K]C_d{}^2}{0.00214}}} =$$

$$\frac{1}{\sqrt{1+\dfrac{(0.287)\,(0.00339)}{0.00214}}} =$$

$$\frac{1}{\sqrt{1+0.455}} = \frac{1}{\sqrt{1.455}} =$$

$$\frac{1}{1.206} = 0.83$$

$$F_p = 0.83$$

(Step 4 — Determine effective C_v)

Effective C_v = (Valve C_v) (F_p)
Effective C_v = (1310) (0.83)
Effective C_v = 1087

NOISE

High rates of fluid flow through valves and pipe fittings will produce noise. The source of this noise may be aerodynamic noise in the case of gases or steam, cavitation in the case of liquids and/or mechanical vibration of the valve components.

Aerodynamic noise resulting from high velocity gas or steam flow is usually of greater intensity than noise produced by other sources. It is caused by turbulence due to flow obstruction, expansion in the pipe size, and sudden turns in the flowing stream. All three of these conditions are found in typical control valve applications.

Cavitation in liquid flow processes will produce noise at the discharge port of a control valve and in the immediate downstream piping. Pressure differentials which equal or exceed the value necessary to produce choked flow will result in noise generation.

Mechanical noise is produced by fluid flow impingement or pressure fluctuations which cause vibration of the mechanical components in the valve. Noise from this source should be avoided at all costs as it will lead to rapid valve failure.

Several steps can be taken to avoid or reduce noise. First, select a valve having rugged construction to avoid the problems of mechanical noise and potential costly failure. Secondly, size and select a large enough valve to prevent sonic or choked flow conditions. Reduce system velocities to prevent severe noise producing shock waves. When system noises cannot be avoided in any of these ways, sound attenuating devices may have to be used. Sound can be attenuated by using heavier downstream piping, special insulation, or a more sophisticated type of muffled sound diffuser.

NOMENCLATURE

- a — Area of orifice or valve opening, in.^{2}
- C — Coefficient of discharge, dimensionless. Includes effect of jet contraction and Reynolds Number, Mach Number (gas at high velocities), turbulence.
- C_d — Relative capacity (at rated C_v) $C_d = C_v d^2$.
- c_p — Specific heat at constant pressure, Btu/lb.°F.
- c_v — Specific heat at constant volume, Btu/lb.°F.
- C_v — Valve flow coefficient.
- d — Valve inlet diameter, inches.
- D — Pipe diameter, inches.
- F — Velocity of approach factor $= \dfrac{1}{\sqrt{1-m^2}}$
- F_c — Percent consistency correction factor.
- F_d — Experimentally determined factor relating valve C_v to an equivalent diameter for Reynolds Number.
- F_F — The liquid critical pressure ratio factor, $F_F = p_{vc}/p_v$.
- F_L — Pressure loss factor, to convert valve coefficient to choked flow conditions when capacity is governed by the apparent pressure at the valve vena contracta. When the valve is not choked.

  $$F_L = \sqrt{(p_1-p_2)/(p_1-p_{vc})}$$
- $F_L{}^2$ — Critical flow factor.
- F_P — Correction factor for piping around valve (e.g. reducers) $F_P C_v$ = effective C_v for valve/fitting assembly.
- $(F_L)_P$ — Pressure loss factor F_L modified for valve/fitting assembly.
- F_{LP} — Combined pressure loss and piping geometry factors for valve/fitting assembly.
- F_R — Correction factor for Reynolds Number, where $F_R C_v$ = effective C_v.
- g — Acceleration due to gravity (taken as 32.17 ft./s^2).
- G_f — Specific gravity of liquids relative to water at 60°F.
- G_g — Specific gravity of gas relative to air with both at standard temperature and pressure.
- h — Effective differential head, ft. of fluid.
- ΣK — Sum total of effective velocity head coefficients where $K(V^2/2g) = h$.
- K_B — Bernoulli coefficient $= 1-(d/D)^4$
- K_c — Cavitation Index.
- K_1 — Resistance coefficient for inlet fitting.
- K_2 — Resistance coefficient for outlet fitting.
- k — Ratio of specific heats of gas $= c_p/c_v$, dimensionless.
- M — Molecular weight.
- m — Ratio of areas.
- p — Absolute static pressure, psia.
- p_v — Vapor pressure, psia.
- P — Static gauge pressure, psig
- q — Volume rate of flow, q_f = gpm, q_g = SCFH.
- R — Gas constant = 144 pv/T.
- Re — Reynolds Number.
- T — Absolute temperature, degrees Rankine.
- U — Average velocity, fps.
- v — Specific volume $(1/\gamma)$, ft^3/lb.
- V — Volume flow rate, ft^3/hr.
- w — Weight rate of flow, lb/hr.
- x — Ratio of differential pressure to absolute inlet static pressure, $x = (p_1-p_2)/p_1$.
- x_T — Terminal or ultimate value of x, used to establish expansion factor, Y.
- x_{TP} — Value of x_T for valve/fitting assembly.
- Y — Expansion factor. Ratio of flow coefficient for a gas to that for a liquid at the same Reynolds Number (includes radial as well as longitudinal expansion effects).
- Z — Compressibility factor = 144 pv/RT.
- γ (gamma) — Specific weight (1/v), lb/ft^3.
- Δ (delta) — Difference, (e.g., $\Delta P = p_1-p_2$).
- μ (mu) — Viscosity, centipoise.
- Θ (theta) — Index for viscosity correction.

SUBSCRIPTS

- 1 — Upstream
- 2 — Downstream
- e — Effective value
- f — Liquid
- g — Gas
- t — Theoretical
- T — Terminal or ultimate value
- u — Uncorrected value
- vc — Vena contracta (point of minimum jet stream area)