VSSTR-9/05

VALVE SIZING & SELECTION TECHNICAL REFERENCE

TABLE OF CONTENTS

Introduction
Valve Flow Terminology
The Sizing Process
- Operating Conditions
- Fluid Properties
- Rangeability
- C_v and Flow Sizing Formulas
  - C_V Formulas for Liquid Flow
  - C_V Formulas for Vapor Flow
  - C_V Formulas for Two Phase Flow
- Flow Velocity Formulas
  - Flow Velocity for Liquid Flow
  - Flow Velocity for Vapor Flow
- Nomenclature
- Conversion to Cg and Cs

Seat Leakage
Actuator Sizing
- ΔP Tables

Application Guide for Cavitation, Flashing and Compressible Flow Services
Liquid Flow
- Cavitation
  - Cavitation Definition
  - Cavitation Countermeasures
  - Application of Warren Trims in Cavitation Service
    - Cavitation Avoidance
    - Cavitation Tolerant
    - Cavitation Containment
    - Cavitation Prevention
  - The Cavitation Phenomena
  - Fluid and Pressure Profiles
  - Choked Flow and Incipient Cavitation
  - Cavitation Damage

Flashing
Flashing Definition
Flashing Countermeasures
Body Material
Trim Selection
Application of Warren Valves in Flashing Service
Body Material:
Trim Selection
The Flashing Phenomena
Liquid Flow Velocity - Body Material
Compressible Flow Noise
Compressible Flow Noise Discussion
Compressible Flow Noise Countermeasures
Application of Warren Trims in Compressible Flow Applications
Standard Trims:
Multiple Orifice Trims
Compressible Flow Velocity Limits:
Two Stage Trims and Backpressure Orifices:
The Compressible Flow Noise Phenomena

TABLES

Trim Rangeability Table 1
Fluid Properties Table 2
F_L Factors Table 3
Flanged Body Inlet and Outlet Diameters Table 4
Allowable Seat Leakage Classes Table 5
Liquid Flow Velocity Limits Table 6

FIGURES

Cavitation

INTRODUCTION

A Control Valve performs a special task, controlling the flow of fluids so a process variable such as fluid pressure, fluid level or temperature can be controlled. In addition to controlling the flow, a control valve may be used to shut off flow. A control valve may be defined as a valve with a powered actuator that responds to an external signal. The signal usually comes from a controller. The controller and valve together form a basic control loop. The control valve is seldom full open or closed but in an intermediate position controlling the flow of fluid through the valve. In this dynamic service condition, the valve must withstand the erosive effects of the flowing fluid while maintaining an accurate position to maintain the process variable.

A Control Valve will perform these tasks satisfactorily if it is sized correctly for the flowing and shut-off conditions. The valve sizing process determines the required $\mathbf{C_V}$, the required $\mathbf{F_L}$, **Flow Velocities**, **Flow Noise** and the appropriate **Actuator Size**

VALVE FLOW TERMINOLOGY

$\mathbf{C_V}$: The Flow Coefficient, C_V, is a dimensionless value that relates to a valve's flow capacity. Its most basic form is $C_V = \frac{Q}{\sqrt{\Delta P}}$ where Q=Flow rate and ΔP=pressure drop across the valve. See pages 6, 7 & 9 for the equations for liquid, gas, steam and two phase flow. The C_V value increases if the flow rate increases or if the ΔP decreases. A sizing application will have a Required C_V while a valve will have a Rated C_V. The valve's rated C_V must equal or exceed the required C_V.

$\mathbf{F_L}$: The F_L, Liquid Pressure Recovery Coefficient, is a dimensionless constant used to calculate the pressure drop when the valve's liquid flow is choked. The F_L is the square root of the ratio of valve pressure drop to the pressure drop from the inlet pressure to the pressure of the vena contracta. See page 7 for the F_L equation. The F_L factor is an indication of the valve's vena contracta pressure relative to the outlet pressure. If the F_L were 1.0, the vena contracta pressure would be the same as the valve's outlet pressure and there would be no pressure recovery. As the F_L value becomes smaller the vena contracta pressure becomes increasingly lower than the valve's outlet pressure and the valve is more likely to cavitate. A valve's Rated F_L varies with the valve and trim style, it may vary from .99 for a special multiple stage trim to .30 for a ball valve.

Rated $\mathbf{F_L}$: The Rated F_L is the actual F_L value for a particular valve and trim style.

Required $\mathbf{F_L}$: The Required F_L is the F_L value calculated for a particular service condition. It indicates the required F_L needed to avoid choked flow. If the Rated F_L is less than the Required F_L, the liquid flow will be choked with cavitation.

Vena Contracta: The vena contracta is where the jet of flowing fluid is the smallest immediately downstream of the trim's throttle point. At the vena contracta, the fluid's velocity is the highest and the fluid's pressure is the lowest.

Vapor Pressure: A fluid's vapor pressure is the pressure where the fluid will change from a liquid to a vapor. The liquid will change to a vapor below the vapor pressure and a vapor will change to a liquid above the vapor pressure. The vapor pressure increases as the temperature increases.

Choked Flow: Liquid flow will become choked when the trim's vena contracta is filled with vapor from cavitation or flashing. Vapor flow also will become choked when the flow velocity at the vena contracta reaches sonic. A choked flow rate is limited; a further decrease of the outlet pressure does not increase flow. Choked flow is also called critical flow.

Cavitation: Cavitation is a two stage phenomena with liquid flow. The first stage is the formation of vapor bubbles in the liquid as the fluid passes through the trim and the pressure is reduced below the fluid's vapor pressure. The second stage is the collapse of the vapor bubbles as the fluid passes the vena contracta and the pressure recovers and increases above the vapor pressure. The collapsing bubbles are very destructive when they contact metal parts and the bubble collapse may produce high noise levels.

Flashing: Flashing is similar to cavitation except the vapor bubbles do not collapse, as the downstream pressure remains less than the vapor pressure. The flow will remain a mixture of vapor and liquid.

Laminar Flow: Most fluid flow is turbulent. However, when the liquid flow velocity is very slow or the fluid is very viscous or both, the flow may become laminar. When the flow becomes laminar, the required C_V is larger than for turbulent flow with similar conditions. The ISA sizing formulas adjust the C_V when laminar flow exists.

THE SIZING PROCESS

The first sizing step is to determine the required C_V value for the application. Next determine if there are unusual conditions that may affect valve selection such as cavitation, flashing, high flow velocities or high flow noise. The valve sizing process will determine the proper valve size, valve trim size , valve trim style and actuator size. Warren's Valve Sizing Program will accurately calculate the C_V, flow velocity and flow noise. The program will also show messages when unusual conditions occur such as cavitation, flashing, high velocity or high noise. The results from Warren's Valve Sizing Program are only one element of the valve selection process. Knowledge and judgment are also required. This overview will give the user some of the sizing basics.

The liquid, gas and steam C_V calculation methods, in this manual, are in accordance with ISA S75.01 and the gas and steam flow noise calculations are in accordance with ISA S75.17. These two ISA Standards are in agreement with IEC-534. These standards have worldwide acceptance as the state of the art in C_V and Flow Noise determination.

Operating Conditions

The most important part of Valve Sizing is obtaining the correct flowing conditions. If they are incorrect or incomplete, the sizing process will be faulty. There are two common problems. First is having a very conservative condition that overstates the C_V and provide a valve less than ½ open at maximum required flow. The second is stating only the maximum flow condition that has minimum pressure drops and not stating the minimum flow conditions with high-pressure drops that often induce cavitation or have very high rangeability requirements.

Fluid Properties
Table 2 lists many fluid properties needed for valve sizing. These fluid properties are in Warren's Valve Sizing Program's database and do not need manual entry.

Rangeability: Rangeability is the ratio of maximum to minimum controllable C_V. This is also sometimes called C_V Ratio or Turndown. The maximum flow for Warren Controls' valves is at maximum travel. The minimum controllable C_V is where the Flow Characteristic (C_V vs. Travel) initially deviates or where the valve trim cannot maintain a consistent flow rate. This is partially a function actuator stiffness as well as valve "stiction". The Trim's rangeability is not always the useable range as seat erosion may be a governing factor with respect to erosive fluids and high drops in the near-closed position. A valve with a significant pressure drop should not be used to throttle near the seat for extended periods of time.

The rangeability values, listed in Table 1, apply to the rated C_V, not the required C_V. For example, an application may require a maximum C_V of 170. A 4" Equal Percentage Trim may be selected that has a maximum CV of 195. Using the rangeability value for this trim, the minimum C_V is 195/100=19.5, not 170/100=17.

Valve applications subject to pressures from nature, such as gas and oil production, are usually sized for full flow at about 80% open as the pressure may be unknown when the valve is sized and the pressure may vary with time.

Those valve applications with fairly consistent inlet pressures, such as process control and power applications are usually sized at full travel. The valve specifier usually includes a fair margin of safety in the stated sizing conditions. If the valve supplier includes additional safety, such as full flow at 80% open, the valve may be at full flow at less than ½ travel giving poor performance.

TRIM RANGEABILITY Table 1

Valve Trim	Rangeability
Globe Valves.	
Equal Percent – All Equal %, Full Port Trim styles	50:1
Linear Flow and Reduced Port Trim styles	30:1
Rotary Valves	
Eccentric Plug Segmented Ball – Modified Linear	100:1
Concentric Plug, Segmented V-Ball – Equal %	200:1

C_V AND FLOW SIZING FORMULAS

The following formulas are for information and for understanding the sizing process. Warren's Valve Sizing Program is recommended for the calculation process. Flow noise equations are not listed below as they are highly complex and should only be made on our verified computer program. Formulas are shown both for calculation the C_V when the flow rate is known and for calculating the flow when the C_V is known.

C_V Formulas for Liquid Flow

$$\text{Required}\ F_L = \sqrt{\frac{P_1 - P_2}{P_1 - P_V F_F}} \qquad F_F = 0.96 - 0.28\sqrt{\frac{P_V}{P_C}}$$

If the Rated F_L is larger than the Required F_L:

$$C_V = \frac{Q}{F_P\ F_R}\sqrt{\frac{G_f}{P_1 - P_2}} \quad \text{or} \quad Q = C_V\ F_P\ F_R\sqrt{\frac{P_1 - P_2}{G_f}}$$

When the Rated F_L is smaller than the Required F_L, choked flow exists in the vena contracta limiting the flow.

If the Rated F_L is smaller than the Required F_L:

$$C_V = \frac{Q}{F_P\ F_L(\text{Rated})}\sqrt{\frac{G_f}{P_1 - F_F\ P_V}} \quad \text{or} \quad Q = C_V\ F_P\ F_L(\text{Rated})\sqrt{\frac{P_1 - F_F\ P_V}{G_f}}$$

$$\Delta P \text{ for choked flow} = F_L^2\left(P_1 - F_F P_V\right) = \text{psi}$$

$$\Delta P \text{ for incipient cavitation} = K_C\left(P_1 - P_V\right) = \text{psi}$$

(See discussion in "Choked Flow and Incipient Cavitation" section)

C_V Formulas for Vapor Flow

$$x = \frac{P_1 - P_2}{P_1} \qquad \text{Limit} \quad x \le x_T$$

$$F_K = \frac{k}{14} \qquad Y = 1 - \frac{x}{3\ F_K\ x_T}$$

If the flow rate is in volumetric units, SCFM, then

$$C_V = \frac{Q}{1360\ F_P\ P_1\ Y}\sqrt{\frac{G_g\ T\ Z}{x}} \quad \text{or} \quad Q = 1360\ C_V\ F_P\ P_1\ Y\sqrt{\frac{x}{G_g\ T\ Z}}$$

If the flow rate is in mass flow units, Lb./Hr., then

$$C_V = \frac{W}{63.3\ F_P\ Y\ \sqrt{x\ P_1\ \lambda_1}} \quad \text{or} \quad W = 63.3\ C_V\ F_P\ Y\ \sqrt{x\ P_1\ \lambda_1}$$

To convert SCFH to Lb./Hr.: $W = 0.0764\ Q\ G_g$ = Lb./Hr.

C_V Formulas for Two Phase Flow

Pressure Drop for liquid phase= $\Delta P_f = F_L^2 \left(P_1 - F_F\ P_V\right)$

Pressure Drop for vapor phase = $\Delta\ P_g = F_K\ x_T\ P_1$

f_f = weight fraction of total flow as liquid

f_g = weight fraction of total flow as vapor

$$C_V = \frac{W}{63.3\ F_P}\sqrt{\frac{f_f}{\Delta P_F\ \lambda_{1f}} + \frac{f_g}{\Delta P_g\ \lambda_{1g}\ Y^2}}$$

FLOW VELOCITY FORMULAS

Flow Velocity for Liquid Flow

Liquid Flow Velocity through the Valve: $V_V = \dfrac{0.408\ Q}{D_b^2} =$ Ft./Sec.

Liquid Flow Velocity through the Pipe: $V_P = \dfrac{0.408\ Q}{D_P^2} =$ Ft./Sec.

Flow Velocity for Vapor Flow

Downstream Specific Volume for a Gas Vapor: $\overline{V}_2 = \dfrac{10.72\ T\ Z}{M\ P_2} =$ $Ft.^3$/Lb.

Downstream Specific Volume for Steam: $\overline{V}_2$ = Refer to Keenan & Keyes' Steam Tables

Vapor Flow Velocity through the Valve: $V_V = \dfrac{3.06\ W\ \overline{V}_2}{D_V^2} = \dfrac{0.234\ Q\ G_g}{D_V^2} =$ Ft./Min.

Vapor Flow Velocity through the Pipe: $V_P = \dfrac{3.06\ W\ \overline{V}_2}{D_P^2} = \dfrac{0.234\ Q\ G_g}{D_P^2} =$ Ft./Min.

Sonic Velocity of a Vapor Fluid: $V_{SONIC} = 4650\sqrt{P_2\ \overline{V}_2} =$ Ft./Min.

Mach Number: $= \dfrac{\text{Vapor Flow Velocity, } V_V \text{ or } V_P}{V_{SONIC}}$

Nomenclature

C_V = Valve Flow Coefficient.
D_B = Inside Diameter of Valve Body Outlet = Inches. See Table 4.
D_P = Inside Diameter of Outlet Pipe = Inches.
F_F =Liquid Critical Pressure Ratio Factor:
F_k = Ratio of specific Heats Factor.
F_L = Liquid Pressure Recovery Factor.
F_L Required = The F_L factor to avoid Choked Flow.
F_L Rated = The F_L factor rated for individual Trim Styles. See Table 3.
F_P = Piping Geometry Factor, If the valve size and pipe size are equal us 1.0, if not refer to ISA S75.01 section 4.3.
F_R = Reynolds Number Factor, Normally = 1.0 but varies with very slow fluid velocities or very viscous fluids. Refer to ISA S75.01 section 4.4.
G_f = Specific Gravity of a Liquid relative to water at 60 °F.
G_g= Specific Gravity of a Vapor relative to air at 60 °F 14.7 PSIA.
k = Ratio of specific Heats. See Table 2.
K_C = Cavitation Index. See Table 3.
M = Molecular Weight. See Table 2.
P_1 = Valve Inlet Pressure (psia).
P_2 = Valve Outlet Pressure (psia).
P_C =Fluid's Critical Pressure (psia) See Table 2.
P_V =Fluid's Vapor Pressure (psia).
Q = Volumetric Flow Rate: Liquids(GPM) Vapor(SCFM)
T = Fluid Temperature in Degrees Rankine. °R = °F + 460.
$\overline{V}_2$ =Specific Volume of vapor, either gas or steam = $Ft.^3$ / Lb.
W = Mass Flow Rate = Lb./Hr.
x = Pressure Drop Ratio.
x_T = Maximum Pressure Drop Ratio, varies with Trim Style. See Table 3.
Y = Fluid Expansion Factor for vapor flow.
Z = Compressibility Factor for vapor flow. Usually 1.0. Refer ISA Handbook of Control Valves, 2nd Edition, pages 488-490.
λ = Specific Weight = $Lb./Ft.^3$
Subscripts:
1 = Inlet conditions
2 = outlet conditions
v = valve
p = pipe
f = liquid
g = vapor
b = body

Flow velocity of a vapor, gas or steam, physically cannot exceed sonic velocity or Mach 1.0. Vapor flow is physically limited at sonic velocity and becomes choked. The choked sonic limitation may apply either at the valve trim or at the valve body's outlet. When the flow rate increases with the velocity at the valve's outlet at sonic, the valve's outlet pressure will rise increasing the fluid density and allowing a higher flow rate still limited at sonic velocity.

The ISA noise prediction formulas for vapor flow loses accuracy at Mach numbers larger than .33..

FLUID PROPERTIES Table 2

Name of Fluid	Fluid Form **L**iquid	**G**as	Molecular Weight M	Critical Pressure Pc psia	Critical Temperature Tc (F)	Ratio of specific Heats k
Acetylene		G	26.038	905.04	95.27	1.26
Air		G	28.966	546. 79	-220.99	1.4
Ammonia	L	G	17.031	1637.48	270.59	1.31
Argon		G	39.948	706.34	-188.23	1.668
Benzene	L	G	78.114	713.59	552.11	1.08
Butane		G	58.124	529.39	274.91	1.1
Butanol	L		74.123	639.62	553.55	
Butene-1		G	56.108	583.4	295.6	1.11
Butylene Oxide	L			63.6		
Butadiene	L		54.092	652.5	339	1.12
1-Butene	L		56.108	583.4	295.6	1.11
n-Butane		G	58.1243	551.1	305.7	1.1
Isobutane		G	58.124	529.10	274.90	1.11
n-Butanol	L			638.3		
Isobutylene	L		56.108	580.5	292.6	1.12
Carbon Dioxide	L	G	44.01	1070.38	87.71	1.295
Carbon Monoxide	L	G	28.01	507.63	-220.45	1.395
Carbon Tetrachloride	L		153.82	661.37	541.85	1.067
Chlorine	L	G	70.906	1116.79	291.29	1.355
Chlorobenzene	L		112.559	655.62	678.32	1.1
Chloroform	L		119.38	786.11	505.13	
Chloroprene	L			616.5		
Cyclobutane	L		56.108	723.24	367.82	1.14
Cyclohexane	L		84.162	590.30	536.45	
Cyclopentane	L		70.135	654.15	460.88	1.11
Cyclopropane	L		42.081	797.71	256.37	
Crude Oil	L					
Ethane	L	G	30.07	707.79	90.05	1.18
Ethanol	L		46.069	925.34	469.49	1.13
Ethylbenzene	L		106.168	523.2	651.1	1.072
Ethyl Chloride		G	64.515	754.20	369.05	1.13
Ethyl Oxide	L			1052.2		
Ethylene	L	G	28.054	732.44	49.91	1.22
Ethylene Glycol	L		62.069	1117.2		
Triethylene Glycol	L					
Freon 11	L	G	137.37	635.00	338.00	1.14
Freon 12	L	G	120.92	596.90	234.00	1.14
Freon 22	L	G	86.48	716.00	204.80	1.18
Helium		G	4.003	33.36	-450.33	1.66
Heptane		G	100.205	396.8	512.7	1.05
Hydrazine	L		32.045	2132.06	716.09	
Hydrogen	L	G	2.016	188.55	-399.73	1.412
Hydrogen Bromide	L		80.912	1240	193.76	1.4
Hydrogen Chloride	L	G	36.461	1205.27	124.79	1.41
Hydrogen Floride	L		20.006	941.30	370.49	
Hydrogen Iodide	L		127.91	1205.27	303.35	
Hydrogen Sulphide		G	34.076	1296.64	229.91	1.32

Name of Fluid	Fluid Form **L**iquid	**G**as	Molecular Weight M	Critical Pressure Pc psia	Critical Temperature Tc (F)	Ratio of specific Heats k
Isoprene	L			532.1		
Methane	L	G	16.043	667.17	-116.77	1.31
Methanol	L		32.042	1153.05	463.01	
Methyl Chloride	L	G	50.49	968.85	289.67	1.2
1-Methylchloride	L		84.922	889.08	458.33	
O-Methylene Chloride	L			910.9		
Napthalene	L		128.17	587.40	887.45	
Natural Gas		G	19.5	670	-80	1.27
Neon		G	20.179	400.30	-379.75	1.667
Nitric Oxide	L	G	30.006	941.30	-135.67	
Nitrogen	L	G	28.013	493.13	-232.51	1.4
Nitrogen Dioxide	L		46.006	1479.8	316.52	1.29
Nitrous Oxide	L	G	44.013	1050.08	97.61	
n-Nonane		G	128.259	335.1	610.6	1.04
n-Octane		G	114.23	362.60	456.35	1.05
Oxygen	L	G	31.999	730.99	-181.39	1.397
Pentane		G	72.151	488.78	385.61	1.07
Phenol	L		94.113	889.56	789.56	1.09
Propane	L	G	44.097	617.86	205.97	1.13
n-Propanol	L			751.3		
Propene		G	42.1	661	198	1.14
Propylene	L		42.081	667.17	197.51	1.154
Propyl Oxide	L			714.7		
Sea Water/Brine	L		18	3200	705.47	1.33
Sulfuric Acid	L					
Sulfur Dioxide	L	G	64.059	1142.90	315.59	1.29
Sulfur Trioxide	L		80.058	1190.7	423.8	
Tolulene	L		92.141	587.40	609.53	1.06
Water	L	G	18.015	3208.24	705.47	1.335
M-Xylene	L		106.168	514.4	650.9	1.072
O-xylene	L		106.168	540.8	674.7	1.049
P-xylene	L		106.168	510	649.5	1.073

F_L, K_C & X_T Factors   Table 3

Valve Trim Style	F_L - Rated	K_C	X_T
1840	0.81	0.69	0.72
1843	0.81	0.69	0.72
2820	0.81	0.69	0.72
2920	0.81	0.69	0.72
2922	0.81	0.69	0.72
2923	0.81	0.69	0.72
3800 Flow-To-Open (average)	0.74	0.64	0.63
3800 Flow-To-Close (average)	0.48	0.42	0.42
5840	0.81	0.69	0.72
5843	0.81	0.69	0.72

∗ = no value for vapor flow   ∗∗ = no value for liquid flow

Flanged Body Inlet and Outlet Diameters Table 4

Nominal	ANSI Pressure Class	
Body Size	150	300
1	1.06"	1.06"
1.5	1.63"	1.63"
2	2.00"	2.00"
3	3.00"	3.00"
4	4.00"	4.00"
6	6.00"	6.00"
8	8.00"	8.00"

SEAT LEAKAGE

The Fluids Control Institute (FCI) Standard ANSI/FCI 70.2 establishes a Valve's allowable seat Leakage Rate. The standard recognizes five degrees of seat tightness.

ALLOWABLE SEAT LEAKAGE CLASSES   Table 5

Leakage Class	Maximum Seat Leakage	Test Fluid	Test Pressure	Relative Seat Tightness
Class II	0.5% of rated C_V	Water	45 to 60 PSI	1.0
Class III	0.1% of rated C_V	Water	45 to 60 PSI	5.0
Class IV	0.01% of rated C_V	Water	45 to 60 PSI	50
Class IV+	*0.0015 ml /min/inch of trim size/ ΔP(PSI)*	*Water*	*Max Operating ΔP*	*150,000*
Class V	0.0005 ml /min/inch of trim size/ ΔP(PSI)	Water	Max Operating ΔP	300,000
Class VI	about 0.9 ml/min ∗	Air	50 PSI	600,000

∗ Leakage rate varies by valve size, Refer to the Standard ANSI/FCI 70.2.
Warren offers Class II, Class III, Class IV, Class IV+, & Class VI
The Relative Seat Tightness is at a 50 ΔP. For example, a Class IV leakage rate is 1/50 as much as Class II
Class IV+ is a proprietary designation of Warren Controls and is not an ANSI/FCI classification.
Class VI is for resilient seated valves; the other classes are for metallic seats.

ACTUATOR SIZING

The actuator sizing process matches our actuator's force output with our valve trim's required stem forces. The result is the maximum obtainable pressure drop at the different seat leakage classes. The process considers the valve's shut off condition. The flowing conditions also require an adequate match between the actuator and trim forces but the shut off condition is dominant and determines the allowable.

$$\text{UA} = \text{UnbalancedArea}(\text{BalancedTrim}) = \left((\text{Cage ID})^2 - (\text{Seat ID})^2\right)\left(\frac{\pi}{4}\right) = \text{In}^2$$

$$\text{UA} = \text{UnbalancedArea}(\text{UnbalancedTrim}) = (\text{Seat ID})^2\left(\frac{\pi}{4}\right) = \text{In}^2$$

$CL = \text{Seat Contact Load} = \left(\text{Seat ID}\right) \pi \left(\text{Load Factor}\right)$ = Lb./In. of circumference

Load Factors vary with seat leakage class

PF = Packing Friction (Teflon Packing)= 20 Lb.

PF = Packing Friction (Grafoil Packing)= (Stem Dia.) (P_1) (Packing Height) (.15)

PF for Grafoil Packing friction should never be less than 25 Lb.

$$RF = \text{Plug Seal Ring Friction} = \left(\text{Cage ID}\right)(2)(\pi) + \left(\left(\text{Cage ID}\right)^2 - \left(\text{Seal Groove}\right)^2\right)\frac{\pi}{4}(0.03)\ \Delta P$$

Direct Actuator Output = (Effective Diaph. Area) (Actuator Press.- Final Spring Pressure)

Reverse Actuator Output = (Effective Diaph. Area) (Initial Final Spring Pressure)

The “Initial Spring Pressure” is the actuator pressure when the valve stem begins to move. The “Final Spring Pressure” is the actuator pressure when the valve stem reaches full travel.

$$\text{Allowable } \Delta P = \frac{\left(\text{Actuator Output}\right) - PF - RF - CL}{UA} \quad \Leftarrow \text{For Balanced Trim Flow to Close}$$

$$\text{Allowable } \Delta P = \frac{\left(\text{Actuator Output}\right) - PF - CL}{UA} \quad \Leftarrow \text{For Unbalanced Trim Flow to Open}$$

Be sure that the allowable pressure drop cannot exceed the Body’s ANSI pressure rating.

ΔP Tables are available in the individual product specifications of each respective valve series.

APPLICATION GUIDE FOR CAVITATION, FLASHING AND COMPRESSIBLE FLOW SERVICES

Valve applications involving cavitation, flashing and noise reduction of compressible flow require special sizing and application considerations and, in most cases, special trims are required. The following section discusses these phenomena with a definition, a list of possible countermeasures, tips, and a technical discussion of the phenomena. Cavitation and flashing are in the "Liquid Flow" Section and compressible flow noise reduction is in the "Compressible Flow Noise" Section.

LIQUID FLOW

Cavitation and flashing applications require accurate prediction to determine when they occur and proper valve selection to supply the best trim for the application.

CAVITATION

Cavitation Definition

Cavitation is a two stage phenomena with liquid flow. The first stage is the formation of vapor bubbles in the liquid as the fluid passes through the trim and the pressure is reduced below the fluid's vapor pressure. The second stage is the collapse of the vapor bubbles as the fluid passes the vena contracta and the pressure recovers and increases above the vapor pressure. The collapsing bubbles are very destructive when they contact metal parts and the bubble collapse may produce high noise levels.

Cavitation Countermeasures

There are several ways to deal with cavitation.

Method 1: Cavitation avoidance: Cavitation can be avoided by selecting a valve style that has F_L (rated) values greater than required for the application. This is an especially useful advantage of globe valves over ball and butterfly valves.

Cavitation can also be avoided with the installation of an orifice plate downstream of the valve that shares the pressure drop. The valve's pressure drop is reduced to the point of avoiding damaging cavitation. The downstream orifice plate also should be sized to avoid damaging cavitation. This may not be suitable for applications with a wide flow range as the low flow condition may put the entire pressure drop on the valve.

Method 2: Cavitation Tolerant: Standard trim designs can tolerate mild cavitation applications. These applications will have increased flow noise from the mild cavitation but should not have damage from cavitation.

Method 3: Cavitation Containment: A trim design that allows cavitation to occur but in a harmless manner can be effective in preventing cavitation damage and reducing cavitation noise. Cavitation containment designs are limited to cavitation applications of moderate intensity.

Method 4: Cavitation Prevention: A trim design that takes the pressure drop in several steps or stages can avoid the formation of cavitation. These trim designs are more expensive than other methods but may be the only alternative in the more severe cases of cavitation.

Application of Warren Trims in Cavitation Service

Cavitation Avoidance: Wherever possible, try to reduce unnecessarily high-pressure drops to avoid cavitation in the first place. Several design constraints can be re-evaluated in this process

Cavitation Tolerant: Hardened trims are tolerant to cavitation service where the F_L (required) exceeds the F_L (rated) <u>and the inlet pressure is 150 psig or less for 17-4 Trim or 300 psig or less with Stellited (Alloy 6) or Ceramic Trim</u>. At these inlet pressures, the severity of cavitation may be small enough to ensure reasonable trim life. Use the Warren Valve Sizing program and assistance from the Application Engineering department to determine.

The unbalanced Plug Control Trims with tungsten carbide or ceramic can withstand cavitation up to an inlet pressure of 2000 psig. However, these trims will not reduce noise. Oversized bodies are recommended to avoid body erosion.

Cavitation Containment: Special cavitation reduction trims are appropriate where the F_L (required) exceeds .94. The flow noise from cavitation will be reduced by the use of such trims. Flow noise calculation is automatic with Warren's Valve Sizing Program. However, at this time, Warren Controls does not offer any special cavitation reduction trim.

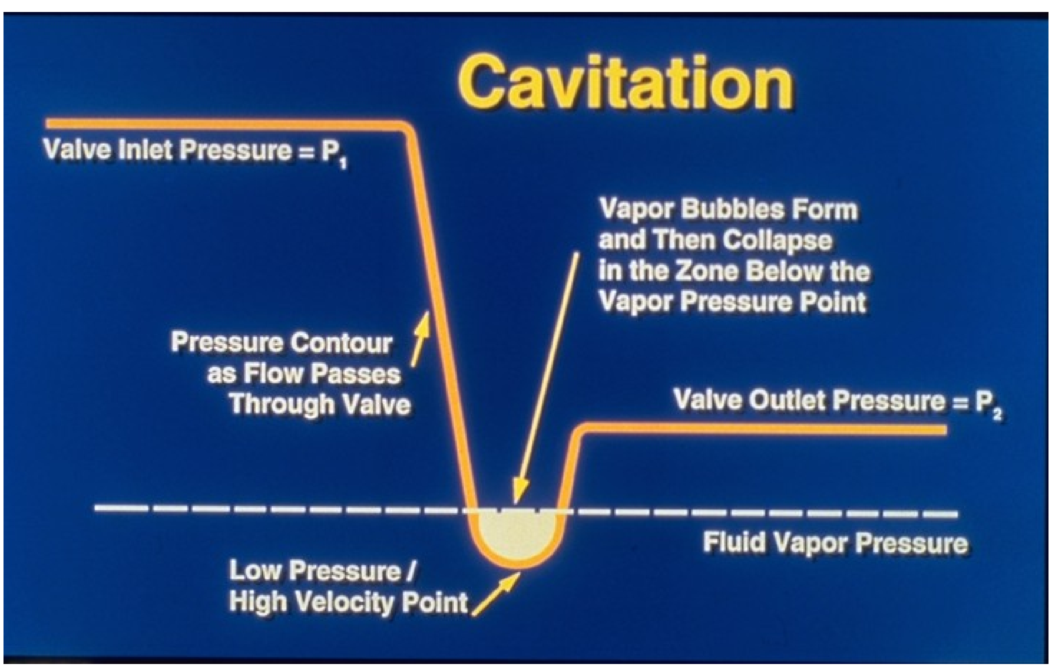
Some cavitation reduction trim will make multiple small cavitation plumes that will not as readily cause erosion damage and will generate less noise than a trim with plug or cage port control. Typically, in a Globe valve, this trim is used only in the flow down direction.

Cavitation Prevention: Special trims with multiple stages might be required to suit a particular application, or paired valves may need to split-drop in series. These trims and two valve solutions will cost significantly more than the other options discussed but will be applicable in conditions beyond the others. Consult with Application Engineering for any cavitating applications to see what may be done.

THE CAVITATION PHENOMENA

FLUID AND PRESSURE PROFILE

A control valve creates a pressure drop in the fluid as it controls the flow rate. The profile of the fluid pressure, as it flows through the valve, is shown in the following graph. The fluid accelerates as it takes a pressure drop through the valve's trim, It reaches its highest velocity just past the throttle point, at a point called the vena contracta. The fluid is at its lowest pressure and highest velocity at the vena contracta. Past the vena contracta the fluid decelerates and some of the pressure drop is recovered as the pressure increases. For globe valves, the pressure difference from the inlet pressure P_1 to the vena contracta pressure P_{VC} is about 125% of the P_1 to P_2 pressure drop. The pressure in the vena contracta is not of importance until it is lower than the fluid's vapor pressure. Then the fluid will quickly form vapor bubbles and, if the pressure increases above the vapor pressure, the vapor bubbles instantly collapse back to liquid. This is cavitation. It will occur when the vapor pressure, as shown in the following graph, is more than the vena contracta pressure but less than the outlet pressure, P_2. When the Vapor pressure is less than the vena contracta pressure, there is full liquid flow with no cavitation.



Cavitation in control valves can have four negative effects;

- Restricts fluid flow
- Causes severe vibrations
- Erodes metal surfaces
- Generates high noise levels.

CHOKED FLOW AND INCIPIENT CAVITATION

The liquid flow rate will increase as the pressure drop increases. However, when cavitation vapor bubbles form in the vena contracta, the vapor bubbles will increasingly restrict the flow of liquid until the flow is fully choked with vapor. This condition is known as "choked flow" or "critical flow".

When the flow is fully choked, the flow rate does not increase when the pressure drop is increased. The relationship of flow to $\sqrt{P_1 - P_2}$ is linear until cavitation begins to form at the point of incipient cavitation. As more cavitation forms, the more the flow curve bends until it is horizontal and fully choked with the flow not increasing with additional pressure drop.

The larger the F_L factor, the greater the pressure drop that can be taken before choked flow occurs. Note the differences in Table 3.

The point of "Incipient Cavitation" can be predicted with the ΔP incipient in the equation in the "C_V Formulas for Liquid Flow" using the K_C factor. Values for K_C are shown in table 3. Cavitation will begin at the point of "Incipient Cavitation" and increase in intensity to the point of choked flow. Cavitation at point of "Incipient Cavitation" is not damaging and is almost undetectable. At some point between incipient and choked, the cavitation may damage most trim styles. The location of the "Damage" point varies with trim style and material. A larger K_C is preferred so the incipient cavitation range to choked flow is as small as possible.

As the point of damaging cavitation is not easily defined, sizing and application methods use the Critical Pressure Drop and the Required F_L to rate trims for cavitation service. The K_C value is not used for trim selection only flow noise prediction.

CAVITATION DAMAGE

Cavitation damage problems are more likely to occur with water flow as water has a well-defined vapor pressure and the vapor bubble collapse is instantaneous. Hydrocarbon fluids have a less precise vapor pressure and are often a compound with several vapor pressures. Cavitation damage with hydrocarbon fluids is usually less severe than water, as the bubble collapse is not as sudden and can be cushioned by other vapors. However the vibration and flow noise problems remain.

The fluid's inlet pressure is proportional to the amount of energy available to cause cavitation damage. Higher inlet pressures will produce more intense and more damaging cavitation. The amount of cavitation is related to the degree the required F_L exceeds the rated F_L. As the required F_L exceeds the rated F_L, the amount of cavitation increases. A valve with a rated F_L of .90 in an application requiring a F_L of .96 will have more cavitation than an application requiring .92. There will be more cavitation but not more flow!

The generation and implosion of the vapor bubbles will cause vibration to the valve's Plug that may cause wear between the Plug and Cage or Guide and can cause Stems to break.

The implosion of the bubbles when near or on a metal surface can generate extremely high shock stresses in the metal surface that usually damages the metal with severe erosion of the metal. This phenomenon, when severe, can destroy trims within hours! The generation and implosion of the vapor bubbles will cause significantly elevated flow noise in addition to vibration.

The cavitation bubbles will form a vapor plume in the liquid. The larger the plume, the noisier the flow and the more likely it is to cause erosion damage. The size of the plume is dependent on trim style and severity of cavitation. Cavitation reduction trim designs with many small orifices will have significantly smaller vapor plumes with less noise and a reduced damage potential than a standard trim. Warren does not currently offer such trim.

There is not much positive to say about cavitation. Valves improperly applied or without adequate cavitation protection can lead to early failure.

FLASHING

Flashing Definition

Flashing is a one-stage phenomenon somewhat similar to cavitation. The difference is the downstream pressure does not recover enough to be above the fluid's vapor pressure. The vapor bubbles in the liquid do not collapse and they remain in the fluid as vapor. Generally only part of the fluid vaporizes so the resulting flow downstream of the valve is two phase, vapor and liquid. Flashing is similar to cavitation in some respects but is not quite as severe. There are means to prevent or retard cavitation but not flashing! If the valves outlet pressure is below the vapor pressure, flashing will occur regardless of the valve's trim.

Flashing Countermeasures

There are several measures that should be made in flashing applications.

Body Material: The flashing process can cause body erosion that may reduce the body's wall thickness to less than required by codes. The fluid in the valve body downstream of the trim is highly turbulent as a two-phase flow mixture of vapor and liquid. The turbulent mixture can easily erode body materials, such as carbon steel, that may not have sufficient erosion resistance.

Trim Selection: Avoid the use of Balanced Plug Control Trim in flashing applications as the flashing process may make the trim unstable. High-pressure drops in flashing service is best served with special cage control trim with multiple small orifices, that reduce the trim's vibration from the fluid's turbulence, or at least Unbalanced Plug Control Trims with tungsten carbide or ceramic.

APPLICATION OF WARREN VALVES IN FLASHING SERVICE

Body Material: The flashing process can cause body erosion that may reduce the body's wall thickness to less than required by codes. All flashing service should have stainless steel or Chrome-Moly (WC6) bodies; Carbon steel is not suitable.

Trim Selection: If the pressure drop is 50 PSI or less, standard Cage Control Trim is suitable. Plug control Trim is not recommended for flashing service. For pressure drops greater than 50 psi, Unbalanced Plug Control Trims with tungsten carbide or ceramic are recommended.

THE FLASHING PHENOMENA

Liquids in flashing service undergo a transformation from all liquid flow to two-phase flow of flashed vapor and the remaining liquid. The liquid will flash until thermodynamic equilibrium is achieved with the vapor fully saturated. Often the majority of the volume will be vapor and some of the remaining liquid will be suspended as droplets in the vapor. As the velocity of the vapor can reach as high as sonic velocity, the liquid droplets can cause severe erosion the valve body and the downstream pipe. The flashing process is highly turbulent with the liquid impacting the valve trim at high velocity. The effects of the turbulent flashing liquid can cause trim instability if it impacts the control surfaces of the Plug. For this reason, Plug Control Trim is not ideal for flashing service. Specifically designed cavitation reduction trim will distribute the flashing process into a large number of small jets reducing the total turbulence and reducing the vibration effects on the Plug and the erosion effects to the body. Often flashing service will be in the flow down direction through an angle style body. The object is the get the flashing through the valve without significant contact with the body. As Warren does not have an angle body or anti-cavitation trim, our best solution is through avoidance. Flashing service with pressure drops less than 50 PSI will have less severe turbulence so the standard Hardened Trims with flow down will be suitable.

LIQUID FLOW VELOCITY - BODY MATERIAL

High liquid flow velocities in valve bodies can cause metal erosion even though there may be no cavitation or flashing. Liquid flow velocity in valve bodies should be limited to the velocities shown in Table 6 to avoid flow erosion. The body's flow velocity, for liquid flow, can be calculated. The body flow velocity at the smallest flow passage, usually the body inlet or outlet, should not exceed the velocities in Table 6.

LIQUID FLOW VELOCITY LIMITS   Table 6

Body Material	Application Limits		
	Pressure Drop		Infrequent
	> 500 PSI	< 500 PSI	< 2% of time
Carbon Steel	30 Ft/Sec	40 Ft/Sec	50 Ft/Sec
Stainless or WC6 (Cr-Mo)	45 Ft/Sec	60 Ft/Sec	90 Ft/Sec

COMPRESSIBLE FLOW NOISE

Compressible Flow Noise Discussion

Flow noise from compressible flow is a major application consideration. The flow noise must be accurately predicted and the appropriate valve trim chosen to meet the customers requirements and assure good valve operation.

Compressible flow noise is generated by fluid turbulence, the more turbulence the more noise. Fluid turbulence is increased by higher flow rates and by a higher fluid pressure drop through valve trim. As the valve's pressure drop reaches the critical condition and the speed of sound is reached in the flow stream's vena contracta, shock waves are produced that increases the noise level above that produced by turbulence alone.

Compressible Flow Noise Countermeasures

There are several methods to reduce compressible flow noise.

Multiple Orifice Trims: A trim with a high number of small flow orifices will produce less flow noise than a trim of equal flow capacity with either four or one flow orifices. The small holes produce smaller flow jets that generate proportionally less noise, as the small holes are less efficient in converting mechanical power to acoustical power than large holes. These trim designs generally have multiple small orifices and are significantly quieter than standard plug or cage control trims.

Backpressure Orifice: The flow noise increases rapidly with increased pressure drop especially when the critical pressure drop is exceeded. However if two devices can share the total pressure drop, the flow noise can be significantly reduced. This can be accomplished with a fixed orifice plate downstream of a control valve. At maximum flow the valve and orifice plate can have about the same pressure drop and generate less noise than taking the total drop across the valve alone. At lower flow rates, the noise from flow through the valve will probably be less than at full flow even though the valve's pressure drop increases as the pressure drop across the fixed orifice plate decreases. The backpressure orifice plate may be in the form of a cylindrical diffuser. The backpressure orifice device also should be sized for flow noise.

Two Stage Trim: A two-stage valve will reduce flow noise beyond the noise reduction of the multiple orifice trim. The two-stage trim is similar to two multiple orifice trims, one inside of the other. The inner stage takes the majority of the pressure drop with the outer stage acting as a diffuser to reduce flow turbulence.

At present, Warren does not offer any such low noise or anti-cavitation trim.

APPLICATION OF WARREN TRIMS IN COMPRESSIBLE FLOW APPLICATIONS

Low noise considerations should be applied when the predicted noise level exceeds the customers requirement or when the noise level exceed 110 dBA.

Standard Trims: Calculate the flow noise for the specified conditions. The standard Plug Control, flow up, or the Cage Control, flow down, may meet the customer's noise requirements or our 110 dBA limit. In this case no further measures are required providing the downstream flow velocity is not excessive.

Compressible Flow Velocity Limits: If flow noise is being controlled, the flow velocity in the valve body and downstream piping should be limited to 1/3 sonic velocity for DB II and 1/2 sonic velocity for DB I trims. Higher velocities will generate significant flow noise in the pipe even though a low noise trim is installed. Applications with low outlet pressures can readily have high downstream velocities. Sonic velocity at the valve's outlet can produce flow noise as high as 135 dBA as the shock waves from the sonic velocity will propagate downstream as the pipe acts as a megaphone! The body's flow velocity, for compressible flow, can be calculated using the body outlet diameter from Table 4.

Two Stage Trims and Backpressure Orifices: Two stage trims and backpressure orifices require special analyses and designs not available as standard. The use of two stage trims and downstream orifices may reduce the flow noise an additional 10 dBA beyond the reduction of a noise reduction trim. Consult Warren’s Application Engineering for applications requiring noise reduction.

THE COMPRESSIBLE FLOW NOISE PHENOMENA

A control valve's purpose is to create a pressure drop, the pressure drop creates fluid turbulence and the turbulence generates flow noise. The resultant flow noise is inevitable but can be minimized by trim and valve selection.

Flow noise produced by a valve will be transmitted through the wall of the downstream pipe. Very little noise will come through the valve body wall as the area of the pipe's wall is tremendously larger and the pipe's wall thickness is less.

High flow noise from compressible flow presents two problems. Mechanical vibrations from excessive noise levels can quickly destroy the trim and also may damage accessories mounted on the valve's actuator. The major problem from high flow noise is hearing damage to people in the vicinity of the valve. OSHA has established noise limits that vary from 115 dBA to 85 dBA depending on the length of daily exposure. the 115 dBA is for 15 minutes exposure and 85 dBA is for an 8 hour exposure. The usual requirement is 85 dBA as it is difficult to limit a person's exposure. Ear protection can help protect a person's hearing, but with today's legal liability rulings, the owner of the process is liable for people's hearing damage even if they exceed posted exposure times and do not use provided ear protection. We should be concerned if the predicted noise level exceeds 110 dBA even if the customer does not impose a limit. Flow noise exceeding 110 dBA, for any significant time can damage the valve trim and accessories.

Warren uses both ISA's C_V formulas from ISA S75.01 and ISA's Control Valve Aerodynamic Noise Prediction formulas from ISA-S75.17. ISA-S75.17 was published in 1989 and has become recognized as the best compressible flow noise prediction method. The major control valve companies, Fisher and Masoneilan, had developed, in the 1960's, empirical noise prediction techniques based on laboratory test data. Formulas were written to fit the test data. In the 1980's ISA developed a theoretical noise prediction method, with the combined input from many valve companies, that is more accurate than the previous empirical methods. The ISA noise prediction method applies only to standard plug or cage control trims. Low flow noise designs require an additional factor to be subtracted from the ISA value.