# Control Valve Sizing Theory, Cavitation, Flashing

# Noise, Flashing and Cavitation

# Valve Pressure Recovery Factor

When a fluid passes through the valve orifice there is a marked increase in velocity.  Velocity reaches a maximum and pressure a minimum  at the smallest sectional flow area just downstream of the orifice opening. This point of maximum velocity is called the **Vena Contracta.**

Downstream of the Vena Contracta the fluid velocity decelerates and the pressure increases of recovers.

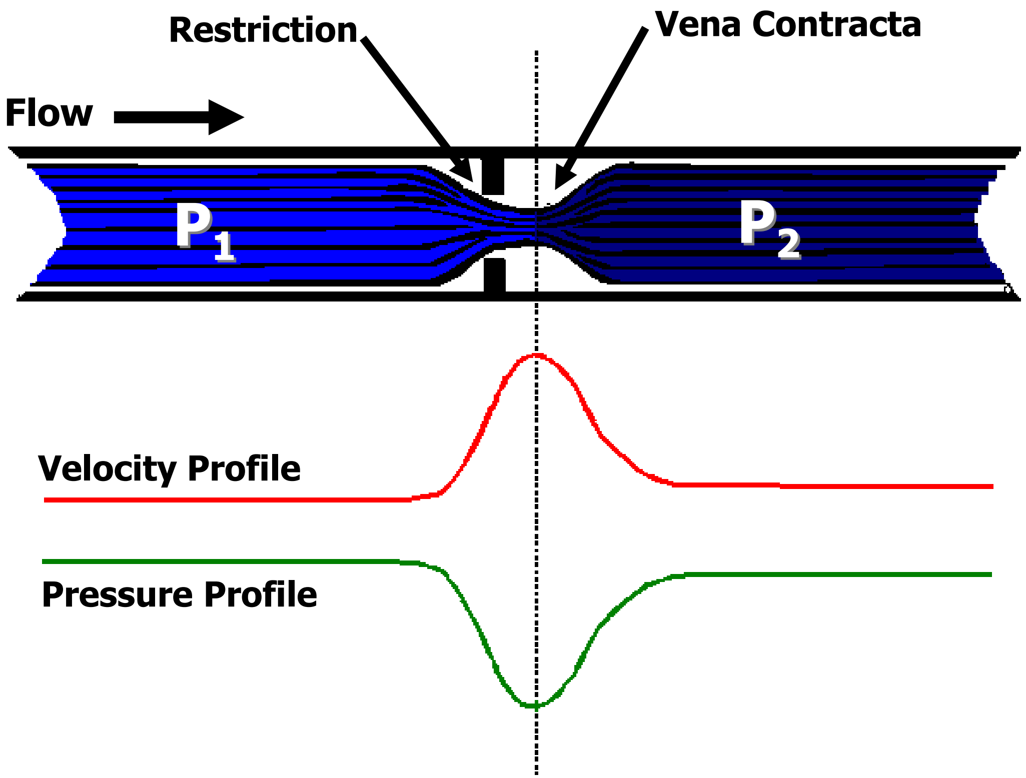
The more stream lined valve body designs like butterfly and ball valves exhibit a high degree of pressure recovery where as Globe style valves exhibit a lower degree of pressure recovery because of the Globe geometry the velocity is lower through the vena Contracta.

The Valve Pressure Recovery Factor is used to quantify this maximum velocity at the vena Contracta and is derived by testing and published by control valve manufacturers. The Higher the Valve Pressure Recovery Factor number the lower the downstream recovery, so globe style valves have high recovery factors.

ISA uses FL to represent the Valve Recovery Factor is valve sizing equations.

# Flow Through a restriction

- As fluid flows through a *restriction*, the fluid's velocity increases.
- The *Bernoulli Principle* states that as the velocity of a fluid or gas *increases*, its pressure *decreases*.
- The *Vena Contracta* is the point of smallest flow area, highest velocity, and lowest pressure.



# Terminology

## Vapor Pressure Pv

The **vapor pressure of a fluid** is the pressure at which the fluid is in thermodynamic equilibrium with its condensed state. Vapor Pressure is sensitive to Temperature. When a fluid drops below it vapor pressure the fluid changes state and goes from liquid to gas.

## Pressure at the Vena Contracta Pvc

This is the pressure at the Vena Contracta which occurs based upon the valve geometry and calculated by flow test conducted by the valve manufacturer.

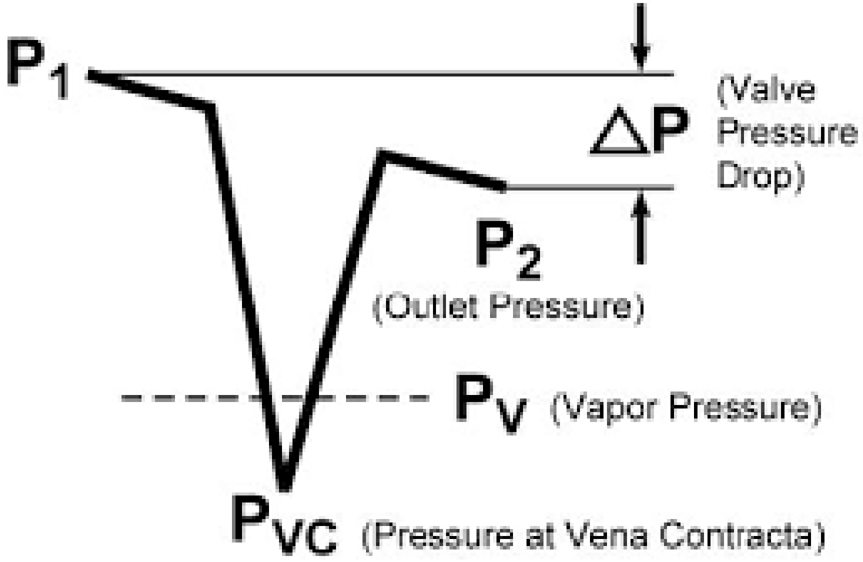
# Differential Pressure (Pressure Drop through the valve)

$$\Delta P = P_1 - P_2$$

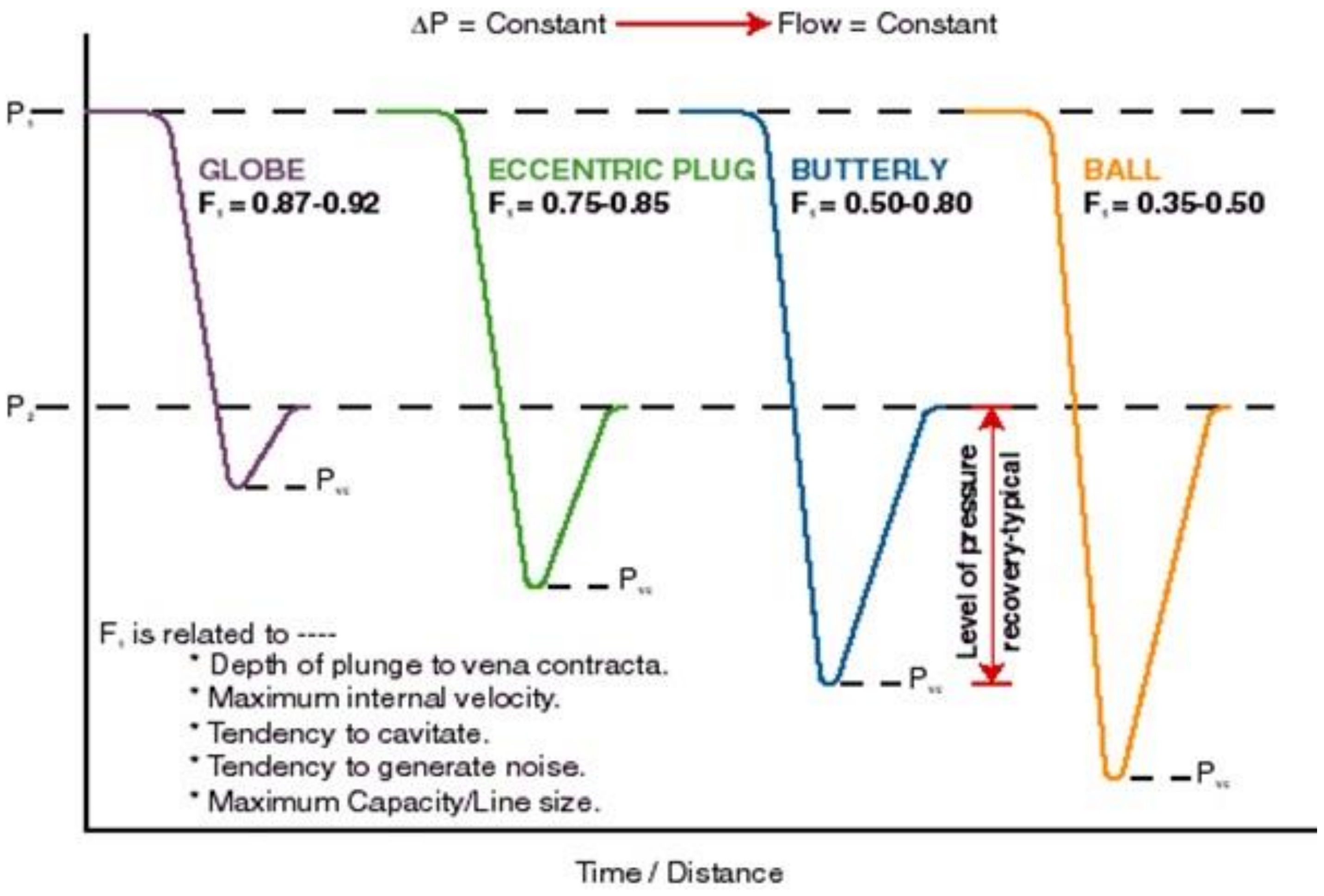
# Valve Recovery Factor

$$F_L = \sqrt{\frac{p_1 - p_2}{p_1 - p_{vc}}}$$

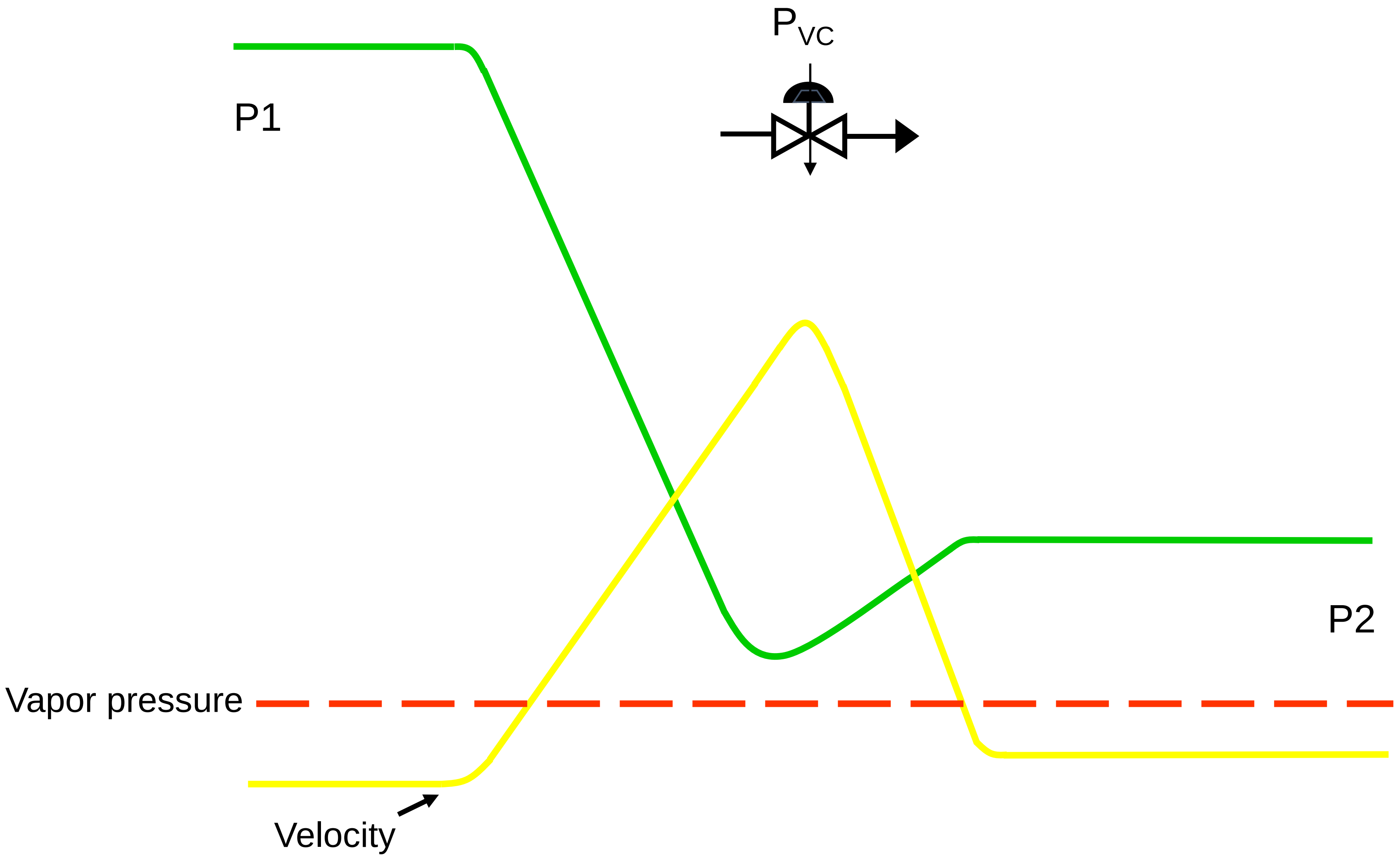
# Pressure Profile of flow through the valve



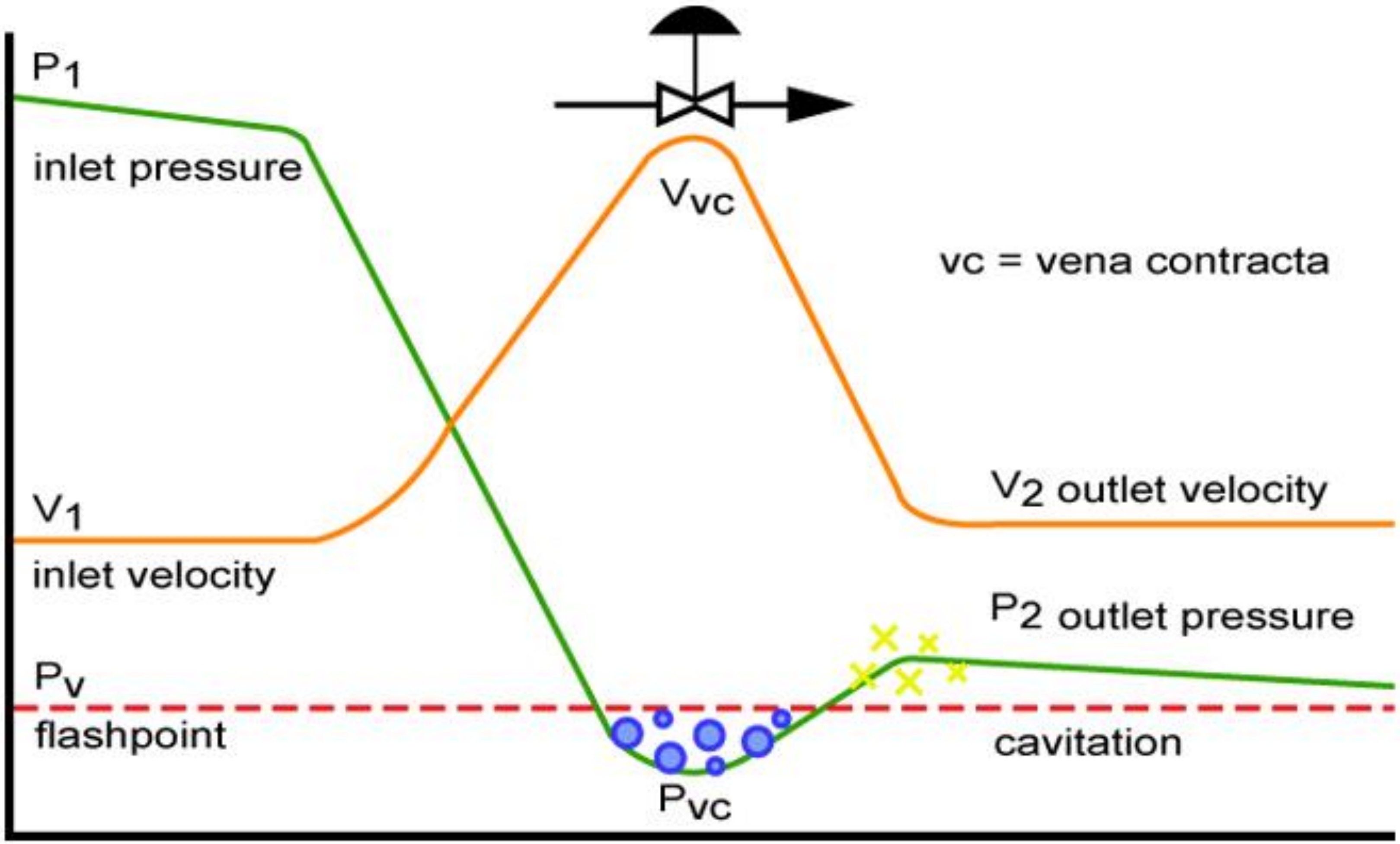
# Recovery Factor Comparison



# Pressure drop profile through a valve (liquid)

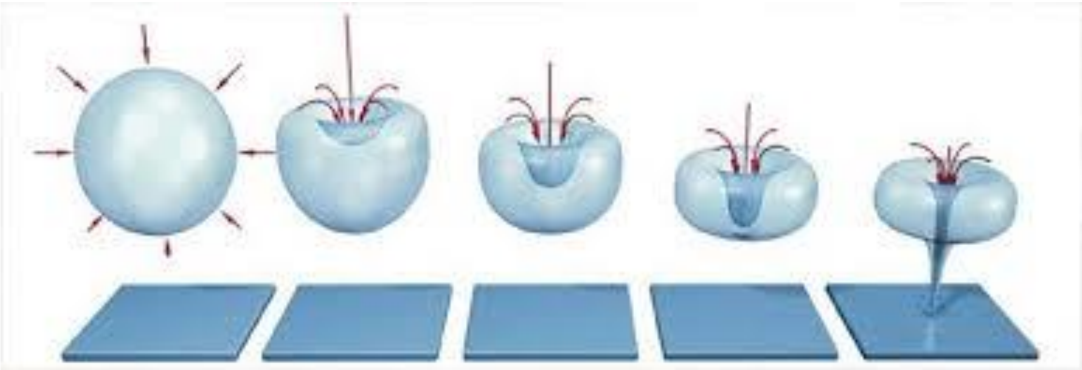


# Cavitation


P1
inlet pressure
Vvc
vc = vena contracta
V1
inlet velocity
V2 outlet velocity
P2 outlet pressure
Pv
flashpoint
cavitation
Pvc

# Cavitation Bubble

The fluid Surface Tension is a key factor in the energy that is developed and released by the cavitation bubble. The higher the surface tension the higher the tendency the bubble resists collapsing compressing the gas as the bubble begins to shrink from the increase in the recovery pressure until it finally implodes.



Cavitation sounds like rocks in the pipe because the compressed gas in the cavitation bubble is many times higher then the downstream pressure. The energy released by the imploding bubble fatigues and pits metal surfaces.

# Cavitation Damage

Damage to valve components by cavitation appears very rough, pitted , crater like  surface. High noise sounds like rocks in the pipe.

# Terminology

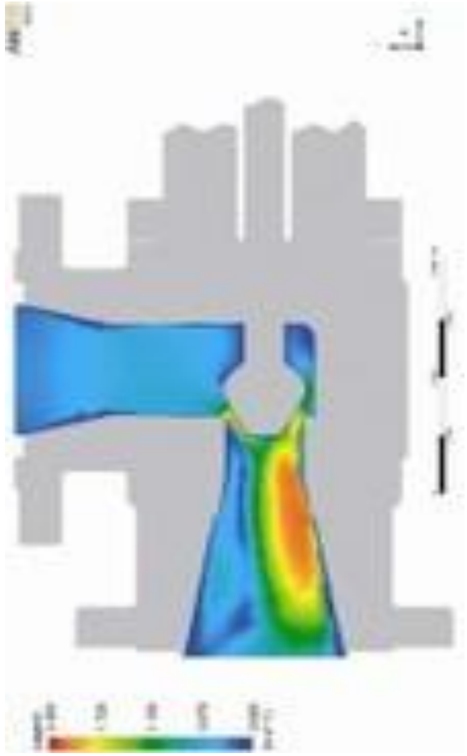
## Full Cavitation

Cavitation consumes the trim outlet area of the valve until the flow is choked.

## Incipient Cavitation

Cavitation bubbles are formed but not enough quantity to consume the outlet area of the valve trim as to choke the flow.

# What is Flashing?



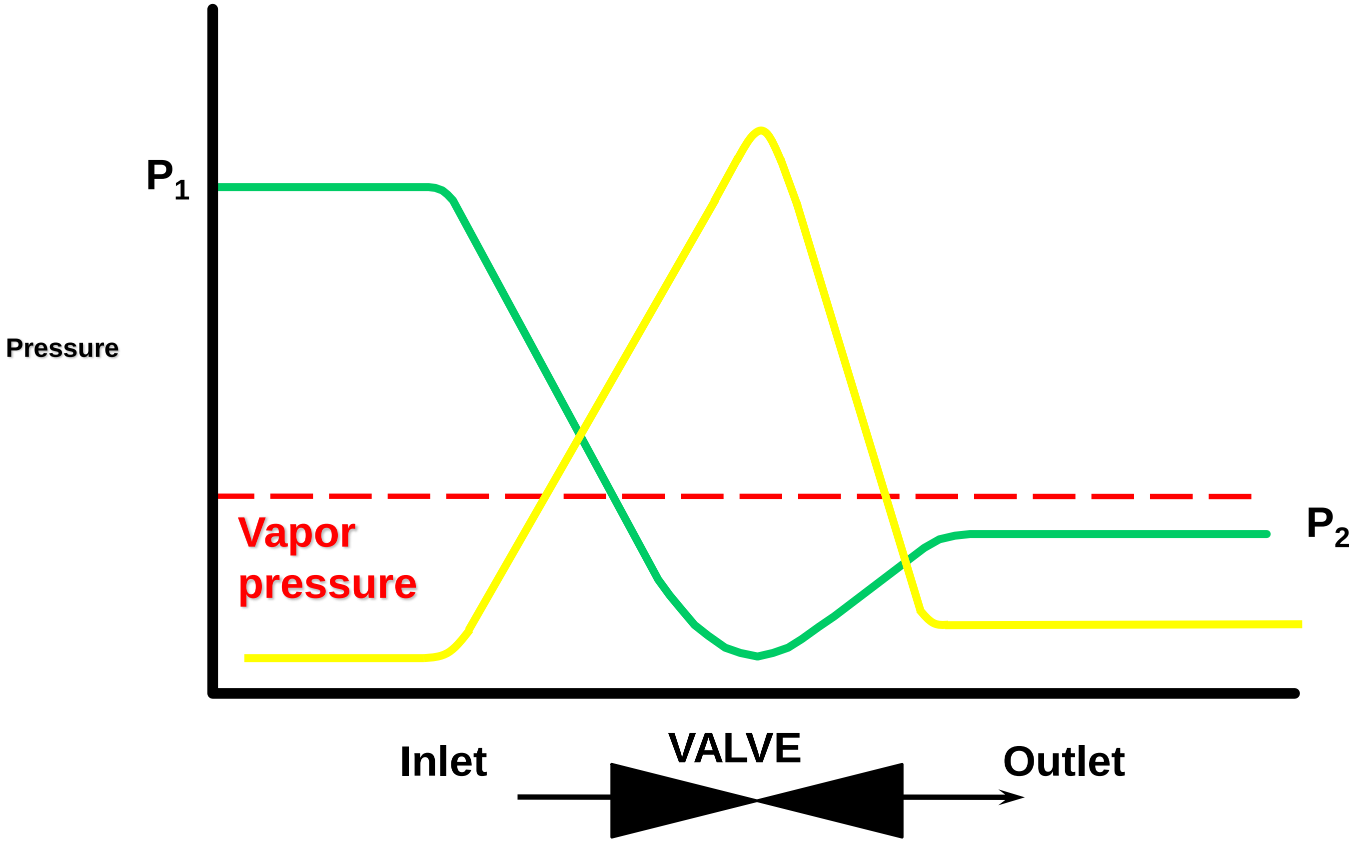
Flashing occurs when

the pressure of a fluid falls below its vapor pressure.

At this point, the fluid begins to change from a liquid to a vapor, both of which have the same chemical makeup.

The result is 2-Phase Flow downstream of the valve.

# Flashing



# Flashing Damage

Because gas has a higher volume than liquid, the gas forming from Flashing causes very high velocity exiting the valve trim and in the downstream pipe. This is caused by large increase in volume fighting for the limited space in the pipe.

High Velocity causes erosion and accelerated corrosion on valve trim and carbon steel valve bodies. Because the gas cushions the liquid at high velocity the result is no noise. You usually can't hear if a valve is flashing.

# Cavitation vs Flashing

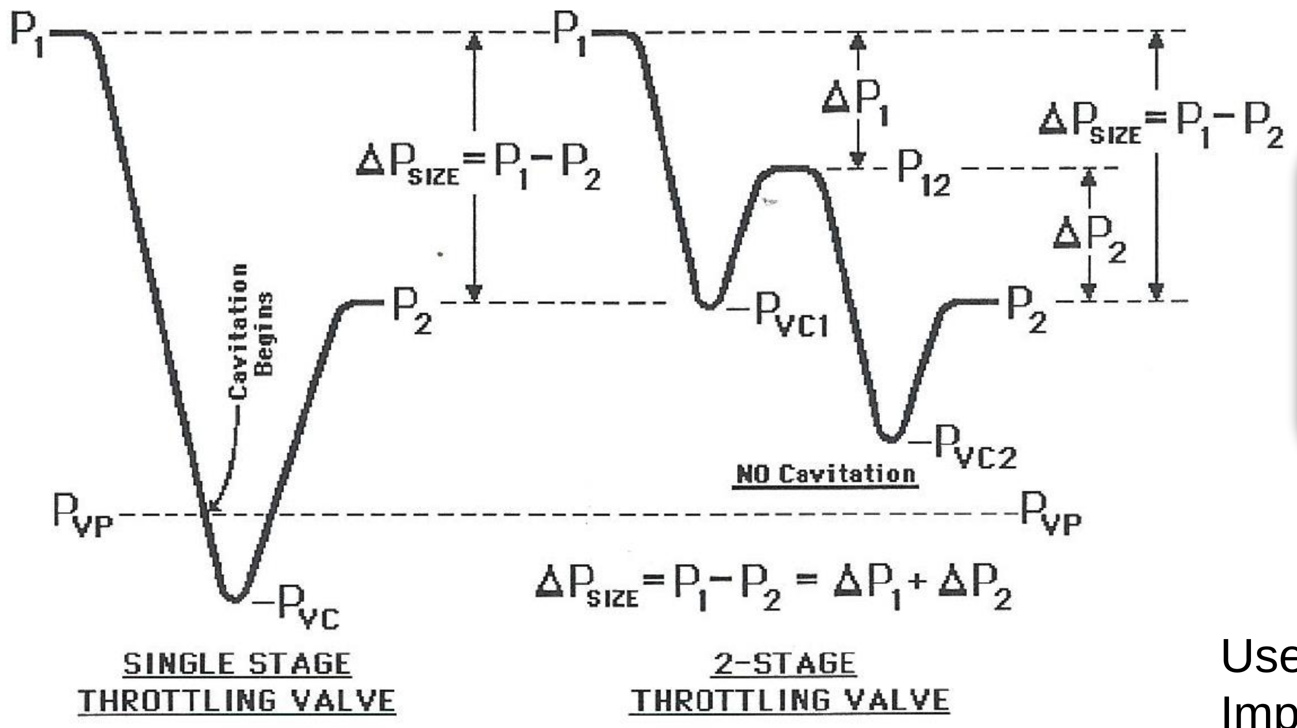
## Cavitation

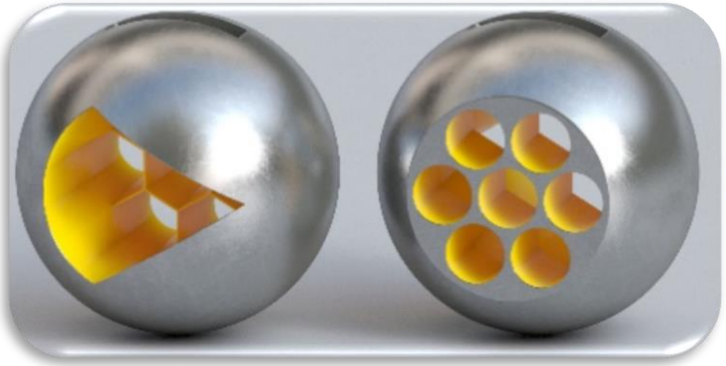
- Can be addressed by selecting a lower recovery valve.
- Can be addressed by trim velocity limiting anti-cavitation trim
- Can be addressed by a downstream back pressure device like an inline diffuser plate.

## Flashing

- Can not be eliminated mechanically  because it is a process issue.
- Carbon steel bodies need to be upgraded to a chrome moly alloy WC6 or WC9 to slow the Velocity induced corrosion. Trim must be hard faced to add longevity to trim life against the high fluid velocity.

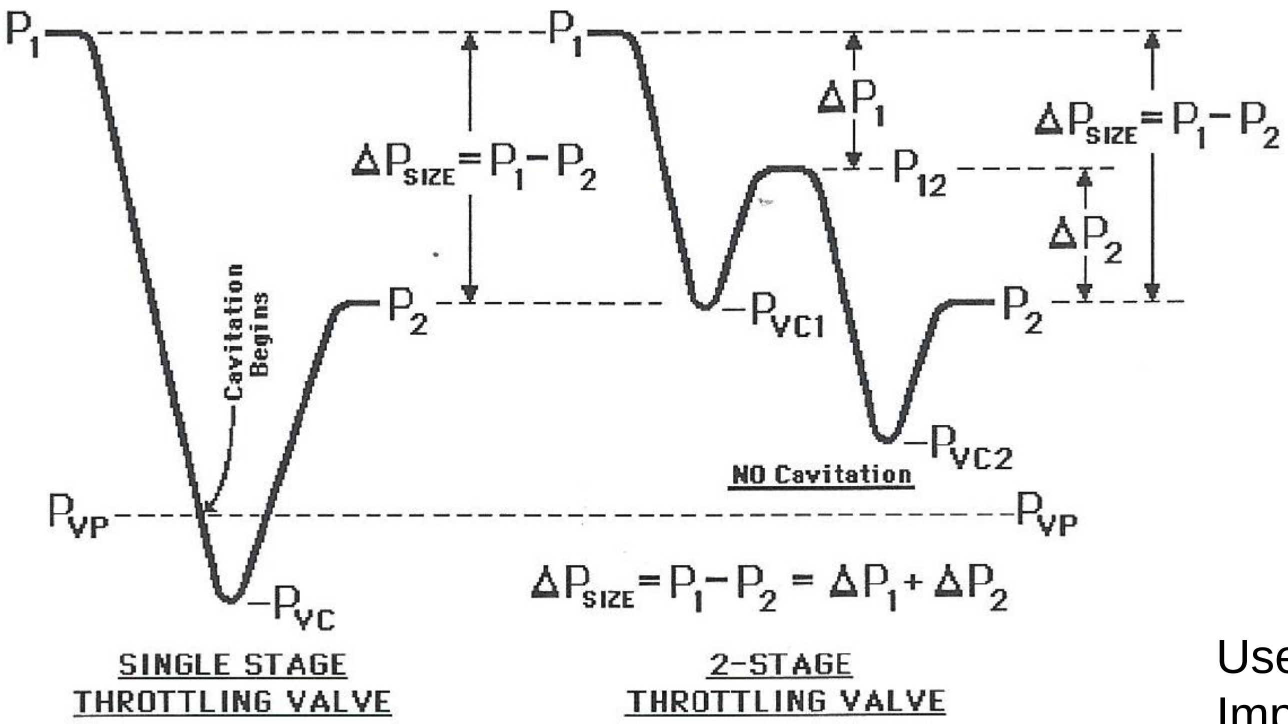
# Remedy for Cavitation

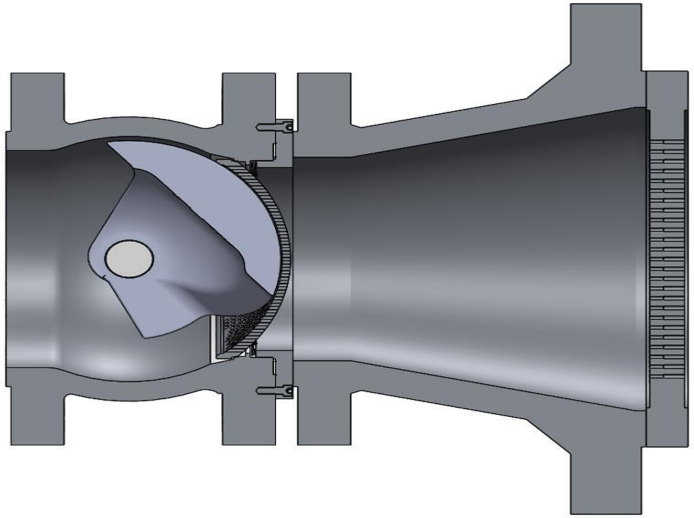


Use Stages in Valve Trim to Impede Velocity Spike

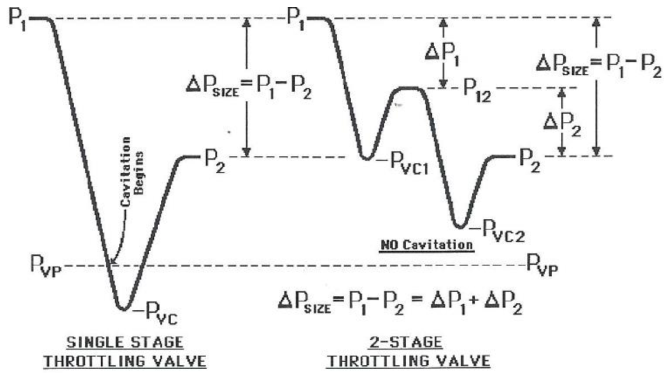
# Remedy for Cavitation

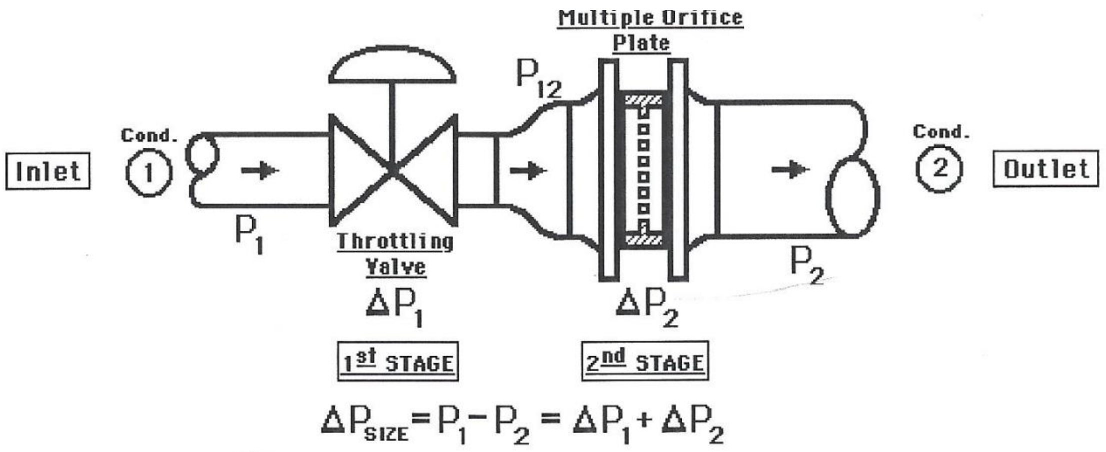


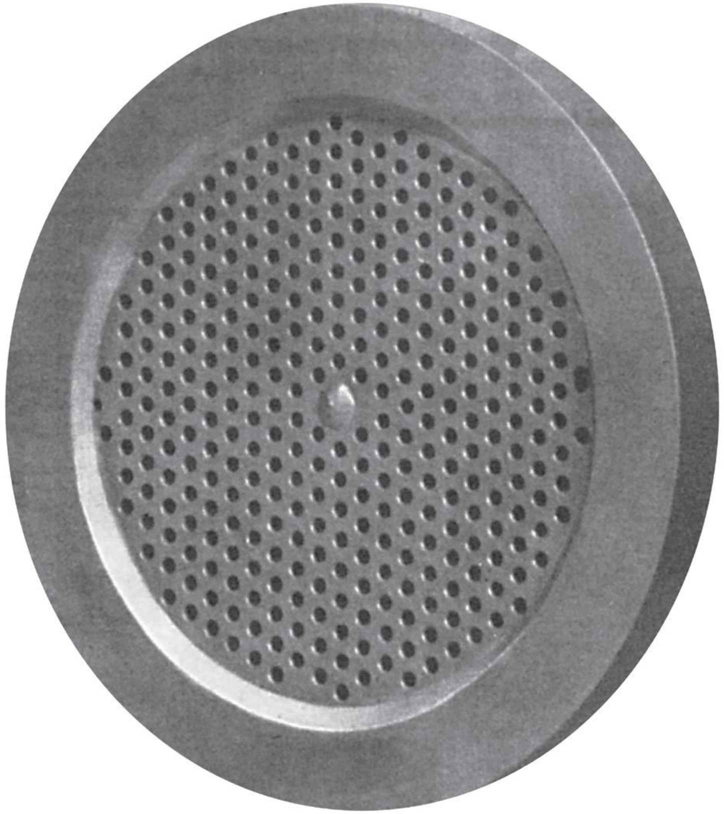



Use Stages in Valve Trim to Impede Velocity Spike

# Remedy for Cavitation



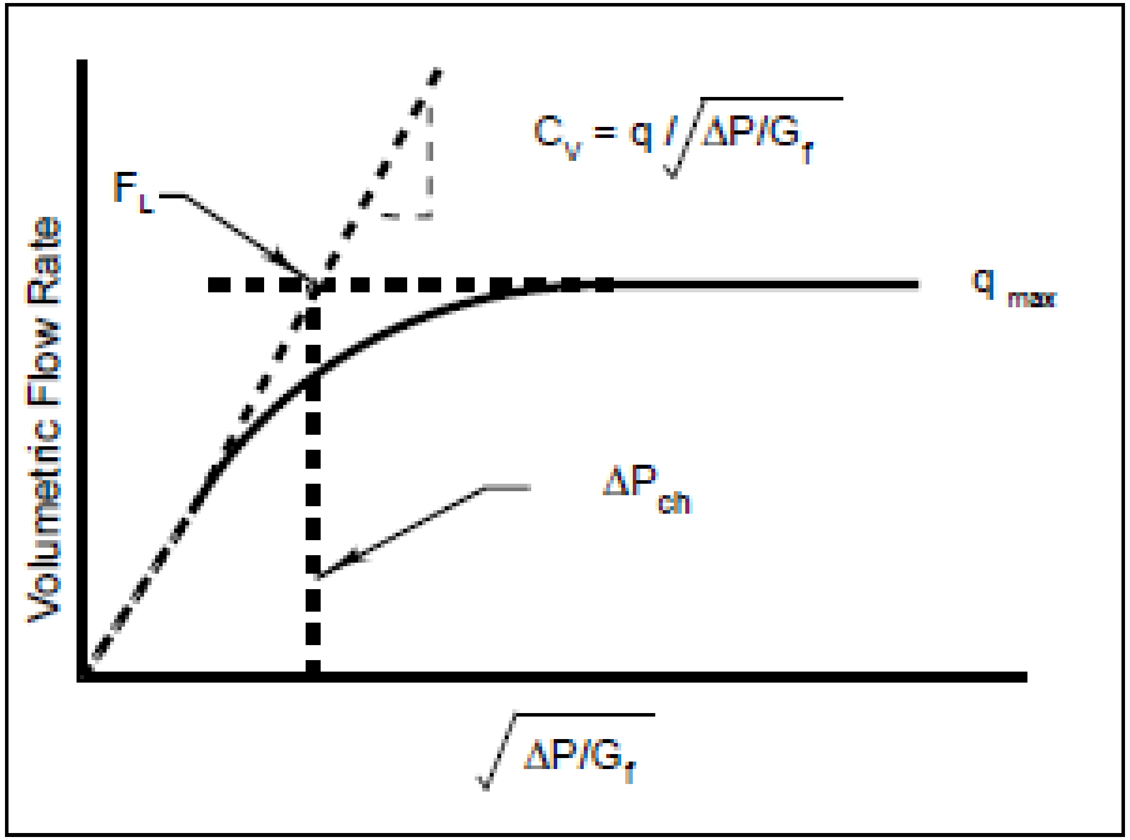
Pressure drop is split between valve and Diffuser Plate

# Choked Flow

Choked flow in liquids occurs when vapor is formed as the result of cavitation or flashing, this increases the specific volume of the fluid.

Flow no longer increases by increasing the differential pressure. In other words, the flow is choked and cannot be increased by lowering the downstream pressure increasing the differential pressure.

# Choked Flow



$C_v = q / \sqrt{\Delta P/G_f}$
$F_L$
$q_{max}$
$\Delta P_{ch}$
Volumetric Flow Rate
$\sqrt{\Delta P/G_f}$

# Choked Flow

Liquid flow is choked if

$$\Delta p \geq F_L^2 \left(p_1 - F_F\, p_v\right)$$

Differential Pressure in Full Cavitation or Flashing

# Liquid Critical Pressure Ratio Factor

$$F_F = 0.96 - 0.28 \cdot \sqrt{\frac{Pv}{Pc}}$$

# Vapor Pressure

The **vapor pressure of water** is the pressure at which water vapor is in thermodynamic equilibrium with its condensed state. At higher pressures water would condense.

| Temperature<br>- *t* -<br>($^oF$) | Absolute Vapor Pressure<br>- $p_v$ -<br>(*psia, lb/in*$^2$) |
|---|---|
| 32 | 0.0885 |
| 40 | 0.1217 |
| 50 | 0.1781 |
| 60 | 0.2563 |
| 70 | 0.3631 |
| 80 | 0.5069 |
| 90 | 0.6979 |
| 100 | 0.9493 |
| 120 | 1.692 |
| 140 | 2.888 |
| 160 | 4.736 |
| 180 | 7.507 |

# Critical Pressure

$p_c$ = pressure at thermodynamic critical point

| Liquid | Critical Press. (psia) | Liquid | Critical Press. (psia) |
|---|---|---|---|
| Ammonia | 1636.1 | Hydrogen Chloride | 1205.4 |
| Argon | 707.0 | Isobutane | 529.2 |
| Benzene | 710.0 | Isobutylene | 529.2 |
| Butane | 551.2 | Kerosene | 350.0 |
| Carbon Dioxide | 1070.2 | Methane | 667.3 |
| Carbon Monoxide | 507.1 | Nitrogen | 492.4 |
| Chlorine | 1117.2 | Nitrous Oxide | 1051.1 |
| Dowtherm A | 547.0 | Oxygen | 732.0 |
| Ethane | 708.5 | Phosgene | 823.2 |
| Ethylene | 730.5 | Propane | 615.9 |
| Fuel Oil | 330.0 | Propylene | 670.3 |
| Fluorine | 757.0 | Refrigerant 11 | 639.4 |
| Gasoline | 410.0 | Refrigerant 12 | 598.2 |
| Helium | 32.9 | Refrigerant 22 | 749.7 |
| Hydrogen | 188.1 | Sea Water | 3200.0 |
| | | Water | 3208.2 |

# Allowable $\Delta p$ Using Liquid Critical Pressure Ratio Factor

Water at 70F
P1= 134.7 psia
4”

Liquid flow is choked if

$$\Delta p \geq F_L^2 \left(p_1 - F_F\, p_v\right)$$

$$F_F = 0.96 - 0.28 \cdot \sqrt{\frac{.3631}{3208.2}}$$

$$F_F = 0.957$$

$$\Delta p \geq F_L^2 (134.7 - .957(.3631))$$

$$\Delta p \geq F_L^2 \ (134.35)$$

# Using Sigma as a Predictor of Cavitation

Method based on the Valve Cavitation Index

ISA-RP75.23-1995: "Considerations for Evaluating Control Valve Cavitation"

$$\sigma \text{ (Sigma)} = \frac{(P1-P_V)}{(P1-P2)}$$

| Criteria | Cavitation Consequence |
|---|---|
| $\partial \geq 2{,}0$ | No Risk of Cavitation |
| $1{,}7 < \partial < 2{,}0$ | No cavitation control required Hardened trim provides protection |
| $1{,}5 < \partial < 1{,}7$ | Some cavitation control required |
| $1{,}0 < \partial < 1{,}5$ | Potential for severe cavitation |
| $\partial \leq 1{,}0$ | Flashing is occurring |

# Valve Cv Calculation for Liquids

- To size a control valve we need to know how much fluid can pass through the control valve. It is important to know what the flow capacity will be at different percent open as well as at different pressure drops.
- Cv is the agreed upon industry unit of measure for valve flow capacity. It is defined as the number of gallons per minute (gpm) of water at 60F will pass through the valve with a pressure drop of 1 psi.
- We must calculate the Cv required for our particular application to verify the size control valve or control valve trim to select.
- Most control valve manufacturers provide Cv tables by size for their valves which provide the Cv value for every 10% of opening.
- The Rangeability of a control valve is defined by dividing the maximum controllable Cv by the minimum controllable Cv for that size and type of valve.

# Valve Cv Calculation for Liquids

$$C_v = \frac{q}{F_P}\sqrt{\frac{G_f}{\Delta P_a}} \qquad ($$

Where:

$C_v$ = Valve sizing coefficient

$F_p$ = Piping geometry factor

$q$ = Flow rate, gpm

$\Delta P_a$ = Allowable pressure drop across the valve for sizing, psi

$G_f$ = Specific gravity at flowing temperature

# Definition of Terms

## What is Specific Gravity?

- The ratio of the density of a substance to the density of a standard, usually water for a liquid or solid, and air for a gas.

  Density = Mass/Volume

  Specific Gravity = Density/Water

## What is Differential Pressure ?

- It is the Pressure Drop through the valve. Upstream P1 – Downstream P2

## What is Piping Geometry Factor ?

- It is a correction factor based on selecting a smaller than line size control valve.

# Piping Geometry Factor

The piping geometry factor represented by Fp is an adjustment to the valve Cv calculation to compensate for the velocity and pressure changes caused by selecting smaller than line size valves correcting for reducers and expanders. It can also correct for other fittings like elbows in close proximity to the valve. It results in a higher required Cv for a given set of conditions.

# Piping Geometry Factor

Here is a quick guide to $F_p$ factors. First, select a valve for say ½ the diameter of the pipe, look up the max. $C_v$ of this valve from your vendor's catalog. Now divide the valve catalog $C_v$ by the valve diameter $d$ (inches) squared, then read $F_p$:

**Table 5-1. $F_p$ Values for Valves, $D/d = 2$**

| $C_v / d^2$ | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
|---|---|---|---|---|---|---|---|---|
| $F_p$ | 0.96 | 0.91 | 0.85 | 0.79 | 0.74 | 0.68 | 0.63 | 0.59 |

$D$ = pipe diameter (inches)

Next you calculate the required $C_v$ from the given process date and, finally divide this calculated $C_v$ by $F_p$. This is the final $C_v$ that should be stated on your purchase order. *Note: You may have to start over if the originally selected valve was not large enough, although this is rare.*

For example. You have a 4″ pipe. Next select a 2″ eccentric rotary plug valve with a catalog $C_v$ of 60. $C_v/d^2$ is 15. This gives an $F_p$ factor of 0.91 from the above table. Now you determine that the process data call for a required $C_v$ of 45. Dividing 45 by 0.91 requires a min. rated $C_v$ of 49.5. This is no problem, since the catalog $C_v$ is 60.

# Fluid Viscosity Cv Correction Factor

The Viscosity(Thickness) of the fluid going through the valve has an effect on the Cv Sizing Calculation. The thicker the fluid the lower the capacity to move the flow through the valve. So thicker fluids require more capacity hence the calculated Cv will be corrected higher resulting in a possible larger valve.

This correction is necessary only when the fluid viscosity is above 40 Centistokes. 90% of fluids are less than this so this correction is a rarity unless you are dealing with Molasses, Heavy Bunker Oil or Asphalt like fluids.

The correction is calculated using a valve Reynolds Number factor calculated using the valve Fl, so type of valve is a factor,

H.D. Bauman  Valve Sizing Made Easy Ch. 5

# Control Valve Maximum Cv Comparison

| Class 150 | | | | |
|---|---|---|---|---|
| Valve Size | Globe | Segmented Ball | V-Ball 90 degree | Double Offset Butterfly |
| 4" | 224 | 436 | 341 | 375 |
| 6" | 394 | 760 | 489 | 1350 |
| 8" | 818 | 1350 | 1136 | 2800 |

# Why is important to know the fluid Temperature?

1- The Fluid Vapor Pressure is determined by the Temperature of the fluid

The **vapor pressure of water** is the pressure at which water vapor is in thermodynamic equilibrium with its condensed state. At higher pressures than the vapor pressure water would condense.

| Temperature - *t* - ($^{o}F$) | Absolute Vapor Pressure - $p_v$ - (*psia, lb/in²*) |
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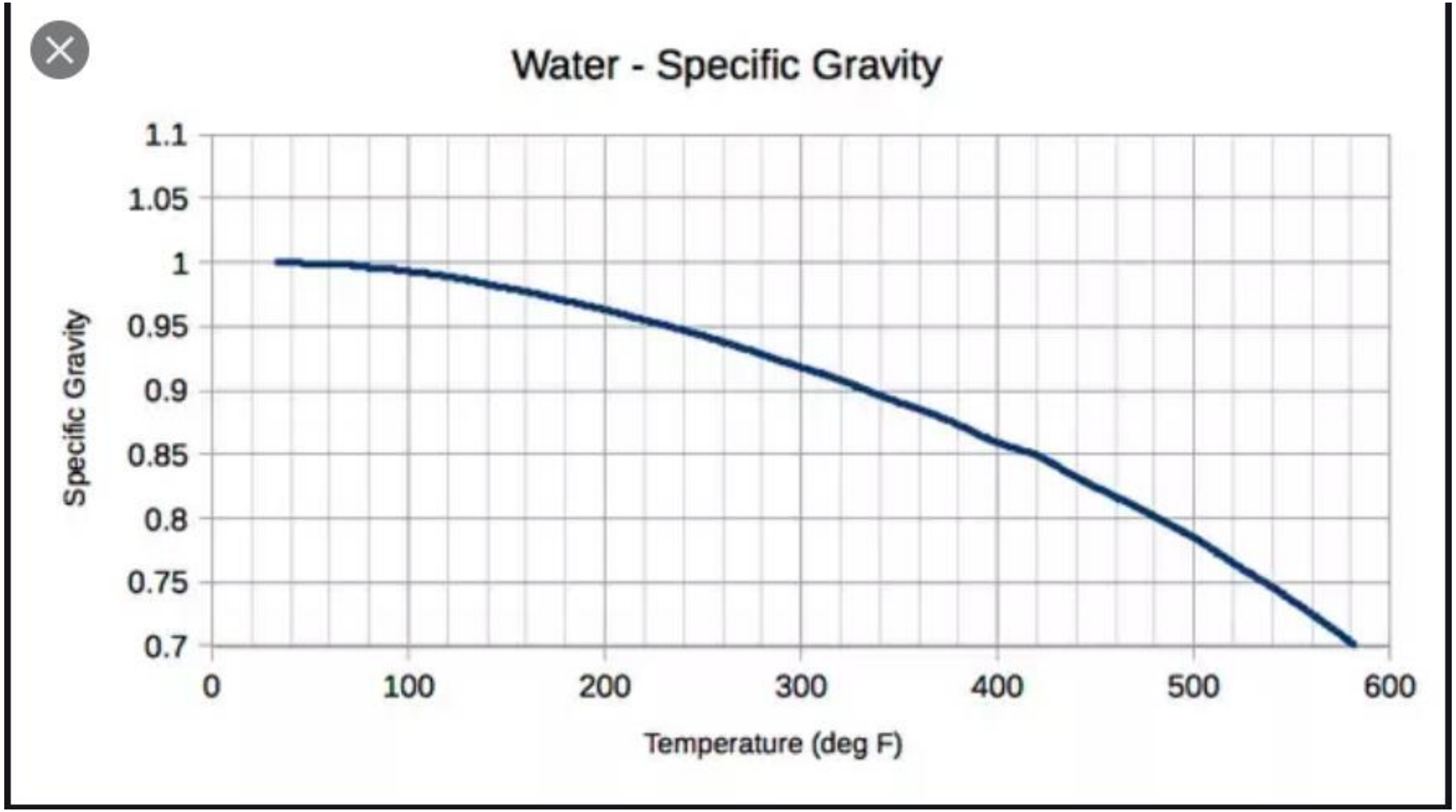
# Why is important to know the fluid Temperature?

2- The Specific Gravity of a Fluid varies with Temperature



# Required Data:

On/Off Valve

- Fluid name
- Line size (upstream and downstream)
- Temperature (min, normal, max)
- Operating pressure range
- End connections
- Material requirements
- Available air supply
- Actuator fail position
- Max shutoff pressure
- Actuator: Pneumatic or Electric
- Preferred valve style
- Speed requirement
- Accessories
- Accessory Voltage

Control Valve

- Fluid name and its properties
- Line size (upstream and downstream)
- Pipe schedule(upstream and downstream)
- Temperature (min, normal, max)
- Upstream pressure (min, normal, max)
- Downstream pressure (min, normal, max)
- End connections
- Pressure class
- Leakage rate
- Preferred valve style
- Material requirements
- Fail position
- Available air supply
- Max shutoff pressure
- Sound level requirements
- Control Signal
- Accessories

# Control Valve Leakage Classification - ANSI/FCI 70-2

| Leakage Class | Maximum Leakage Allowable |
|---|---|
| **Class I** | No test required |
| **Class II** | 0.5% of rated capacity |
| **Class III** | 0.1% of rated capacity |
| **Class IV** | 0.01% of rated capacity |
| **Class V** | 0.0005 ml per minute of water per inch of port diameter per psi differential |
| **Class VI** | Bubbles/min by port size |

# Isolation/Block Valve Shutoff Standards

## LEAKAGE COMPARISON

UNITS ARE IN DROPS OF LIQUID OR BUBBLES OF AIR

| Diameter | | API 598 Metal Seated | | MSS SP61 Metal Seated | | API 598/API 6D Soft Seated | FCI 70-2 Class VI |
|---|---|---|---|---|---|---|---|
| MM | INCH | Liquid | Air | Liquid | Air | Liquid/Air Diameter | Air |
| 80 | 3 | 12 | 24 | 0.5 | 160 | 0 | 6 |
| 100 | 4 | 12 | 24 | 0.7 | 200 | 0 | 11 |
| 150 | 6 | 12 | 24 | 1 | 300 | 0 | 27 |
| 200 | 8 | 20 | 40 | 1.3 | 400 | 0 | 45 |
| 250 | 10 | 20 | 40 | 1.7 | 500 | 0 | 63 |
| 300 | 12 | 20 | 40 | 2 | 600 | 0 | 81 |
| 350 | 14 | 28 | 56 | 2.3 | 700 | 0 | - |
| 400 | 16 | 28 | 56 | 2.7 | 800 | 0 | - |
| 450 | 18 | 28 | 56 | 3 | 900 | 0 | - |
| 500 | 20 | 28 | 56 | 3.3 | 1000 | 0 | - |
| 600 | 24 | 28 | 56 | 4 | 1200 | 0 | - |

# Specifying Control Valves

# Customer Supplied Operating Requirements

- Specify Control valve function i.e. daily start up, continuous or batch control, duration at min flow.
- Specify process data for normal flow, maximum flow, & minimum flow. (Fluid, Pressure Inlet & Outlet, Temperature)
- Provide process conditions which define the *performance* requirement of the control valve
- In the case of severe duty valves, service life expectation.
- Air supply or voltage available for actuation and accessories.

# Valve Supplier's Responsibility

- **Supplier's basic responsibility:**
  1. **Meet pressure boundary requirements**
  2. **Meet maximum flow capacity at 80 – 95% travel**
  3. **Meet the minimum flow with at least 10% travel**
- **Suppliers *performance* responsibility**
  1. **Confirm methodology for trim sizing,  do not exceed exit velocity limits, do not exceed maximum noise specified.**
  2. **Provide actuators that supply valve seat forces to meet seat leakage requirements.**

*Thanks for your time.*
*Questions/feedback please.*