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# Control Valve Basics:

## *Sizing and Selection*

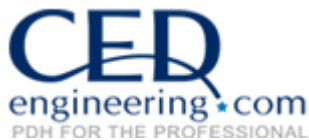
Course No: M04-034

Credit: 4 PDH

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## CONTROL VALVE BASICS – SIZING & SELECTION

### Introduction

A control valve is a power operated device capable of modulating flow at varying degrees between minimal flow and full capacity in response to a signal from the controlling system. Control valves may be broadly classified by their function as “on-off” type or “flow regulating” type.

A control valve is comprised of an actuator mechanism that is capable of changing the position of flow controlling element in the valve. The valve modulates flow through movement of a valve plug in relation to the port(s) located within the valve body. The valve plug is attached to a valve stem, which, in turn, is connected to the actuator. The actuator, which can be pneumatically or electrically operated, directs the movement of the stem as dictated by the external control device. The actuator responds to an external signal which usually comes from a controller. The controller and valve together form a basic control loop.

There are many types of valves available, each having their advantages and limitations. The basic requirements and selection depend on their ability to perform specific functions such as:

1. Ability to throttle or control the rate of flow;
2. Lack of turbulence or resistance to flow when fully open - turbulence reduces head pressure;
3. Quick opening and closing mechanism - rapid response is many times needed in an emergency or for safety;
4. Tight shut off - prevents leaks against high pressure;
5. Ability to allow flow in one direction only - prevents return;
6. Opening at a pre-set pressure - procedure control to prevent equipment damage; and
7. Ability to handle abrasive fluids - hardened material prevents rapid wear.

This course will discuss the selection process and provide the basic principles of sizing the control valves.

## BASIC VALVE TYPES

Valves are available with a wide variety of valve bodies in various styles, materials, connections and sizes. Selection is primarily dependent on the service conditions, the task, and the load characteristics of the application. The most common types are ball valves, butterfly valves, globe valves, and gate valves.

### Ball Valves:

Ball valves are a quick opening valves that give a tight shutoff. When fully open, a ball valve creates little turbulence or resistance to flow. The valve stem rotates a ball which contains an opening. The ball opening can be positioned in the fully open or fully closed position but must not be used to throttle flow as any abrasive wear to the ball will cause leakage when the valve is closed.

*Ball valves are considered high recovery valves, having a low pressure drop and relatively high flow capacity.*



Best Suited Control: Quick opening, linear

Recommended Uses:

- Fully open/closed, limited-throttling
- Higher temperature fluids

Applications:

- Ball valves are excellent in chemical applications, including the most challenging services (e.g. dry chlorine, hydrofluoric acid, oxygen).

- General sizes available are 1/2" to 12".
- Compliant with ASME is the flange rating, either 150, 300, 600, 900# or occasionally higher classes, enabling high performance ball valves to withstand up to 2250 psi.
- The operating temperature which is primarily dependent on seats and seals may be rated as high as 550°F.
- Standard valves comply with ASME face-to-face dimensions, making the ball valve easy to retrofit and replace.

Advantages:

- Low cost
- High flow capacity
- High pressure/temperature capabilities
- Low leakage and maintenance
- Tight sealing with low torque
- Easy quarter turn operation- desirable to most operators
- Fairly easy to automate.

Disadvantages:

- Limited throttling characteristics
- Prone to cavitation
- Not suitable for slurry applications due to cavities around the ball and seats. Slurries tend to solidify or clog inside the cavities, greatly increasing the operating torque of the valve and in some cases rendering the valve inoperable.

**Butterfly Valves:**

Butterfly valves consist of a disc attached to a shaft with bearings used to facilitate rotation. These are considered high recovery valves, since only the disc obstructs the valve flow path. The flow capacity is relatively high and the pressure drop across the valve is relatively low.

The butterfly valves are used for limited throttling where a tight shut off is not required. When fully open, the butterfly creates little turbulence or resistance to flow.



Best Suited Control: Linear, Equal percentage

Recommended Uses:

- Fully open/closed or throttling services
- Frequent operation
- Minimal fluid trapping in line
- Applications where small pressure drop is desired

Applications:

- Most economical for large lines in chemical services, water treatment, and fire protection systems. General sizes available are 2" to 48", although sizes up to 96" are available from certain manufacturers.
- Due to the valve design, incorporating a small face-to-face dimension and lower weight than most valve types, the butterfly valve is an economical choice for larger line sizes (i.e. 8" and above).
- The butterfly valve complies with ASME face-to-face dimensions and pressure ratings. This enables the valve to be easily retrofitted in line regardless of the manufacturer
- The ASME pressure classes adhered to by most manufacturers include 150, 300 and 600# allowing a maximum pressure of 1500 psi.

#### Applicable Standards:

- AWWA C504 for rubber-seated butterfly valves
- API 609 for lug and wafer type butterfly valves
- MSS SP-69 for general butterfly valves
- UL 1091 for safety butterfly valves for fire protection services

#### Advantages:

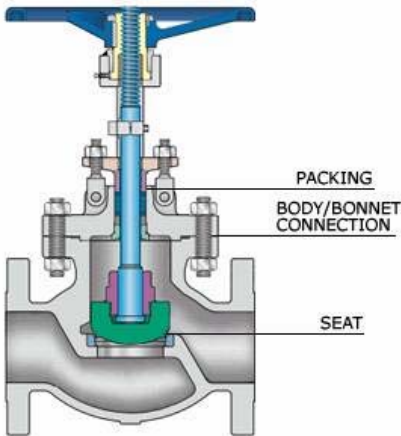
- Low cost and maintenance
- High capacity
- Good flow control
- Low pressure drop

#### Disadvantages:

- High torque required for control
- Prone to cavitation at lower flows
- Lack of cleanliness and inability to handle slurry applications.
- Generally not rated as bubble tight, and the cavities and leak paths around the disc stem are potential entrapments for fluids and slurries. Some high performance butterfly valves meeting ASME class VI leakage ratings are however available on demand.

#### **Globe Valves:**

Globe valves consist of a movable disk-type element and a stationary ring seat in a generally spherical body. The valve stem moves a globe plug relative to the valve seat. The globe plug can be at any position between fully opened and fully closed to control flow through the valve. The globe and seat construction gives the valve good flow regulation characteristics. Turbulent flow past the seat and plug, when the valve is open, results in a relatively high pressure drop, limited flow capacity, and low recovery.



Best Suited Control: Linear and Equal percentage

Recommended Uses:

Applications requiring:

- Precise flow regulation
- Frequent and wide throttling operation
- Suited to very high pressure drops

Applications:

- Suitable for most liquids, vapors, gases, corrosive substances
- General sizes available are 1/2" to 8".
- Pressure limitations are relatively high, ranging from 1480 to 1500 psi, dependent on materials of construction, size and temperature.
- Minimum and maximum temperatures are also very broad ranging from -425°F to 1100°F, depending again on the materials of construction.
- Depending on the specific construction and application, the globe valve may comply with ASME class II, III, IV, V or VI shut-off requirements.
- Easily automated and available with positioners, limit switches, and other accessories

Advantages:

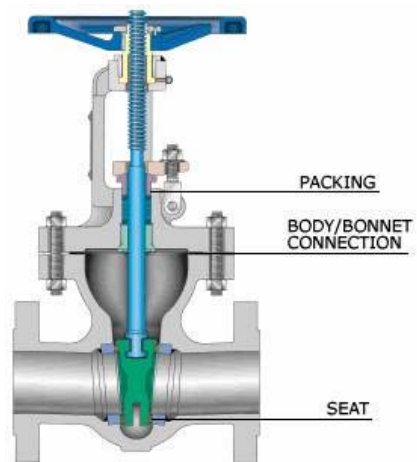
- Efficient and precise throttling
- Accurate flow control

Disadvantages:

- Low recovery and relatively low coefficient of flow (Cv).
- High pressure drop, higher pump capacity and system wear
- More expensive than other valves
- The sealing device is a plug that offers limited shut-off capabilities, not always meeting bubble tight requirements.

**Gate Valves:**

Gate valves use linear type of stem motion for opening and closing of a valve. These valves use parallel or wedge shaped discs as closure members that provide tight sealing.



Best Suited Control: Quick Opening

Recommended Uses:

- Fully open/closed, non-throttling
- Infrequent operation
- Minimal fluid trapping in line



#### Applications:

- Suitable for oil, gas, air, heavy liquids, steam, non-condensing gases, abrasive and corrosive liquids
- Sizes available range from standard cast configurations as small as 2" to special fabricated valves exceeding 100".
- Standard cast configurations have ASME 125/150 bolting patterns and are rated at 150 psi.

#### Advantages:

- High capacity
- Tight shutoff
- Low cost
- Little resistance to flow
- Ability to cut through slurries, scale and surface build-ups
- Provide unobstructed flow paths that not only provide high flow capacity (Cv), but even allows slurry, large objects, rocks and items routinely found in mining processes to safely pass through the valve.

#### Disadvantages:

- Poor control
- Cavitate at low pressure drops
- Cannot be used for throttling
- Relatively low pressure limitation - general pressure limitations are 150 psi at maximum.

***Refer to the summary table at the end of this section to check more valves and their characteristics.***

## ACTUATORS

A valve actuator is a device that produces force to open or close the valve utilizing a power source. This source of power can be manual (hand, gear, chain-wheel, lever, etc.) or can be electric, hydraulic or pneumatic.



Control valve with an actuator

Basic actuators turn valves to either fully opened or fully closed positions. But modern actuators have much more advanced capabilities. They not only act as devices for opening and closing valves, but also provide intermediate position with high degree of accuracy. The valve actuator can be packaged together with logic control and digital communication ability to allow remote operation as well as allowing predictive maintenance data.

### **Type of Actuators:**

Two types of actuators are common: pneumatic and electric actuators.

### **Pneumatic:**

Pneumatic actuators utilize an air signal from an external control device to create a control action via a solenoid. These are commonly available in two main forms: piston actuators and diaphragm actuators.

- **Piston actuators** - Piston actuators are generally used where the stroke of a diaphragm actuator would be too short or the thrust is too small. The compressed air is applied to a solid piston contained within a solid cylinder. Piston actuators can be single acting or double acting, can withstand higher input pressures, and can offer smaller cylinder volumes which can act at high speed.
- **Diaphragm actuators** - Diaphragm actuators have compressed air applied to a flexible membrane called the diaphragm. These types of actuators are single acting, in that

air is only supplied to one side of the diaphragm, and they can be either direct acting (spring-to-retract) or reverse acting (spring-to-extend).

Their range of applications is enormous. For example, the smallest can deliver a few inch-pounds of torque where the largest are capable of producing in excess of a million inch-pounds of torque.

### **Electric:**

Electric actuators are motor driven devices that utilize an electrical input signal to generate a motor shaft rotation. This rotation is, in turn, translated by the unit's linkage into a linear motion, which drives the valve stem and plug assembly for flow modulation. In case of electric signal failure, these actuators can be specified to fail in the stem-out, stem-in, or last position. Commonly used motors for electric actuators include steppers and servos.

- A step motor uses gears with increments in the range of 5,000 to 10,000 at 90 degree rotation for accurate positioning at lower speeds. The disadvantage is that steppers may lose synchronization with the controller when employed in an open loop without an encoder or if they are undersized for an application.
- Servos, by definition, are closed loop and provide superior performance at high speeds, but at a higher cost. High precision screws and anti-backlash mechanics provide accuracies to ten-thousandths of an inch. Standard precisions with standard components range from a few hundredths to a few thousandths of an inch.

Brush DC motors and AC motors are sometimes used with limit switches when positioning accuracy is less critical. The motor is connected to a gear or thread that creates thrust to move the valve. To protect the valve the torque sensing mechanism of the actuator turns off the electric motor when a safe torque level is exceeded. Position switches are utilized to indicate the open and closed position of the valve. Typically a declutching mechanism and hand wheel are included so that the valve can be operated manually should a power failure occur.

### **Pneumatic v/s Electric Actuators:**

The major difference between pneumatic and electronic actuators is the speed of operation. The two technologies are so different that one cannot be a drop-in replacement for the other. Each has inherent advantages and disadvantages.

### Advantages of Pneumatic Actuators

- The biggest advantage of the pneumatic actuators is their failsafe action. By design of the compressed spring, the engineer can determine if the valve will fail closed or open, depending on the safety of the process.
- Provide high force and speed, which are easily adjustable and are independent of each other
- Have a delayed response which makes them ideal for being resilient against small upsets in pressure changes of the source.
- Most economical when the scale of deployment matches the capacity of the compressor.
- Provide inherent safety and are ideal for hazardous and explosive environment.
- Low component cost and smaller footprint. Prices for non-repairable, rod-type cylinders range from \$15 to \$250 depending on body diameter, stroke and options.

### Limitations of Pneumatic Actuators

- Maintenance and operating costs can be high, especially if a serious effort has not been made to quantify and minimize the costs. Maintenance costs include replacement cylinder costs and plugging air-line leakages whereas the operating costs include the cost of compressed air, i.e. electricity for the compressor.

### **Electric actuators:**

#### Advantages

- Provide precise control and positioning in comparison to pneumatic actuators.
- Response time is essentially instantaneous.
- High degree of stability.
- Help adapt machines to flexible processes.
- Low operating cost. Controllers and drivers low voltage circuitry consume power to a far lesser degree.

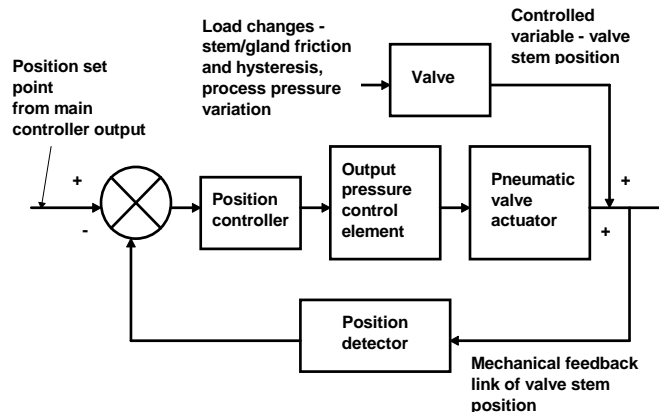
## Disadvantages

- The primary disadvantage of an electric actuator is that, should a power failure occur, the valve remains in the last position and the fail-safe position cannot be obtained easily unless there is a convenient source of stored electrical energy.
- Higher cost than pneumatic actuators. The total cost ranges from \$800 to \$3,000 and up. High component costs often deter the use of electric actuators because savings in operating costs compared to pneumatics are often not adequately considered or are outright ignored.
- The actuator needs to be in an environment that is rendered safe. Generally not recommended for flammable atmospheres.

## **VALVE POSITIONER**

Valve positioner is a control device designed to impart sensitivity to the valve and to ensure accurate positioning as dictated by a control signal. It receives an electronic or pneumatic signal from a controller and compares that signal to the actuator's position. If the signal and the actuator position differ, the positioner sends the necessary power—usually through compressed air—to move the actuator until the correct position is reached.

A positioner may be used as a signal amplifier or booster. It accepts a low pressure air control signal and, by using its own higher pressure input, multiplies this to provide a higher pressure output air signal to the actuator diaphragm, if required, to ensure that the valve reaches the desired position. Some positioners incorporate an electro-pneumatic converter so that an electrical input (typically 4 to 20 mA) can be used to control a pneumatic valve. Some positioners can also act as basic controllers, accepting input from sensors.



**Block-diagram of the control valve assembly**

## When should a positioner be fitted:

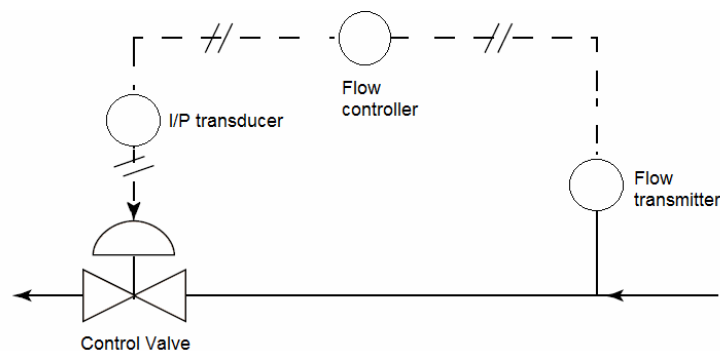
A positioner should be considered in the following circumstances:

- When accurate valve positioning is required;
- To speed up the valve response. The positioner uses higher pressure and greater air flow to adjust the valve position;
- To increase the pressure that a particular actuator and valve can close against. (To act as an amplifier);
- When the valve pressure drop at the maximum operating flowrate, exceeds 5 bar for single seated valves or 10 bar for double seated valves;
- To linearize a non-linear actuator;
- Where varying differential pressures within the fluid would cause the plug position to vary;
- When controlling with wide throttling range; and
- When valves are handling sludge or solids in suspension.

Furnish positioners for all control valves in critical service and where the variable, such as flow, has to be closely controlled. Specify that the positioner be furnished with the control valve or damper instead of separate procurement.

## CONTROLLING THE VALVE

A control loop consists of a sensing element, a controller and the final control element - the valve and its actuator.



The sensing element transmits a signal to a single controller or a distributed control system (DCS). The controller compares the signal with the setpoint, and then makes any needed corrections by sending a signal to the control valve. The correction is measured and verified by the sensing element, completing the loop. The I/P transducer changes an electronic signal into one that is pneumatic. A control valve should react instantaneously to any change in the signal. To be effective, a valve should: operate over a wide range of flows (have a wide rangeability); accurately respond to any signal across its operating range; exhibit little dead time or hysteresis; react to incremental adjustments from the controller (resolution); and respond with the required speed (stroking speed).

A fast response may not be suitable for all applications. For example, a quick or sudden reduction in the bore of a valve in a pipeline may be harmful, causing a shock wave. A valve's ability to control flow depends upon the quality of its actuator. A positioner may be added to obtain a more-precise response and tighter control. The quality of any control device can be quantified in terms of its gain, time constant and dead-time lag. Of these, the gain is the most important for a control valve. **Gain** is the ratio of the percentage change in a process variable to the percentage change of the valve travel. Gain depends upon the valve characteristics and process conditions.

**Summary of Valve Types:**

VALVE TYPE	CHARACTERISTICS
Globe valve	<ul style="list-style-type: none"> <li>• Suitable for regulating flow</li> <li>• Tight shut-off</li> <li>• Pressure drop when open</li> <li>• Used for high pressure clean fluids</li> </ul>
Needle valve	<ul style="list-style-type: none"> <li>• Suitable for regulating flow</li> <li>• Fine control in small diameter piping</li> <li>• Tight shut-off</li> <li>• Used for clean fluids that have low flows</li> <li>• High pressure drop when open</li> </ul>

Ball valve	<ul style="list-style-type: none"> <li>• Not suitable for regulating flow except in some specialized ball valves</li> <li>• Tight shut-off</li> <li>• Low pressure drop when open</li> <li>• Used for gas, liquids or slurries</li> </ul>
Butterfly valve	<ul style="list-style-type: none"> <li>• Suitable for regulating flow</li> <li>• Not suitable for tight shut-off</li> <li>• Low pressure drop when open</li> <li>• Used for low line pressure and large pipe line diameters</li> <li>• Wide range of service: gas, liquids and slurries</li> </ul>
Gate valve	<ul style="list-style-type: none"> <li>• Not suitable for flow regulation, only suitable for on or off</li> <li>• Tight shut-off</li> <li>• Low pressure drop when open</li> </ul>
Diaphragm valve	<ul style="list-style-type: none"> <li>• Suitable for on/off or narrow range throttling control</li> <li>• Tight shut-off</li> <li>• Low pressure drop when open</li> <li>• Used for corrosive fluids and slurries</li> </ul>
Plug valve	<ul style="list-style-type: none"> <li>• Suitable for regulating flow</li> <li>• Tight shut-off</li> <li>• Quick opening</li> <li>• High pressure drop when open</li> </ul>

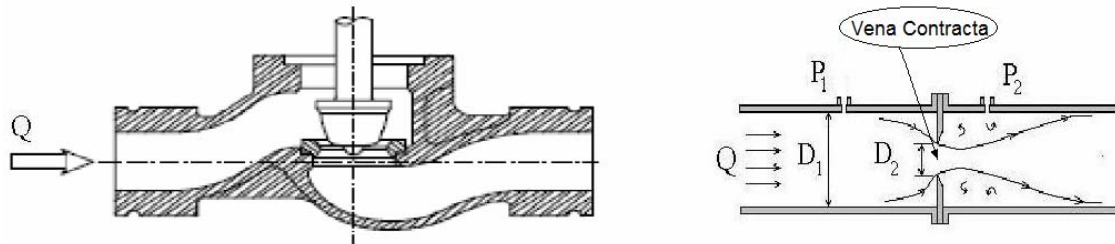


Non-return valve	<ul style="list-style-type: none"><li>• Allow flow in one direction only</li><li>• Self closing</li><li>• Low pressure drop when open</li><li>• Not suitable for reciprocating pump discharge</li></ul>
Pressure relief valve	<ul style="list-style-type: none"><li>• Opens at pre-determined pressure level</li></ul>

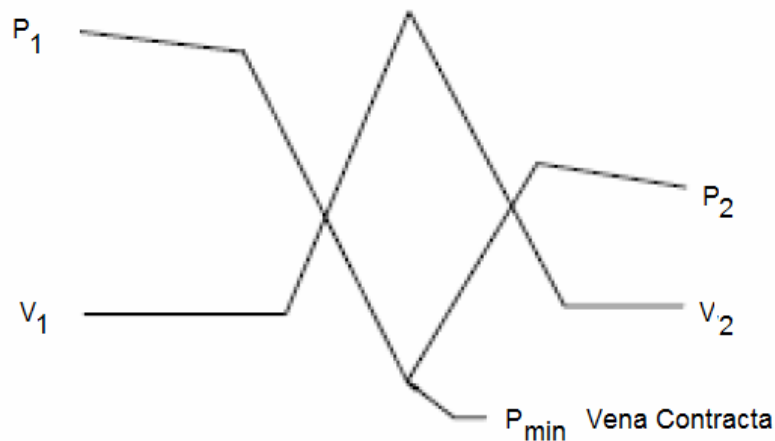
## SECTION -2:

## CONTROL VALVE FUNDAMENTALS

The flow regulation in a valve is accomplished by the varying resistance as the valve is stroked, i.e. its effective cross sectional area is changed. As the fluid moves from the piping into the smaller diameter orifice of the valve, its velocity increases to enable mass flow through the valve. The energy needed to increase the velocity comes at the expense of the pressure, so the point of highest velocity is also the point of lowest pressure (smallest cross section). The point where the pressure is at the lowest is called "vena contracta". To display the general behavior of flow through a control valve, the valve is simplified to an orifice in a pipeline as shown in the figure below:



As the liquid passes the point of greatest restriction (vena contracta); its velocity reaches a maximum and its pressure falls to a minimum. Hence we would expect the highest velocity at the internal to the valve than on upstream and downstream. Beyond the vena contracta, the fluid's velocity will decrease as the diameter of piping increases. This allows for some pressure recovery as the energy that was imparted as velocity is now partially converted back into pressure (refer pressure-velocity profile below).



**Static Pressure and Velocity Profiles across the Control Valve**

It is important to understand how the pressure-velocity conditions change as the fluid passes through the restriction. This is best described by the continuity equation:

$$V_1 * A_1 = V_2 * A_2$$

Where:

- V = mean velocity and
- A = flow area.
- Subscript 1 refers to upstream conditions
- Subscript 2 refer to downstream conditions

The equation shows that the velocity and hence the pressure can be changed by adjusting the valve opening (area). With this introduction, we will jump straight to control valve basics and the readers interested in further reading should read the basic principles of hydraulics.

### **Control Valve Capacity - Cv:**

For sizing a control valve we are interested in knowing how much flow we can get through the valve for any given opening of the valve and for any given pressure differential. The relationship between pressure drop and flow rate through a valve is conveniently expressed by a flow coefficient (Cv).

#### What is Flow Coefficient (Cv)?

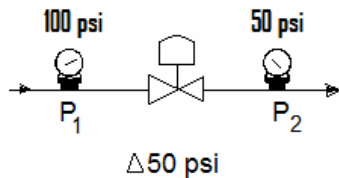
Flow coefficient (Cv) is defined as the number of gallons per minute (gpm) at 60°F that will pass through a full open valve with a pressure drop of 1 psi. Simply stated, a control valve which has a Cv of 12 has an effective port area in the full open position such that it passes 12gpm of water with 1 psi pressure drop. The Cv for water is usually determined experimentally by measuring the flow through a valve with 1 psi applied pressure to the valve inlet and have a 0 psi pressure at the outlet.

For incompressible fluids like water, a close approximation can be found mathematically by the following equation;

$$C_v = Q \sqrt{(S / \Delta P)}$$

Where,

- $C_v$  = Valve flow coefficient
- $Q$  = Fluid flow, US GPM (also given by Area of pipe x mean velocity)
- $S$  = Specific gravity of fluid relative to water @ 60°F
- $\Delta P$  = Pressure drop ( $P_1 - P_2$ ) across the control valve at maximum flow, psi



The equation shows that the flow rate varies as the square root of the differential pressure across the control valve. Greater the pressure drop, higher will be the flow rate. Pressure drop across a valve is highly influenced by the area, shape, path and roughness of the valve.

**Example:**

Assume there is a 15 psi pressure drop across a control valve when the valve is wide open with a flow rate of 150 gpm of water through the valve. The specific gravity of water is one. The valve coefficient can be calculated as:

$$C_v = 150 * (1 / 15)^{1/2} = 38.72 \text{ gpm}$$

Once we know the valve coefficient, we can then calculate the pressure drop across the valve for a given flow rate, OR a flow rate for a given pressure drop. For example, determine the pressure drop across the above valve if the flow rate increases to 200 gpm.

$$\Delta P = (Q / C_v)^2 \times S = (200 / 38.72)^2 \times 1 = 26.68 \text{ psi}$$

In practice, once you know the design flow rate and the desired pressure drop, one can calculate the required valve  $C_v$  and select a proper valve from the manufacturers' literature.

**Note:**

The  $K_v$  value is the metric equivalent of  $C_v$  expressed in in  $m^3/hr$  with 1 bar pressure drop at a temperature between 5 °C and 40 °C.  $C_v = 1.15 \times K_v$ .

### **Choked Flow:**

The flow coefficient (Cv) equation illustrates that the flow rate through a valve (Q) increases with the pressure differential ( $\Delta P$ ). Simply stated, as the pressure drop across the valve gets larger, more flow will be forced through the restriction due to the higher flow velocities.

$$Q = C_v \sqrt{(\Delta P / S)}$$

In reality, the above relationship only holds true over a limited range. As the pressure drop across the valve is increased, it reaches a point where the increase in flow rate is less than expected. This continues until no additional flow can be passed through the valve regardless of the increase in pressure drop. This condition is known as choked flow.

Choked flow (otherwise known as critical flow) takes place:

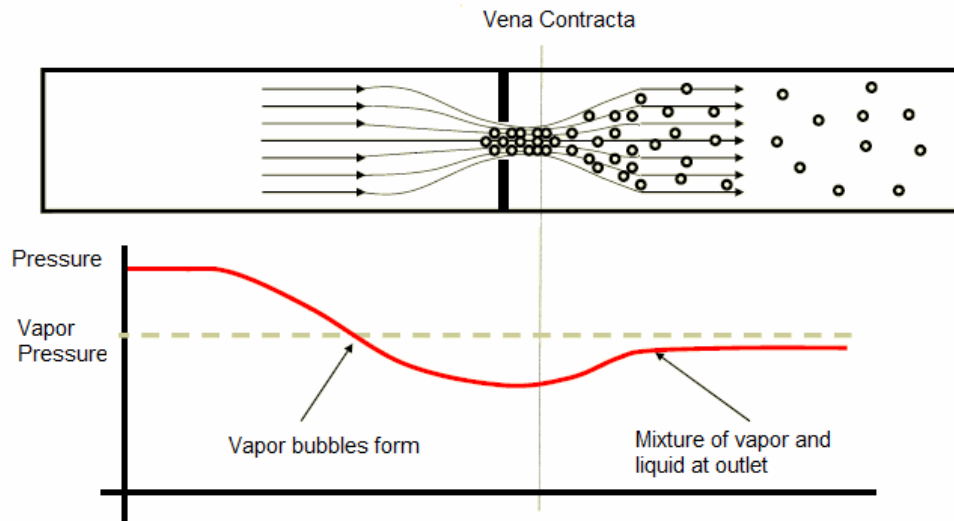
- When an increase in pressure drop across the valve no longer has any effect on the flow rate through the valve.
- When the velocity of the gas or vapor reaches sonic velocity (Mach 1) at the vena contracta.

To understand more about what is occurring, it is necessary to return to the basics again. Recall that as a liquid passes through a restriction, the velocity increases to a maximum and the pressure decreases to a minimum. As the flow exits, velocity is restored to its previous value, while the pressure never completely recovers, thus creating a pressure differential across the valve. If the pressure differential is sufficiently large, the pressure may, at some point, decrease to less than the vapor pressure of the liquid. When this occurs, the liquid partially vaporizes and is no longer incompressible.

It is necessary to account for choked flow during the sizing process to ensure against undersizing a valve. In other words, it is necessary to know the maximum flow rate that a valve can handle under a given set of conditions. When selecting a valve, it is important to check the pressure recovery characteristics of valves for the thermodynamic properties of the fluid. High recovery valves, such as ball and butterfly, will become choked at lower pressure drops than low recovery valves such as globe which offer a more restricted flow path when fully open.

### **Flashing;**

As previously mentioned, at the point where the fluid's velocity is at its highest, the pressure is at its lowest. Assuming the fluid is incompressible (liquid), if the pressure falls below the liquid's vapor pressure, vapor bubbles form within the valve and collapse into themselves as the pressure increases downstream. This leads to massive shock waves that are noisy and will certainly ruin the equipment.



**Requirements for occurrence of flashing:**

- The fluid at the inlet must be in all-liquid condition, but some vapor must be present at the valve outlet;
- The fluid at the inlet may be in either a saturated or a subcooled condition; and
- The valve outlet pressure must be either at or below the vapor pressure of the liquid.

**Flashing effects:**

- Material damage is associated with the formation of sand-blasted surfaces;
- Decreased efficiency - valve ability to convert pressure drop across the valve into mass flowrate is compromised.

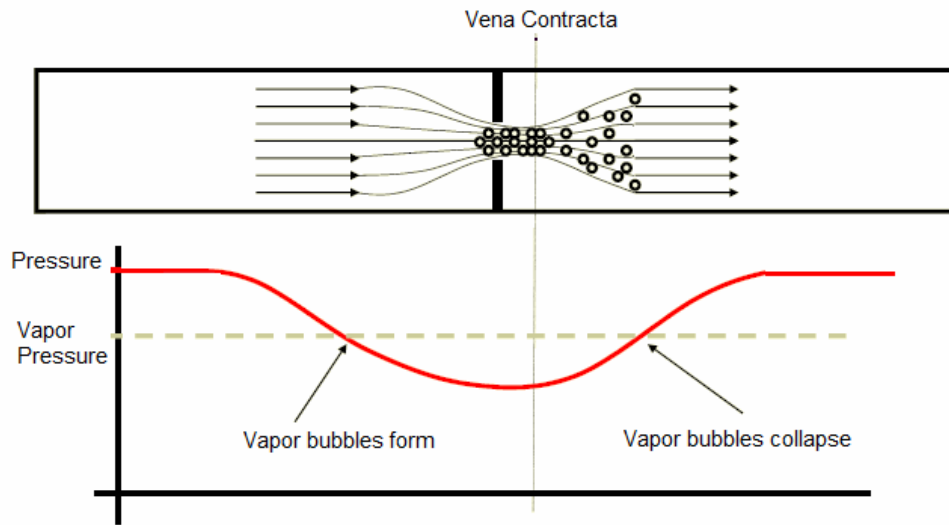
**How can flash damage be contained:**

Under such scenario, there are two phases flowing downstream of the valve: liquid and vapor. Flashing cannot be eliminated in the valve if the downstream pressure is less than the vapor pressure of liquid. However, the damage can be minimized by:

- Hard face trim (using hard facing materials such as Stellite or Tungsten Carbide), more erosion resistant body material.
- Increasing size of the valve, therefore reducing the velocity
- Using angle valve – flow over plug

**Cavitation:**

Cavitation is similar to flashing in a way that the liquid pressure drops to value below its vapor pressure, causing a liquid to vaporize into vapor bubbles. Both cavitation and flashing occurs because the pressure energy in a fluid is converted to kinetic energy due to the contraction at the valve closure member, causing an increase in velocity. In addition, as the temperature of the liquid increases, the likelihood of cavitation becomes more likely because of the increased vapor pressure. The extent of the cavitation depends mainly on the downstream pressure and the differential pressure across the valve.



The difference is that with the cavitation phenomenon, the liquid pressure increases over its vapor pressure during pressure recovery and turns back into liquid state while during flashing the liquid pressure remains below the vapor pressure throughout. The key differences are:

<b>Requirements for occurrence of cavitation:</b>	<b>Requirements for occurrence of flashing:</b>
The fluid at both the inlet and outlet must be in all-liquid condition.	The fluid at the inlet must be in all-liquid condition, but some vapor must be present

	at the valve outlet.
The liquid must be sub-cooled state at the inlet, because if the liquid will be in a saturated state, then any pressure drop across the valve will cause the presence of vapor downstream.	The fluid at the inlet may be in either a saturated or a sub-cooled condition.
The valve outlet pressure must be either at or above the vapor pressure of the liquid.	The valve outlet pressure must be either at or below the vapor pressure of the liquid.

### **How to avoid Cavitation:**

If cavitation is ever encountered, consider the following corrective actions:

1. The first is to equip the control valve with special trim and ensure that the plug and seat are made of a hard facing material that can resist both the onset and effect of cavitation (e.g. stellite hard facing).
2. The second is to use a valve with a low recovery coefficient (see below).
3. The third is to increase the downstream pressure by installing a flow restrictor if possible or reducing the pipe size of a short piece downstream.

### **Valve Recovery Coefficient:**

Valve recovery refers to the pressure recovery from the low pressure at vena contracta to the valve outlet. The term "valve recovery" is usually applied when a valve is employed as a restriction. It is a given that any valve could cause cavitation to a differing degree and in different closure positions. If using a valve to cause a pressure drop as compared to control the flow of volume, it is safe to say that a low recovery valve will resist causing cavitation more than a high recovery type.

The valve recovery coefficient is a dimensionless, numerical factor that represents a valve's flow vs. liquid pressure curve, and thus the valve's tendency to cavitate. If this factor is higher than desired, cavitation might develop. The valve coefficient is affected by the internal geometry of the valve, valve size, pressure, and the presence or absence of piping reducers adjacent to the valve.



## CONTROL VALVE CHARACTERISTICS

Each valve has a flow characteristic, which describes the relationship between the flow rate and valve travel. As a valve opens, the flow characteristic, which is inherent to the design of the selected valve, allows a certain amount of flow through the valve at a particular percentage of the stroke. This enables flow regulation through the valve in a predictable manner. The three most common types of flow characteristics are:

1. Linear
2. Equal percentage
3. Quick opening

### Linear valve characteristics:

This characteristic provides a linear relationship between the valve position and the flowrate. The flow through a linear valve varies directly with the position of the valve stem. This flow-travel relationship, if plotted on rectilinear coordinates, approximates a straight line, thereby giving equal volume changes for equal lift changes regardless of percent of valve opening.

These valves are often used for liquid level control and certain flow control operations requiring constant gain.

### Equal percentage valve characteristics:

The equal percentage valve plug produces the same percentage change in flow per fixed increment of valve stroke at any location on its characteristic curve. For example, if 30% stem lift produces 5 gpm and a lift increase of 10% to 40% produces 8 gpm or a 60% increase over the previous 5 gpm, then a further stroke of 10% now produces a 60% increase over the previous 8 gpm for a total flow of 12.8 gpm.

### Comparison of Equal Percentage Change between Lift and Flow

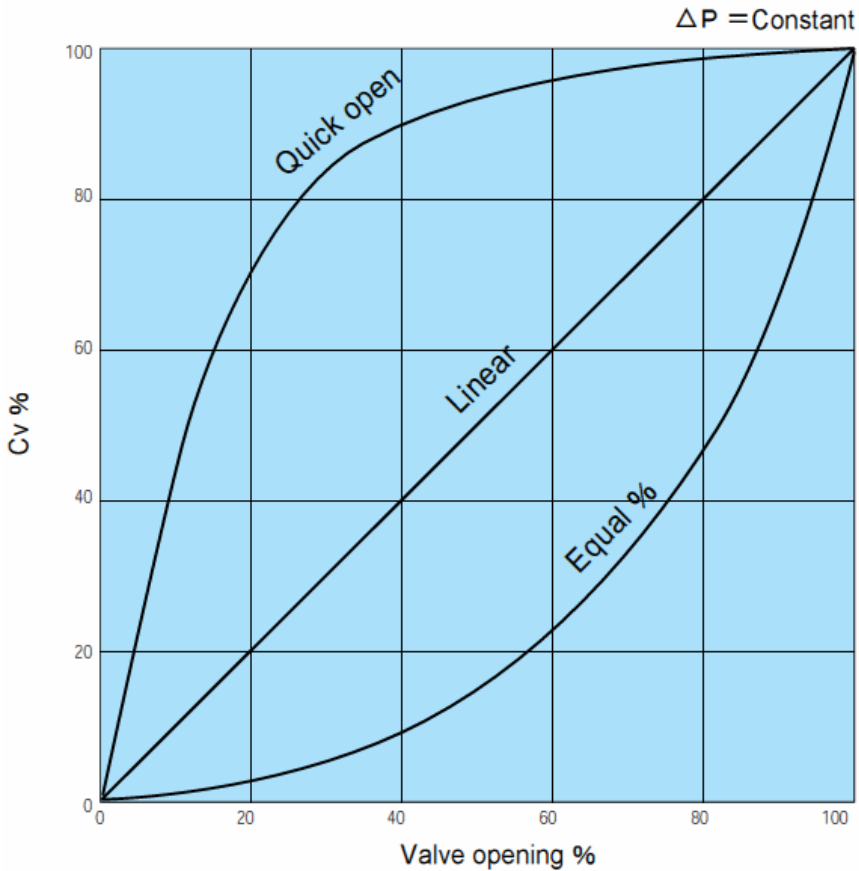
Lift (%open)	Change %	Flowrate	Change %
30%		5 GPM	
	10%		60%
40%		8 GPM	

	10%		60%
50%		12.8 GPM	

These types of valves are commonly used for pressure control applications and are most suitable for applications where a high variation in pressure drop is expected.

**Quick opening valve characteristics:**

A quick opening valve plug produces a large increase in flow for a small initial change in stem travel. Near maximum flow is reached at a relatively low percentage of maximum stem lift. Quick opening plugs are normally utilized in two position “On-Off” applications but may be used in some linear valve applications. This is possible because of its initial linear characteristic at a low percentage of stem travel. The slope of this linear region is very steep which produces a higher initial gain than the linear plug but also increases the potential instability of the control valve.



**Commonly observed inherent flow characteristic types**

### **Inherent valve characteristics:**

An inherent flow characteristic is the relation between valve opening and flow under constant pressure conditions. The inherent characteristic of a valve is obtained when there is a constant pressure drop across the valve for all valve positions; the process fluid is not flashing, cavitating or approaching sonic velocity (choked flow); and the actuator is linear (valve stem travel is proportional to the controller output).

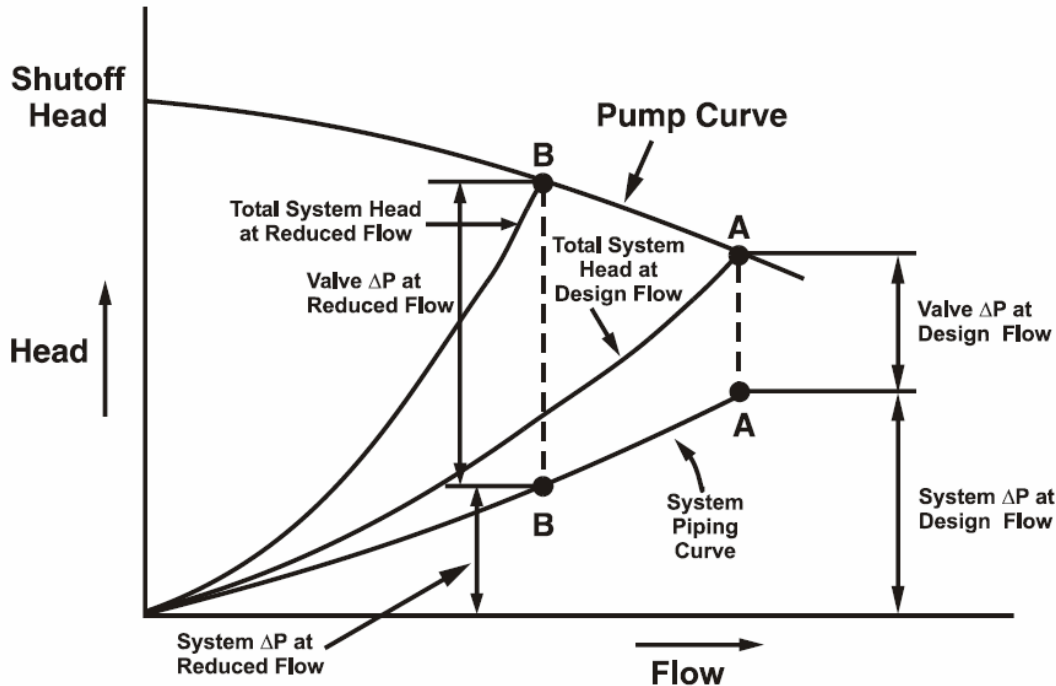
Some valves have inherent characteristics that cannot be changed, such as full port ball valves and butterfly valves. For other valve types, such as the globe type, the inherent characteristics can be changed to suit the application.

### **Difference between installed and inherent characteristics:**

The inherent flow characteristics do not reflect the actual performance of the valve as installed. The ideal condition of constant valve pressure drop ( $\Delta P$ ) is unlikely to be true and the 'operating' characteristics will have deviation from the inherent characteristics and is termed the "**Installed Flow Characteristics**".

The deviation in the characteristics depends on the pressure drop variation across the control valve, as the control valve operates from minimum flow at its initial travel position to its maximum flow at its fully opened position. The variations in pressure drop across the valve can be attributed to two basic causes:

1. The pump characteristic which results in an increase in pump head as the flow is reduced; and
2. The reduction in line losses as the flow is reduced, causing more and more of the pump head to appear across the valve.



In a pipeline carrying fluid, the dynamic system pressure ( $P_s$ ) is made up of two components: 1) the pressure drop across the control valve ( $P_v$ ) and 2) the pressure drop along the pipeline ( $P_L$ ), excluding any fixed static or elevation pressure head component. It is given by:

$$P_s = P_v + P_L$$

In the pump curve above, the point “A” is the point where the system resistance curve crosses the pump characteristic curve and indicates the operating conditions (flow and head). As the valve modulates to the closed position; the resistance to the system flow that the valve provides (valve pressure drop) will increase by shifting from point “A” towards point “B”. This increasing resistance will use more of the head in the system, as well as decrease system flow.

- Pressure drop across the control valve increases ( $\Delta P_v - \uparrow$ ). The change in pressure drop across the valve can be attributed to two basic causes: 1) the pump characteristic, which results in an increase in pump head as the flow is reduced, and 2) the reduction in line losses as the flow is reduced, causing more and more of the pump head to appear across the valve. The amount that the pump head will increase with a decrease in system flow will depend upon the operating characteristics of the pump. A pump with a steep characteristic will produce a considerable increase in pressure head as the system resistance is increased. However, a flat characteristic

pump will produce a relatively constant, high pressure head for any system flow. The relatively constant pressure would be preferable from a control standpoint.

- Pressure loss in the pipeline reduces ( $\Delta P_L - \downarrow$ ). This is because the decrease in system flow will result in a decrease in pressure drop along the pipeline and is proportional to the square root of the flow rate.

This indicates that the pressure drop across the valve in the system is not constant and it varies with flow and other changes in the system. This has a significant impact on the actual installed valve flow characteristic. The deviation from the inherent flow characteristic is a function of a property called **Valve Authority**. It is defined as the ratio of the full flow valve pressure drop to the system pressure drop (including the valve)

$$N = \frac{\Delta P_v}{\Delta P_s} = \frac{\Delta P_v}{\Delta P_v + \Delta P_L}$$

Where:

- $N$  = Valve Authority
- $\Delta P_v$  = Pressure drop across the control valve
- $\Delta P_L$  = Pressure drop due to pipeline friction losses
- $\Delta P_s$  = System pressure drop =  $\Delta P_v + \Delta P_L$

When “N” approaches 1.0, then  $\Delta P_L$  is almost zero and  $\Delta P_v$  approaches  $\Delta P_s$ . This satisfies the requirement for the definition of valve inherent characteristics.

Distortion occurs when “N” falls from 1.0. This is the situation when the pipeline system pressure drop ( $\Delta P_s$ ) is not concentrated at the control valve alone but well distributed along the pipeline. An inherently equal % characteristics control valve operating under such condition will behave like a linear valve and an inherently linear characteristics control valve will behave like a quick-opening control valve.

The effect of these system variables can be minimized by keeping the relative change in valve pressure drop as small as possible.

When the total flow is low, control valve pressure drop tends to be large fraction of the total system pressure loss; but at high flows this may not be true. A good design will respond well over the full range of conditions, hence it is important to pick the right characteristic for your

system and size the valve for the right amount of pressure drop. For good control, it is nice to take a fairly large pressure drop across a control valve. This way it will have a big influence on the total system, making the operators and control engineers happy. However, design engineers will worry that increasing pressure drop will tend to increase pumping and other operating costs. Compromise is necessary. As a rule of thumb, design the system and size the valve so that 25 to 33% (1/3<sup>rd</sup>) of the total system pressure drop (including the valve) is taken across the control valve, with a minimum of 10-15 psig.

At this point, let's define two additional terms: 1) **Rangeability**, and 2) **Turndown** and define their relationship with respect to valve authority.

**Valve Rangeability** - Rangeability indicates the extent of flow values that the valve can reliably regulate and is often reported as a ratio of the largest to the smallest flows that can be controlled acceptably.

$$\text{Rangeability} = \frac{\text{Maximum Flow}}{\text{Minimum Controllable Flow}}$$

A control valve with higher rangeability will control flow over wider flow rates. For example, a valve with a rangeability of 50 and having a total flow capacity of 100 GPM, will control flow accurately down to as low as 2 GPM when fully open. Rangeability is affected by three factors:

1. Valve geometry – inherent rangeability due to the design of the body and the regulating element.
2. Seat leakage – excessive seat leakage can cause instability as the valve lifts off of the seat.
3. Actuator – diaphragm actuators are seldom accurate at less than 5% of the valve opening, whereas piston-cylinder actuators can provide control within 1% of valve lift due to the presence of air in two chambers.

Valves with high rangeability are sometimes desirable but these will be expensive to manufacture since very close tolerances are involved between the disc and the seat. A typical commercial valve generally has a rangeability of about 35 to 50.

**Turndown** - It is the ratio between maximum usable flow and the minimum controllable flow; usually less than the rangeability. For instance, as stated above, after the 100 GPM valve has been applied at a job, it might turn out that the most flow you would ever need through

the valve is 68 GPM. Since the minimum controllable flow is 2 GPM, the turndown for this valve is 34 to 1. In comparing rangeability and turndown, we may say that rangeability is a measure of the predicted stability of the control valve, and turndown is a measure of the actual stability of the valve.,

**Note:**

*The term rangeability applies to the valve whereas the term turndown applies to the application. The rangeability of the selected valve must exceed the turndown requirements of the application.*

Mathematically we can define rangeability as:

$$R = (Q_{\max} / Q_{\min}) \times \beta^{1/2}$$

Where:

- R = valve rangeability
- Qmax = design flow rate
- Qmin = controllable flow rate
- $\beta$  = installed valve authority

The minimum controllable flow rate through a valve is a function of the valve design. It is directly affected by all sources of friction within the valve assembly. In an ideal valve, any change in the signal applied to the actuator, even an infinitely small change, will force the valve stem to move, even if that movement is infinitely small. However, friction represents a force that must be overcome by the actuator. When the actuator exerts sufficient force to overcome friction, the valve stem will move some finite amount. When this occurs when the valve is fully closed, this finite movement results in a certain minimum flow rate.

**Example:**

A valve has an installed authority of 35%. The design flow rate is 350 gpm. For good low-flow control, we wish a minimum flow rate of not more than 2 gpm. We can calculate the required rangeability as:

$$R = (350 / 2) \times 0.35^{1/2} = 123$$

This means the valve must have a manufacturer's rangeability rating of 123:1 or greater. A typical commercial valve generally has a rangeability of about 50:1. Industrial valves can have a rangeability as high as 200:1. This is part of the reason why industrial valves are so much more costly than a commercial valve.

### ***Summarizing....***

The installed characteristic of a control valve matches the inherent characteristic of a control valve:

- When the friction losses in the pipeline are negligible and the major drop is due to control valve.
- When the valve authority approaches 1.
- When the valve pressure drop at the maximum flow rate is nearly  $1/3^{\text{rd}}$  of the overall system pressure drop (valve + line).

### **General rules:**

How do you decide which valve control to use?

Here are some rules of thumb:

### **Linear Characteristics:**

- Used in liquid level or flow loops.
- Used in systems where the pressure drop across the valve is expected to remain fairly constant (i.e. steady state systems).
- Used when the pressure drop across the valve is a large proportion of the total pressure drop.

### **Equal Percentage Characteristics:**

- Used in processes where large changes in pressure drop are expected.
- Used in processes where a small percentage of the total pressure drop is permitted by the valve.
- Used in temperature and pressure control loops.



### **Quick Opening Characteristics:**

- Used for frequent on-off service.
- Used for processes where "instantly" large flow is needed (i.e. safety systems or cooling water systems).

Two rules of thumb for choosing the right flow characteristic:

1. If most of the pressure drop is taken through the valve and the upstream pressure is constant, a linear characteristic will provide better control.
2. If the piping and downstream equipment cause significant resistance to the system, equal percentage will provide better control.

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### **SECTION - 3:**

### **CONTROL VALVE SIZING PARAMETERS**

The valve is very important component of any process system. It is important not to choose a valve that is too small or too large.

- If the control valve is undersized ( $C_v$  - too small), the required flow rate will not be achieved even when the valve is fully opened. If a higher pressure is applied to force a higher flow rate across the undersized valve; not only the pump energy will be excessive but also the valve may cavitate or develop flashing.
- If a selected control valve is too large ( $C_v$  – too large), it will not provide the desired control and may cause the system to hunt or cycle. When a valve is operated at below 10% of its  $C_v$  for an extended period of time, the valve seat and the closure member may get damaged.

Control valve sizing and selection is based on a combination of theory and empirical data. Typical parameters used to select a valve are:

- Flow medium
- Service requirements (flow regulation or on-off type)
- Pressure-Temperature rating
- Material of construction
- Valve Action (Normally Open vs. Normally Closed)
- Valve size or valve coefficient ( $C_v$ )
- Precision control
- Leakage or Tight shut-off

#### **Flow medium:**

Identifying the fluid that will flow through the valve is the first and most important consideration.

- Highly erosive fluids, such as those carrying suspended solids or slurries, may require full port valves which do not provide any obstruction to flow in the full open position. Never specify butterfly valves for such services.
- If the flow stream contains fibrous particles, it may block or plug the valve openings. Diamond port plug valves, V-plug and V-ball valves have port shapes that minimize plugging.
- Highly viscous or gummy fluids create a high pressure drop through valves and piping. Ball valves, diaphragm valves and butterfly valves are ideal for these services.

**Service requirements:**

Ask the following questions:

- Should the valve merely start and stop the flow?
- Should it regulate (throttle) flow within a preset flow range limit?
- Should it provide a combination of two functions above?
- How much through valve leakage can the system tolerate?

Gate valves will provide tight shutoff but should not be used to regulate flow. Many inexpensive control valves will provide throttling but may not provide shut-tight, e.g., butterfly valves can provide excellent flow control, but may not be bubble tight. It is often not possible to achieve operational needs with a single, standard, off-the-shelf valve. A custom-built valve, or two standard valves in series, may often be required to obtain the desired results.

**Pressure – Temperature Rating (P-T Rating):**

Ask the following questions:

- What is the maximum pressure that the valve needs to be rated for?
- What are the upstream and downstream pressures for each of the maximum, normal and minimum flow rates?
- Is the valve operating consistently near the system's maximum design pressure and temperature?

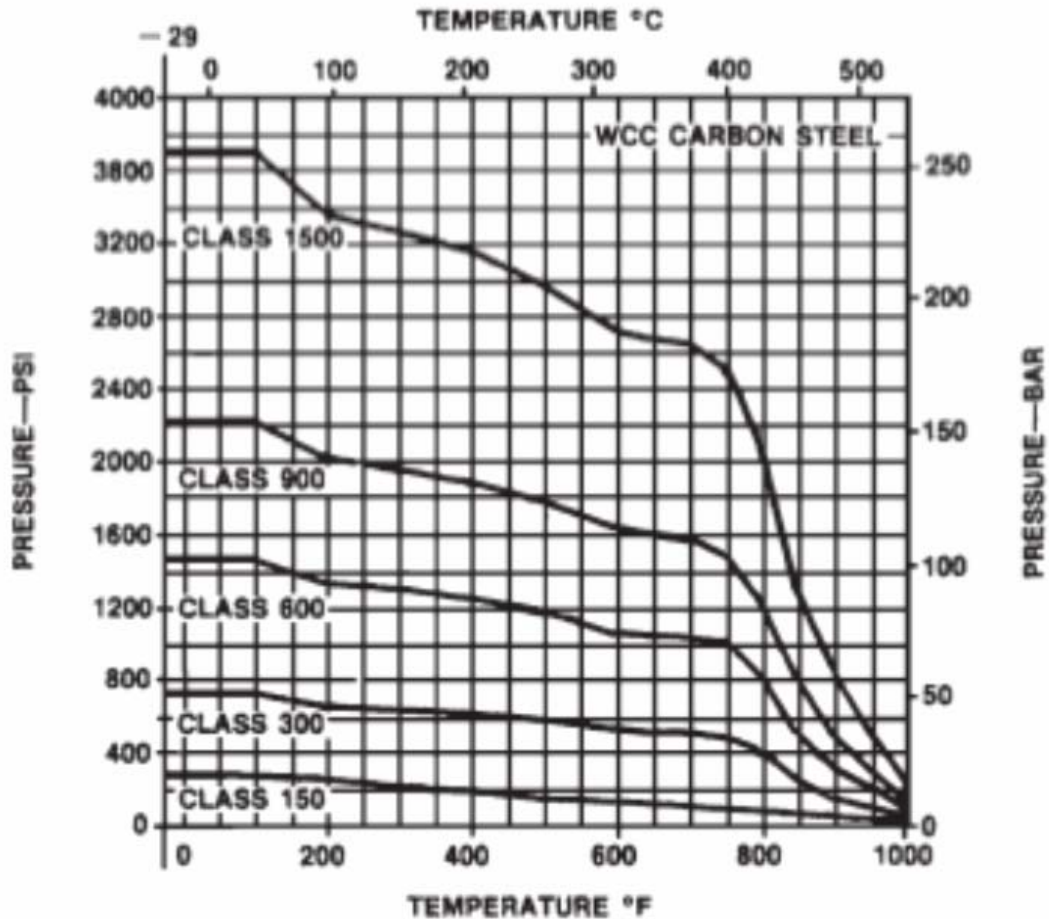
- Do the system's peak pressure and temperature occur simultaneously? Do these conditions peak out only when the valve is open?

These questions would decide the type of valve and its seating material. Here, we need to make distinction between “line pressure v/s valve pressure drop”.

Often this is misunderstood. The valve pressure envelope (valve body) is subjected to the full line pressure (valve upstream pressure), whereas the pressure drop ( $\Delta P$ ) is the difference between the valve upstream pressure and the pressure that exists just downstream of the valve. Both pressures are equally important when selecting a control valve. *The line pressure determines the valve body (and pipe flange) rating, whereas the pressure drop determines the valve trim or seat rating.*

The pressure-temperature rating of a valve is simply the maximum pressure the valve is designed to handle at a particular temperature and varies with the material of construction. The higher the process temperature, the less pressure can be handled by the body sub-assembly.

Valve's pressure rating describes the range of pressures a valve can handle - the higher the rating, the thicker the walls of the valve vessel to prevent rupture. The standard ANSI ratings are: 150, 300, 600, 900 etc. ANSI 150 rating valve does not mean that the maximum pressure rating of this valve is only 150 psi; a steel valve that is rated as ANSI class 150 can handle pressures up to 285 psi at 100°F (refer to the chart below).



Source: ANSI B16.34

**Materials of construction:**

General Service valves are specified with commonly found materials to match the pipe material. The standard materials are:

- Carbon Steel
- Stainless Steel
- Chrome-moly

For special services, the construction is often guided primarily by the type of fluid, service temperature, etc. Here are few examples:

- Concentration of the material in the fluid is very important. Most chemicals are easier to handle in dilute concentrations. However, acids—such as sulfuric acid—become

more aggressive as they are diluted with water. Some organic materials that are not corrosive by themselves become so in the presence of water.

- Temperature is an important factor in choice of materials because high temperature increases corrosion. In addition, at very elevated temperatures, the pressure rating of the valve can be severely lowered due to deterioration of either metallic or non-metallic material properties.
- Materials used in valves in hydrocarbon service experience sulfide stress cracking. NACE standard MR-01-75 provides specific guidelines for their selection criteria.
- Cast carbon steel (ASTM A216 – Grade WCB) is the most popular steel for valve bodies in moderate service such as air, superheat or saturated steam, non-corrosive fluids.
- Cast chrome-moly steel (ASTM A217 – Grade WCB-C9) has addition of chromium/Molybdenum that provide corrosion resistance and also suitable for temperature up to 1050°F.
- Cast type 304 SST (ASTM A351 – Grade CF8) is for oxidizing and very corrosive fluids.
- Cast type 316 SST (ASTM A351 – Grade CF8M) is same as 304 SST but since it has addition of Molybdenum it has better resistance to corrosion.
- Cast Iron (ASTM A126) is used for steam, water, gas and non-corrosive fluids and is inexpensive.
- Cast Bronze (ASTM B61 and B62) is used for steam, air, water, oil and non-corrosive fluids.

Also ask this question: Does the valve stay closed (or open) most of the time? Many materials exhibit different corrosion characteristics in stagnant versus flowing conditions. A case in point is Monel - a nickel-copper alloy. Monel is extremely well-suited to handling brine in flowing conditions, but is a poor choice in stagnant conditions (Inconel would be a better choice).

**Valve Action:**

Valve action defines whether the valve will be fully open, or fully closed in the event of any process failure. The engineer must define whether the safest condition for each valve is fully open or fully closed. This will be the failure position, and the combination of the actuator and valve body must achieve this position upon loss of power. We must analyze the entire process, including integrated units to identify the safest conditions. In a few cases, the failure condition is “unchanged”. If the air power is lost, air leakage will result in a slow drift to either open or closed.

Let's take an example:

If the valve is used to control steam or fuel flow, the valve should be shut off completely. On the other hand, if the valve is handling cooling water to a reactor, the flow should be maximum in case of emergency. Control valves operated through pneumatic actuators can be either (i) air to open, or (ii) air to close. If all the power goes out or some other emergency occurs, the decision on the fail-safe mode of the valve is a huge factor in saving lives.

**Valve Size (Capacity):**

Valves are sized according to their Cv value. For liquid service, the equation for Cv is:

$$C_v = Q \sqrt{S / \Delta P}$$

The required flow and pressure drop information used to size a valve is based on the process operations and equipment. Once the Cv value is known, the rated\* Cv can be determined from the manufacturer's data books. A general guideline is that valves should be sized so that maximum flow is obtained at about 90% valve open. Valves should be able to provide normal flow condition at around 60% to 70% of the travel. Valve should provide minimum flow when about 10% open. The control valve need not be of the same size as the pipe. It is better to make an error in under sizing a control valve than to oversize it.

As a good engineering practice, the rated Cv of the valve shall be in accordance with following criteria:

**If normal flow is specified:**

- Calculated Cv – Based on the normal flow
- Selected Cv – Based on 1.4 x normal flow

If maximum flow is specified but is equal to or less than 1.4 x normal flow

- Calculated Cv – based on normal flow
- Selected Cv – based on 1.5 x normal flow

When maximum flow is specified but is greater than 1.4 x normal flow

- Calculated Cv – Based on normal flow
- Selected Cv – Based on 1.1 x maximum flow

**Precise system control:**

Some system control loops require highly accurate control in the face of severe disturbances. Ideally the control valve should have low friction, no backlash, and a stable flow pattern.

- Rotary valves, such as high-performance butterfly and plug valves employing low-friction bearings and packings provide good control.
- Ball valves have large backlash and are not recommended.
- Linear motion valves, such as globe valves cannot match the low friction of rotary valves and must be critically evaluated.

**Leakage or Tight shut-off :**

A valve having tight shutoff will have virtually no flow or leakage in its closed position. Generally speaking, only single-seated valves have tight shutoff. Double-seated valves may be expected to have a leakage of 2 to 5% while in closed position. Control valve seat leakage shall be designed and constructed in accordance with the requirements to ANSI B 16-104.

- Class I – N/A
- Class II - 0.5% of maximum valve capacity
- Class III - 0.1% of maximum valve capacity
- Class IV - 0.01% of maximum valve capacity
- Class V – 0.0005 ml/min/inch of port dia./psi differential



Close-off pressure is an important parameter that defines the differential pressure required to seat the valve and stop flow completely and is a function of the hydraulic design of the system and the criteria for deciding the type of valve actuator. Typically, actuators are either electronic or pneumatic. The significant performance differentiator between the two is speed of operation. While the electric actuators are better known for their high levels of precision; the pneumatic actuators are very popular due to their relatively low cost, high power output, and reliability. The choice of pneumatic or electric actuators involves an evaluation of performance, component costs, system costs, and productivity gains. Each has inherent advantages and disadvantages. Refer to Section 1 for a detailed comparison.

**Note-** Automatic control valves are not designed to produce “tight shutoff” and will likely to be prone to small amount of leakage when closed. Consequently, most control valve installations include block valves or manual valves which can be turned when complete shutoff is needed.

## **CONTROL VALVE SIZING EQUATIONS**

In order to determine the correct size of a valve for a specific system, many factors must be considered. The most important factor is the capacity parameter, Cv, or the **flow coefficient**. To determine the valve size needed for your system, you can estimate Cv with the following equations:

### **Liquids (water, oil, etc.):**

Because liquids are incompressible fluids, their flow rate depends only on the difference between the inlet and outlet pressures ( $\Delta P$ , pressure drop). The flow is the same whether the system pressure is low or high, so long as the difference between the inlet and outlet pressure is the same. The equation below shows the relationship:

$$C_v = Q \sqrt{S / \Delta P}$$

Where,

- Cv = Valve flow coefficient, US GPM with P = 1 psi
- Q = Fluid flow, US GPM
- S = Specific gravity of fluid relative to water @ 60F
- $\Delta P$  = Pressure drop ( $P_1 - P_2$ ) at maximum flow, psi

Specific gravity correction is negligible for water below 200°F (use S = 1.0). Use actual specific gravity S of other liquids at actual flow temperature. Use the following equation for fluids with viscosity correction factor. Use actual specific gravity S for fluids at actual flow temperature.

$$C_v = K Q \sqrt{(S / \Delta P)}$$

Where,

- K = Viscosity correction factor for fluids

Estimating diameter of pipe:

Another important piece of information about sizing and specifications is what diameter pipe may be used with a certain flow, seen in the following equation:

$$d = \sqrt{\frac{4 Q_{max}}{\pi v}}$$

Where:

- d = diameter of pipe (ft.)
- $Q_{max}$  = maximum flow through the valve ( $ft^3/s$ )
- v = velocity of flow (ft./s)

**Air and Gaseous Flow (natural gas, propane etc.):**

Gas flow calculations are slightly more complex because gases are compressible fluids whose density changes with pressure. In addition, there are two conditions that must be considered: low pressure drop flow and high pressure drop flow.

Use the following equation when outlet pressure ( $P_2$ ) is greater than one half of inlet pressure ( $P_1$ ).

$$C_v = \frac{Q_a \sqrt{G (T + 460)}}{1360 \sqrt{\Delta P (P_2)}}$$

Use the following equation when outlet pressure ( $P_2$ ) is less than or equal to  $\frac{1}{2}$  of inlet pressure ( $P_1$ ).

$$C_v = \frac{Q_a \sqrt{G(T + 460)}}{660 P_1}$$

Where,

- $C_v$  = Valve flow coefficient, US GPM with  $P = 1$  psi
- $Q_a$  = Air or gas flow, standard cubic feet per hour (SCFH) at 14.7 psig and 60F
- $T$  = Flowing air or gas temperature (F)
- $\Delta P$  = Pressure drop ( $P_1 - P_2$ ) at maximum flow, psi
- $P_2$  = Outlet pressure at maximum flow, psia (abs.)
- $P_1$  = Inlet pressure at maximum flow, psia (abs.)

The relationship between the inlet and outlet pressure is important, as seen above, in determining which equation to use for gaseous flow. When the outlet pressure is less than  $\frac{1}{2}$  the inlet pressure, this is said to be a **critical** pressure drop. The gas will behave differently when the pressure drop is critical; therefore it is necessary to use the correct equation depending on the extent of pressure drop. Once you have computed the desired value of  $C_v$ , you can choose the valve. The chosen valve must have a valve coefficient greater than or equal to the computed value.

**For Steam (saturated or superheated):**

Use the following equation when  $P_2$  is greater than  $\frac{1}{2} P_1$

$$C_v = \frac{WK}{2.1 \sqrt{\Delta P (P_1 + P_2)}}$$

Use the following equation when  $P_2$  is less than or equal to  $\frac{1}{2} P_1$

$$C_v = \frac{WK}{1.82 P_1}$$

Where,

- $C_v$  = Valve flow coefficient, US GPM with  $P = 1$  psi

- $W$  = Steam flow, pound per hour (lb. /hr.)
- $K = 1 + (0.0007 \times F \text{ superheat})$  for steam
- $T$  = Flowing air or gas temperature (F)
- $\Delta P$  = Pressure drop ( $P_1 - P_2$ ) at maximum flow, psi
- $P_1$  = Inlet pressure at maximum flow, psia (abs.)
- $P_2$  = Outlet pressure at maximum flow, psia (abs.)

### **CONTROL VALVE SIZING – SIMPLIFIED EXAMPLE**

#### **Define the system:**

Water is pumped from one tank to another through a piping system with a total pressure drop of 150 psi. A control valve is provided in the piping loop to modulate the flow rates. Assume the following key variables:

- Fluid temperature - 70°F
- Design (maximum) flow rate - 150 gpm
- Operating flow rate - 110 gpm
- Minimum flow rate - 25 gpm
- Pipe diameter - 3 inches
- Specific gravity – 1.0
- Valve characteristic – Globe valve, equal percentage

#### **STEP #1:**

#### **Define a maximum allowable pressure drop for the valve**

When defining the allowable pressure drop across the valve, you should first investigate the pump. What is its maximum available head? Remember that the system pressure drop is limited by the pump. Essentially the Net Positive Suction Head Available (NPSHA) minus the Net Positive Suction Head Required (NPSHR) is the maximum available pressure drop for the valve to use and this must not be exceeded or another pump will be needed. It's

important to remember the trade off, larger pressure drops increase the pumping cost (operating) and smaller pressure drops increase the valve cost because a larger valve is required (capital cost).

The usual rule of thumb is that a valve should be designed to use 10 to 15% of the total pressure drop or 10 psi, whichever is greater. For our example, 10% of the total pressure drop is 15 psi which is what we'll use as our allowable pressure drop when the valve is wide open (the pump in this system is easily capable of the additional pressure drop).

## **STEP # 2:**

### **Calculate the valve coefficient (Cv)**

The next step is to figure out what size the valve will need to be. Key elements to consider in valve sizing are the pressure-flowrate relationship and the flow characteristics to ensure an appropriate size for the desired valve.

$$C_v = Q \sqrt{(S / \Delta P)}$$

For our system,

$$C_v = 150 (1/15)^{1/2} = 38.7 = 39$$

## **STEP # 3:**

### **Preliminary valve selection**

The Cv value should be used as a guide in the valve selection, but before trying to match a valve with the calculated Cv value, some other considerations are:

- Decide what type of valve will be used for a given process characteristic;
- Never use a valve that is less than half the pipe size;
- Avoid using the lower 10% and upper 20% of the valve stroke. The valve is much easier to control in the 10 to 80% stroke range.

In our example we are using an equal percentage, globe valve. Obtain the valve chart for this type from the manufacturer; typical shown below:

Size (NPT)	Cv @ 10% VT	Cv @ 25% VT	Cv @ 50% VT	Cv @ 75% VT	Cv @ 100% VT
1/2"	0.03	0.075	0.3	0.5	1
1/2"	0.05	0.12	0.48	0.8	1.6
1/2"	0.08	0.19	0.75	1.25	2.5
1/2"	0.13	0.3	1.2	2	4
3/4"	0.21	0.47	1.89	3.15	6.3
1"	0.33	0.75	3	5	10
1 1/4"	0.53	1.2	4.8	8	16
1 1/2"	0.83	1.88	7.5	12.5	25
2"	1.33	3	12	20	40
2 1/2"	2.10	4.73	18.9	31.5	63
3"	3.33	7.5	30	50	100
4"	5.33	12	48	80	160
5"	8.33	18.75	75	125	250
6"	13.33	30	120	200	400

For our case, it appears that the 2½ inch valve will work well for our Cv value at about 80 to 85% of the stroke range. Notice that we're not trying to squeeze our Cv into the 2" valve which would need to be at 100% stroke to handle our maximum flow. If this valve was used, two consequences would be experienced: the pressure drop would be a little higher than 15 psi at our design (max) flow, and the valve would be difficult to control at maximum flow. Also, there would be no room for error with this valve, but the valve we've chosen will allow for flow surges beyond the 150 gpm range with severe headaches!

So it looks like a 2½" valve will suffice, but before we make a decision, there are still some characteristics to consider as indicated in step # 4.

**STEP # 4:**

**Check the Cv and stroke percentage at the minimum flow**

If the stroke percentage falls below 10% at our minimum flow, a smaller valve may have to be used in some cases. Judgments plays role in many cases.

For example, is your system more likely to operate closer to the maximum flowrates more often than the minimum flowrates? Or is it more likely to operate near the minimum flowrate for extended periods of time. It's difficult to find the perfect valve, but you should find one that operates well most of the time. Let's check the valve we've selected for our system:

$$Cv = 25 (1 / 15)^{1/2} = 6.5$$

Referring back to our valve chart, we see that a Cv of 6.5 would correspond to a stroke percentage of around 30 to 35% which is certainly acceptable. Notice that we used the

maximum pressure drop of 15 psi once again in our calculation. Although the pressure drop across the valve will be lower at smaller flowrates, using the maximum value gives us a "worst case" scenario. If our Cv at the minimum flow would have been around 1.5, there would not really be a problem because the valve has a Cv of 2.1 at 10% stroke and since we use the maximum pressure drop, our estimate is conservative. Essentially, at lower pressure drops, Cv would only increase which, in this case, would be advantageous.

**STEP # 5:** Check the gain across applicable flow rates:

Gain is defined as:

$$\text{Gain} = \Delta \text{Flow} / \Delta \text{Travel}$$

Now, at our three flow rates:

- Qmin = 25 GPM
- Qop = 110 GPM
- Qdes = 150 GPM

We have corresponding Cv values of 6.5, 28, and 39. The corresponding stroke percentages are 30%, 68%, and 82% respectively. Now we construct the following table:

Flow (GPM)	Stroke or Valve Travel, VT (%)	Change in flow (GPM)	Change in VT (%)
25	30	110 – 25 = 85	68 – 30 = 38
110	68	150 – 110 = 40	82 – 68 = 14
150	82		

$$\text{Gain \#1} = 85/38 = 2.2$$

$$\text{Gain \#2} = 40/14 = 2.86$$

The difference between these values should be less than 50% of the higher value.

$$0.5 \times (2.85) = 1.43 \text{ and } 2.86 - 2.2 = 0.66.$$

Since 0.66 is less than 1.43 there should be no problem in controlling the valve. Also note that the gain should never be less than 0.50.

So for our example, 2½" valve size will work fine.

**OTHER NOTES:**

Under most situations, sizing of a control valve for liquids can be based on valve Cv using a simple flow equation. However, in many situations, other factors, such as compressible flows, choked flow, viscous flows, pipe size, elbows, pipe reducers/expanders etc. must be determined. Formulae for these situations can be extremely complex, and the valve manufacturers should be consulted. Refer to the manufacturer's catalogs for more details:

[http://www.pro-quip.com/images/proquip/PDFs/Library/ValtekSizingSelection/SS\\_03.pdf](http://www.pro-quip.com/images/proquip/PDFs/Library/ValtekSizingSelection/SS_03.pdf))

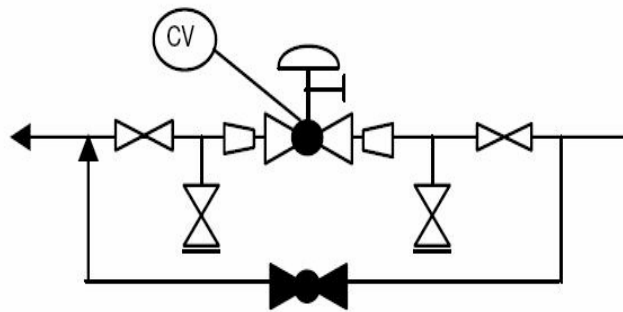
<http://www.cheresources.com/content/articles/fluid-flow/valve-sizing-and-selection?pg=2>



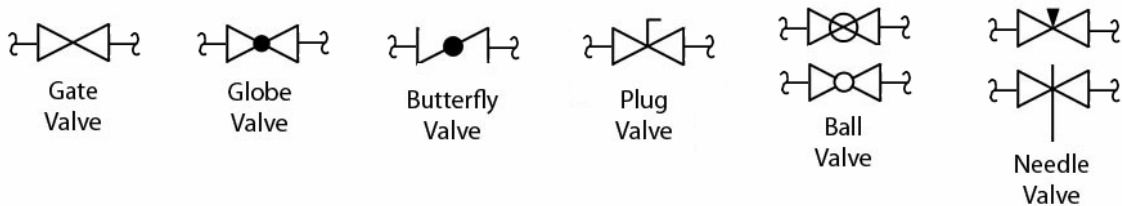
**SECTION - 4: CONTROL VALVES IN PROCESS DRAWINGS**

Engineers document their work using many complementary methods. A Piping and Instrumentation Diagram (P&ID) is the most common method of illustrating the functional relationship of piping, valves (automated and manual), pipe sizes, sample points and instrumentation. A moderate level of mechanical detail is provided for process equipment, so that the piping and instrumentation can be precisely documented. International symbol standards are used for piping, equipment and instruments (ISA, 1992).

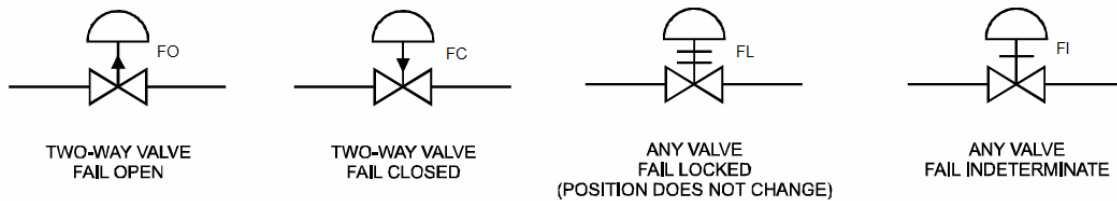
A typical arrangement used to represent control valves on P&ID is depicted below.



The figure below shows a list of typical valve symbols used in industry.



Control valves may fail in various positions: open, closed, locked, or indeterminate, and it needs to be shown on the P&ID.



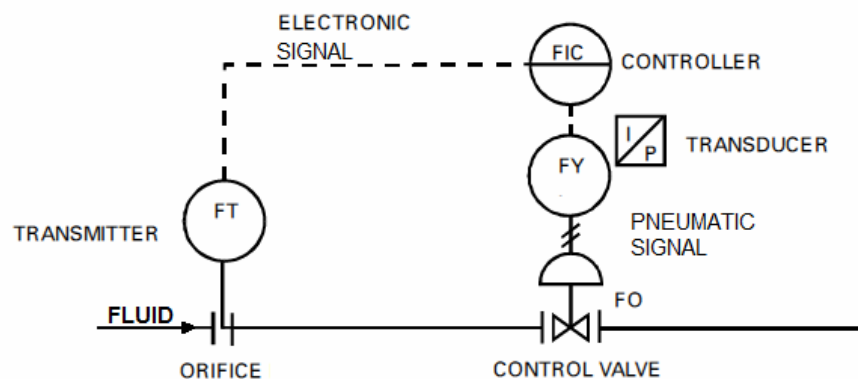
The fail positions may be identified using letters below the valve symbol: FO for Fail Open; FC for Fail Closed; FL for Fail Last or Locked; and FI for Fail Indeterminate. The fail positions

may also be identified by an arrow. An arrow up signifies the valve fail open and an arrow down is fail close. A crossing line is fail indeterminate. Two crossing lines indicate fail locked or last position.

### Control Loop Representation on P&ID:

Instrumentation and control design engineers add all the loop and local instruments to the P&ID, to define the instrumentation and control scheme. Let's take a problem statement of controlling flow rate in the pipeline.

Figure below shows an electronic loop consisting of a flow control element (orifice plate), flow transmitter, controller, transducer and a fail open control valve.



AN ELECTRONIC CONTROL LOOP - CONTROLLING FLOW

- FT (Flow transmitter) senses the differential pressure proportional to the flow rate in the line caused by a flow element or orifice plate and transmits a 4-20 mA dc (direct current) signal corresponding to the varying differential pressure.
- FIC (Electronic flow controller) transmits a 4-20 mA dc signal to the converter or transducer, FY.
- FY (Transducer) converts the 4-20 mA DC signal into a pneumatic signal. This signal changes the position of the valve actuator, which in turn changes the position of the control valve trim causing change in flow through the control valve.

The dotted line indicates that information is transmitted electronically from the flow transmitter, FT, to the controller, FIC, and from the controller to pneumatic converter (I/P), FY. Simple instruments permit direct reading of a process variable in the field. These devices include pressure gauges, thermometers, level gauges and rotameters. Other loops are

slightly more complex, transmitting a signal to the remote control room, where the measurements can be read or recorded.

### **Controllers:**

There are three basic types of controllers: 1) digital (e.g. microprocessor or computer based), 2) analog, and 3) pneumatic. The following guidelines may be applied in selecting the appropriate controller:

- For plants with many control loops use digital type of controllers.
- For the expansion of existing controls within a plant use the existing technology. This may be either digital, analog electronic, or pneumatic controllers.
- Use pneumatic controllers in hazardous areas.
- Avoid use of pneumatic controllers in the control room.
- When using digital control avoid depending on a single or a few control devices for the entire plant without having a backup. A redundant controller might not be required if only a single controller controls one loop. However, if a single controller controls a large number of loops then provide redundancy so that if the controller fails another controller will automatically take over.
- Use the type of controller that is the most economical and reliable.

### **Process Controllers:**

Process controllers use one or several of the following control modes:

1. On-off
2. Proportional
3. Integral (also called reset)
4. Derivative (also called rate)

Most digital controllers have all of the above control modes included. They are also usually provided with anti-reset windup. Analog and pneumatic controllers often do not include all three control modes or anti-reset windup.

## Control modes:

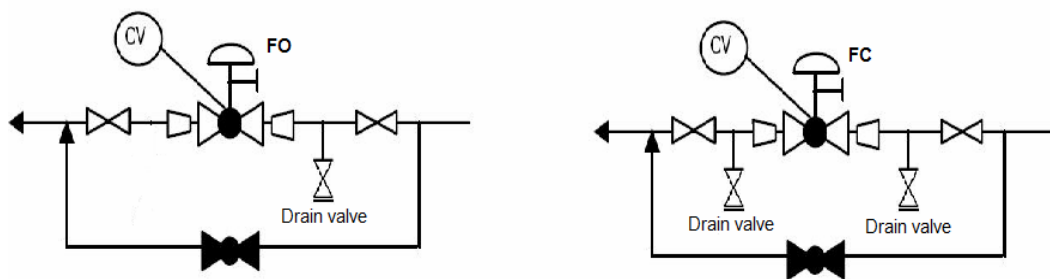
In general, use the following control modes for the indicated control loop.

- Flow -- Use proportional plus integral.
- Level -- Use proportional plus integral.
- Pressure and Temperature -- Use proportional plus integral.

**Note** - Use proportional plus integral plus rate when the application requires a quick response time

## General Good Engineering Guidelines

1. The control valve size is generally smaller than the corresponding line size. This change in diameter should be clearly indicated in the P&ID with a reducer and expander.
2. Provide manual block and bypass valves around control valves where practical to allow for control valve removal and servicing while the system is operational. If a manual bypass is not provided then furnish the valve with a hand wheel.
3. A drain valve is normally always provided between the control valve and upstream isolating valve. If the control valve is of 'Fail Open' type, this drain valve is sufficient to drain the piping segment. If the control valve is of 'Fail Close' or 'Fail in Position' type, then additional drain valve is required between the control valve and downstream isolating valve.



4. Additional details such as failure position, tightness class, # rating etc. are also indicated on the P&ID for control valves, as per the project standards.
5. End Connections

- Threaded ends are cheap but can be stripped and leak; use these where this isn't a worry.
  - Welded ends provide no leaks and are cheap initially, but if there are problems the valve must be cut out.
  - Flanged ends are the most expensive but are the best from an installation and removal standpoint.
6. Locate control valves at grade where practical. Install the control valve near the operating equipment that has to be observed while in local manual control. Equipment must be located so that they do not interfere with each other and so that space is available for people to travel through the process and perform tasks, such as maintenance.

## **COMMON QUESTIONS**

### **1. What are the common control valve applications?**

Control valves are used in following applications:

- Pressure Reducing
- Pressure Relief/Sustaining
- Pump Control
- Rate-of-Flow Control
- Level Control
- Cavitation Control
- Surge Anticipation
- Electronic Control
- Metering

### **2. What is a pressure reducing valve?**

Pressure reducing valve reduces a higher inlet pressure to a constant downstream pressure regardless of demand and supply pressure fluctuations. It enables delivery

of water at safe pressures and adequate levels in various applications such as main feed, fire and irrigation systems.

**3. What is a pressure relief valve?**

Pressure relief valve relieves excess pressure while maintaining a minimum upstream pressure. It prevents downstream demand from sacrificing supply of an upstream zone. It is typically installed in protection of in-line distribution piping at booster pump stations.

**4. What is the rate of a flow control valve?**

Rate of flow control valve maintains a maximum flow rate setting downstream regardless of pressure changes. It is typically installed within distribution systems and process control applications.

**5. Can two control valves be used in series in high pressure drop applications?**

Dropping the pressure across two valves rather than one is theoretically better. However, in practice, the two valves will not usually control well together unless the process can operate with a very low proportional band with slow response times.

A better and usually less expensive approach is to use a valve that is designed with multiple pressure drop restrictions inside the trim.

**6. Can two control valves be used in parallel to handle high turndown applications?**

Two valves in parallel working on split range signals can give very high turndown capability. The situation that should be avoided if possible is that the larger valve operates in the "cracked open" position – one way to avoid this is to program the PLC or DCS to shut the small valve and use only the larger unit once the capacity of the small valve is exceeded.

An alternative to the two valves in parallel is to select a valve with a high rangeability such as a V-port ball valve.

**7. Is flow through a Control Valve – Turbulent or Laminar?**

Flow through control valves is almost always turbulent.

Laminar flow takes place with liquids operating at low Reynolds numbers. This occurs with liquids that are viscous; working at low velocities. Laminar flow in gases and vapors very seldom will be experienced in process plants.

**8. The control valve size is essentially always equal to the line size. Is this correct?**

NO. The control valve does not need to be of the same size as the pipe.

Don't assume a 4" valve will handle the flow in a 4" line. The flow path is the critical factor and shape of the flow passage in the valve can be a problem. Look at the pressure through the valve and if the valve creates a pressure drop, then a slightly larger valve may be needed. Always calculate the flow coefficient. Even for a given size of valve, there is no industry-wide standard pressure for valve sizes; no two manufacturers design a 4" valve the same way, and different designs have different pressure considerations. Contrary to conventional wisdom, it is better to make an error in under sizing a control valve than to oversize it.

**9. Is the velocity of a fluid in a control valve critical?**

The velocity is one of the most important considerations in sizing a control valve. For long life on liquid applications the velocity at the exit of the valve body should be less than 10 m/s. This compares with generally accepted line velocities of about 3 m/s, which explains why control valves often are smaller than the line size.

On gases and vapors the velocity at the exit of the valve body should be less than 0.33 Mach (1/3rd of sonic) for noise control valves and less than 0.5 Mach where noise is not a consideration.

**10. What is a "modulating pressure independent" control valve?**

A modulating pressure independent control valve does not allow a change in flow rate when the pressure differential across the valve changes. Flow only changes with a change in valve position.

**11. What pressure and temperature requirements should be considered in selection of control valves?**

The selection of a control valve must be in accordance with established material properties. ANSI Standard B16.34 lists the allowable temperature and pressure

combinations for a variety of body materials. Standard pressure classes include ANSI Classes 150, 300, 600, 900, 1500, 2500 and 4500. For a given body material, each class denotes the maximum working pressure for a given operating temperature. Due to loss of material strength, the allowable working pressure decreases as the operating temperature rises. Lower temperature limits are also specified due to loss of ductility in some materials. Although a pressure class is usually indicated for an application, proper attention to selection of the pressure class is crucial to the safe operation of the control valve.

**12. What's the difference between balanced and unbalanced valves?**

Outlet balancing is required for proper valve functioning in those applications where the outlet pressure is more than 25% of the inlet pressure. When the outlet pressure is relatively high compared to the inlet pressure, the normally closed poppet will sometimes be pushed up off the internal orifice by the back pressure on the valve. Outlet balancing prevents the backpressure from acting on the poppet.

**13. How do the characteristics of the actuator influence the control valve operation?**

The valve and actuator are engineered to work together. Most manufacturers provide an anti-hunting algorithm in the valve that prevents the valve from modulating until it exceeds the tolerance of the valve. Use spring-loaded diaphragm type actuators where practical. Spring-less operators and cylinder operators are acceptable only when spring-loaded diaphragm type actuators cannot provide the desired performance. Select the actuator so that the valve or damper that it controls will fail safe. Fail safe is defined as lock in position or take a position (either open or closed) that will result in the least upset.

**14. What type of end connections specified for control valves?**

Most control valve specifications request raised face flange connections suitable for bolting to the process piping. In power piping and nuclear applications, butt weld ends suitable for welding to the process piping are typical. For limited applications, screwed end connections (NPT) and socket-weld ends are specified for globe valves in sizes 2-inch and smaller. Some high pressure applications may require the use of RTJ (ring-type joint) flanges. Flangeless, wafer-style connections are specified in applications where rotary valves are suitable for the process conditions. These connections are usually raised face.



### **15. What are the common types of flow characteristics for control valves?**

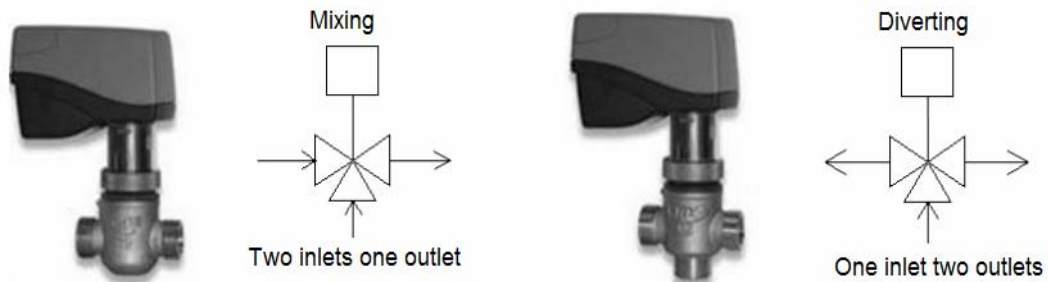
There are three basic types of control valve characteristics. These are quick opening, linear, and equal percentage. A quick opening valve would flow approximately 70% of its full flow at a valve opening of approximately 30%; a linear valve would flow approximately 50% of its full flow at a valve opening of approximately 50%; and the equal percentage valve (logarithmic) would flow 30% at approximately 70% of its full opening. So the question is - where would you use one style of valve over another?

- A quick-opening characteristic is recommended for shut off service only. Not much use for modulating process control except in ON-OFF application.
- If the piping and downstream equipment cause significant resistance to the system, equal percentage will provide better control. This is a condition, when the valve pressure drop at the maximum flow rate is less than about one third of the overall system pressure drop (valve + line).
- If most of the pressure drop is taken through the valve and the upstream pressure is constant, a linear characteristic will provide better control. Also use linear characteristic when a PLC is used to control the valves in a system. Avoid linear flow characteristics at low flow conditions.

Control valves with equal percentage flow characteristics are generally specified for most applications. Both types offer the best throttling control. In case of doubt, use equal percentage.

### **16. What are 3-way valves and how these are different from 2-way control valves?**

In HVAC applications, control valves are used to maintain space temperature conditions by altering the flow of water to the cooling coil. Valves can be two-position or modulating 3-port configuration. The difference between the two applications is in the piping layout and the internal design of the valve.



Two way and three way valve

Two-way valves throttle flow while three-way divert or mix flow. Two-way valves have two ports and are used to control the flow in variable flow systems. Three-way valves have three ports and can be piped for by-pass application either in mixing or diverting service.

**Mixing Valves-** A three-port valve with two inlet flows and one common outlet flow is defined as a mixing valve, and it provides a variable temperature outlet at a constant flow rate. A three-port motorized valve can be used to MIX, in varying proportions, two flows of different temperatures while maintaining a constant rate of flow in the common outlet port. Example: Mix hot and cold water (2 inlets) to make warm water (1 outlet). This is like a single handle sink faucet where you move the lever to get the water temperature you want. A mixing valve is used normally for radiator circuits.

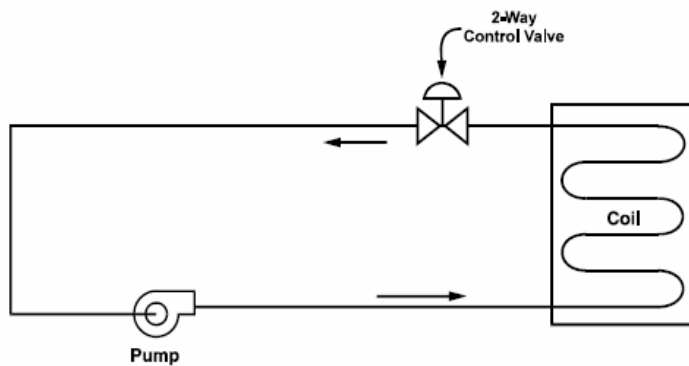
**Diverting Valves-** A three-port valve may also be used to divert a common flow in varying proportions. The valve will have one inlet and two outlets and provides a constant temperature and variable flow rate. Example: 100 GPM of flow (1 inlet) is divided into a 70 GPM stream and a 30 GPM stream (2 outlets). A diverting valve is used normally for circuits with convective heat transfer such as; heat exchangers, primary coil in indirect cylinder, heater battery, cooling coil.

### **2-way Valve or 3-way Valve**

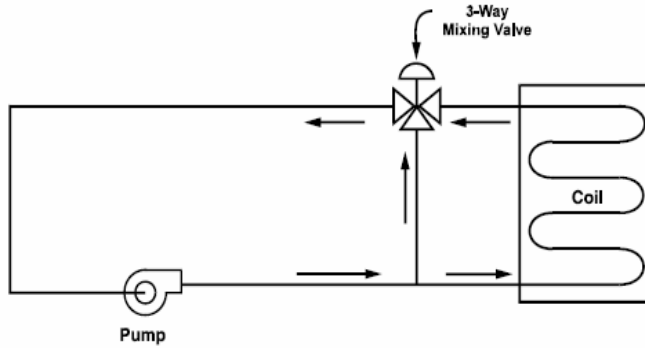
A 2-way valve is best used when applied with variable speed pumps. In fact, variable-pumping systems should only use 2-way valves to reap the energy saving benefits.

The constant volume systems may employ a 2-way or 3-way valve. While pumping costs will decrease to a small amount with a 2-way valve, other problems occur. The 2-way valves with constant volume system may some time lead to balancing problems in a large network and may lead to water scarcity at some terminal locations. The pumps must incorporate the minimum recalculating system should the 2-way valve/s close to 100% close position. The systems incorporating a 3-way valve ensure continuous circulation.

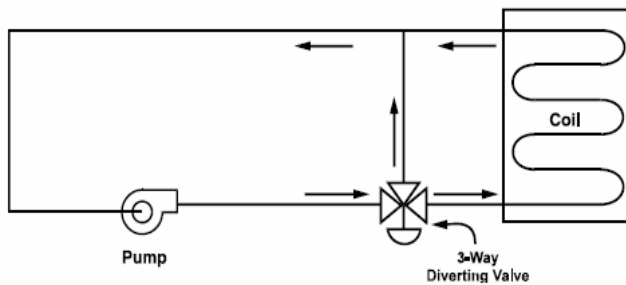
The type of a 3-way valve selected will determine its location in the system.



2 -way control valve



Mixing 3-way control valve



Diverting 3-way control valve

### 2-way and 3-way Valve Circuits for HVAC Applications

**Note** - The mixing valves are placed on the return side of the circuit and the diverting valves are placed on the supply side.

## 17. What are the common issues associated with the control valves selection?

The major issues in valve selection are summarized below. The relative importance of each issue depends upon the specific application; for example, one application might require a low pressure drop, while another might require a large range. Generally, we find that the greater the requirements for good performance, the higher the cost for purchase and maintenance. Therefore, we must find the proper balance of performance and cost, rather than always specify the best performing valve.

### Precision

Ideally, the valve would move to exactly the position indicated by the signal to the valve, which is usually a controller output. However, the valve is a real physical device that does not perform ideally. The following factors prevent ideal performance.

- **Deadband** - A valve with dead band acts like there is some backlash between the controller output and the actual valve position. Every time the controller output changes direction, the dead band has to be traversed before the valve physically starts moving. Although dead band may be caused by mechanical backlash (looseness or play in mechanical linkages); it can also be caused by excessive friction in the valve, an undersized actuator, or a defective positioner. Many people use the term Hysteresis instead of dead band but the ISA clearly calls the mechanical backlash phenomenon in control valves as dead band.
- **Resolution** - The smallest amount that the signal to the valve can be changed without a change to the valve opening (stem position). This change is after a change that has overcome deadband and is in the same direction.

Two major causes of non-ideal valve behavior are backlash and stiction.

- **Backlash** - A relative movement between interacting parts, resulting from looseness, when motion is reversed.
- **Stiction** - Resistance to the start of motion usually required to overcome static friction. If a valve with stiction stops moving, it tends to stick in that position. Then additional force is required to overcome the stiction. The controller continues to change its output while the valve continues to stick in position. Additional pressure

mounts in the actuator. If enough pressure builds up to overcome the static friction, the valve breaks free. The valve movement quickly absorbs the excess in pressure, and often the valve overshoots its target position. After this, the valve movement stops and the valve sticks in the new position. Stiction might be caused by an over-tight valve stem seal, by sticky valve internals, by an undersized actuator, or a sticky positioner.

The valve precision can be improved by the addition of a valve positioner.

## **Noise**

Valve components will tend to vibrate whenever they are subjected to high velocity turbulent flow. Standard control valves will therefore tend to be noisy on high pressure drop applications particularly where flow rates are high, since the low pressure experienced downstream of the seat ring (at the vena contracta) is accompanied by very high velocities reaching as high as the speed of sound.

If noise level is less than 100 dBA, the most economical way to reduce noise would be to use some form of path treatment such as insulation, heavier walled pipe, or a silencer. Noise level greater than 100 dBA may create dangerous pipe vibration. Path treatment alone is not likely to be effective, so some form of source treatment (such as labyrinth plugs or multi-step angle valves or using some flow restrictor in series with the valve) is needed.

## **Upstream Pressure Increase**

If a control valve is sized incorrectly and is too small, fluid velocity upstream of the valve will be slow, causing an increase in pressure (much like when the end of a garden hose is partially obstructed). This increase in upstream pressure can be detrimental to certain processes, i.e. membrane filtration processes, where a large pressure difference across the membrane is desired. If the valve increases the pressure on the permeate side of the membrane, the driving force for separation will be reduced.

## **Hysteresis**

Hysteresis, regarding control valves, is the principle that a control valve is dependent on the prior valve position. A common valve opening may correlate to different flow rates depending on if the valve was opened or closed to get to that position. This shows that the direction a valve is being changed may need to be accounted for in a

control system to obtain a desired flow rate. If hysteresis becomes too large, it can cause the control architecture to force a system to oscillate around a desired point.

### **Fire-Safe or Not**

In many processes, it may be necessary to minimize dangerous product leakage and maintain effective shutoff of a valve. Valves that satisfy this condition are known as fire-safe. This term fire-safe is one of the least understood valve specifications. To date, there is no test protocol to establish whether a valve is fire-safe. The common definition used for a fire-safe valve is when a valve is exposed to fire conditions, it will allow minimal leakage through the seat and stem, and continue to provide effective shutoff during or following a fire or exposure to excessive temperatures.

Gate and globe valves made from metals that do not melt during a catastrophic fire have also been classified as fire-safe. Their design and construction assured metal-to-metal seating before, during and after a fire. Butterfly valves are commonly manufactured with a "tandem" soft seat over metal to achieve a fire-safe application.

### **Cost**

Engineers must always consider cost when making design and operations decisions. Valves involve costs, but when selected properly they provide benefits. These must be quantified and a profitability analysis performed. In some cases, a valve can affect the operating costs of the process, where the pumping (or compression) costs can be high, and the pressure drop occurring because of the valve can significantly increase the pumping costs. In such situations, a valve with a low (non-recoverable) pressure drop is selected.

Remember that the total cost includes costs of transmission (wiring around the plant), installation, documentation, plant operations, and maintenance over the life of the valve.

### **TIPS AND TRICKS**

Take the following tips into consideration when choosing a valve.

1. Choose a valve that will pass the maximum flow when about 90% open.
2. Choose a valve that will pass the minimum flow when about 10% open.
3. Choose a valve that will pass the normal flow when about 60-70% open.

4. Size control valves to absorb about  $1/3^{\text{rd}}$  of the total system pressure drop.
5. Control valves should not be less than half the pipe size. Normally the valves exclusively envisaged for shut-off service shall be line size. Alternatively, they could be sized as control valves.
6. In the case of lines with a diameter of up to 1" the valve size shall normally equal that of the line. In the case of lines with a diameter larger than 1" the valve size shall not be less than 1".
7. Valves shall generally have flanged connections as per rating envisaged in the line specification with the exception of valves with a nominal diameter smaller than or equal to 1½" which shall have a minimum rating of 300 ANSI.
8. If you are dealing with a corrosive fluid, choose the valve body and trim material to match the pump casing and impeller.
9. Velocity is the key to handling abrasive materials. Keep line velocity of about 10 ft/s for clean liquid. If you have a fluid that is abrasive, keep the velocity as low as possible, without having the particles drop out of suspension. When dealing with high pressure drop situations try always to keep the velocities below 0.3 mach on the inlet pipe, valve body, and outlet pipe.
10. Always sense pressure where you want to control it. Many control valves and pressure regulators do not function properly simply because they are sensing pressure at one point and being asked to control it somewhere else.
11. If you use a transducer in a control loop, specify a positioner on the valve. Otherwise the transducer will rob the actuator of available thrust, and the valve will leak when it is supposed to shut off.
12. In cavitating fluids "be sure to allow a straight run of downstream pipe after the valve - even when the control valve has cavitation trim in it". If there is a pipe "T" or elbow immediately downstream, the flow will choke out and back up into the valve.
13. Remember that control valves only do what you tell them to. Many control valve problems turn out to be a problem somewhere else.

## Summary

A control valve is the final control element in a process control. Thus the effectiveness of any control scheme depends heavily on the performance of the control valve. The proper design and fabrication of the valve is very important in order to achieve the desired performance level. Moreover control valves are of different size and shapes. There are distinct guidelines for selecting the valve size and shape depending on load change, pipeline diameter, etc. To properly select a control valve, the following fluid and system properties must be known:

1. Medium - What is passing through the valve? – If it is a special liquid, provide specific gravity (at flowing temperature), critical pressure, vapor pressure and viscosity.
2. Pressures - What is the maximum pressure that the valve needs to be rated for?
3. What are the upstream and downstream pressures for each of the maximum, normal and minimum flow rates?
4. Flow rates - Maximum, normal and minimum. The maximum is used to select the valve size, the minimum to check the turndown requirement and the normal to see where the valve will control.
5. Temperature - Maximum temperature for design plus temperatures at maximum, normal and minimum flow conditions.

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