JOHNSON CONTROLS

Section Vb1: Valves

Code No. LIT-347Vb

Valves

Control Valves

The valve is a controlled device that regulates the flow of a liquid or gas in a system. This regulation is accomplished by the varying resistance that the valve introduces into the system as the valve is stroked. As the valve modulates to the closed position the system pressure drop shifts to the valve and reduces the flow in the system.

The valve is very important to the operation of the system. Without a properly sized valve the system will never operate at an efficient level. For valves that are oversized the result is poor controllability that may cause the system to hunt or cycle. Undersizing a valve will require a larger pressure drop across the valve to maintain adequate flow and may not provide required capacity. This results in the pump working harder and leaves the valve susceptible to the effects of cavitation.

Valve Components

Johnson Controls currently manufactures three different styles of globe valve. They are the VT series valve, the Cage Trim style valve, and the Iron Body Flange valve. The normally open versions of these valves are shown in Figures 1, 2, and 3. For information on butterfly valves consult the *Engineering Data Book Section Vb2: Butterfly Valves.*

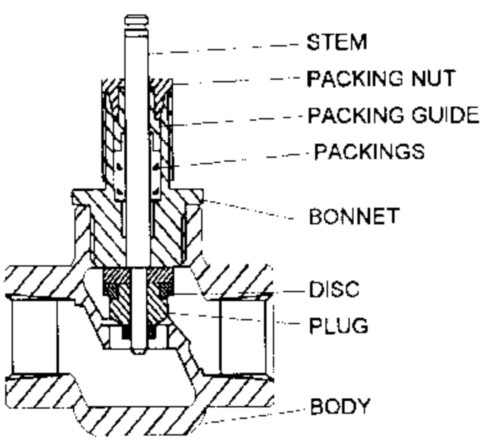


Figure 1: N.O. VT Valve Body

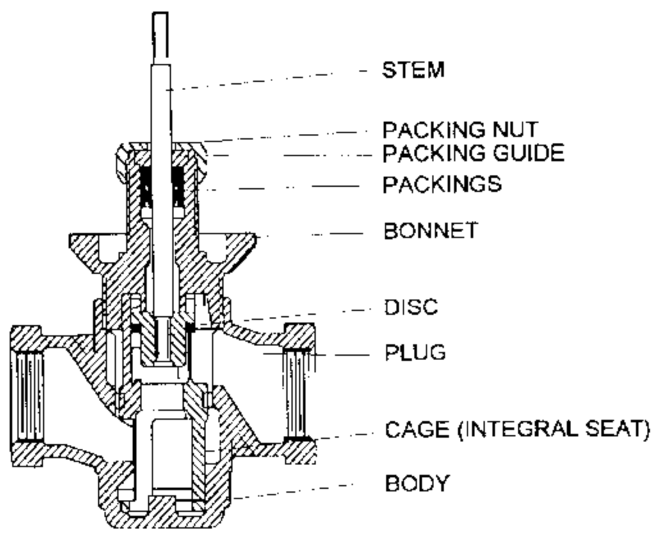


Figure 2: N.O. Cage Trim Valve Body

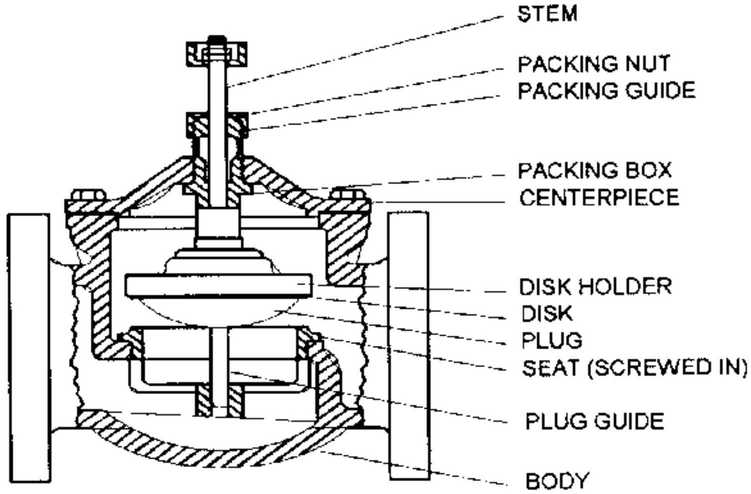


Figure 3: N.O. Cast Iron Flanged Style Valve Body

All globe style valves contain the same four basic sections; (1) Body, (2) Trim, (3) Bonnet, and (4) Actuator. The **Body** contains the orifice and is the main housing through which the controlled fluid flows. The **Trim** is the part of the valve excluding the body that comes in contact with the fluid. It is composed of the valve seat, plug, disc and disc holder, and stem. The **Bonnet** is an assembly that provides a mounting for the actuator and a guide through which the stem must pass. It is composed of the centerpiece, packing, packing guide, and packing nut. The packing provides a seal between the stem and bonnet to prevent leakage. The standard packing available on the current valves is the EPDM (Ethylene Propylene Diene Monomer) Ring Pack as shown in Figure 4. Many of the discontinued JCI valves used a Teflon or graphite packing.

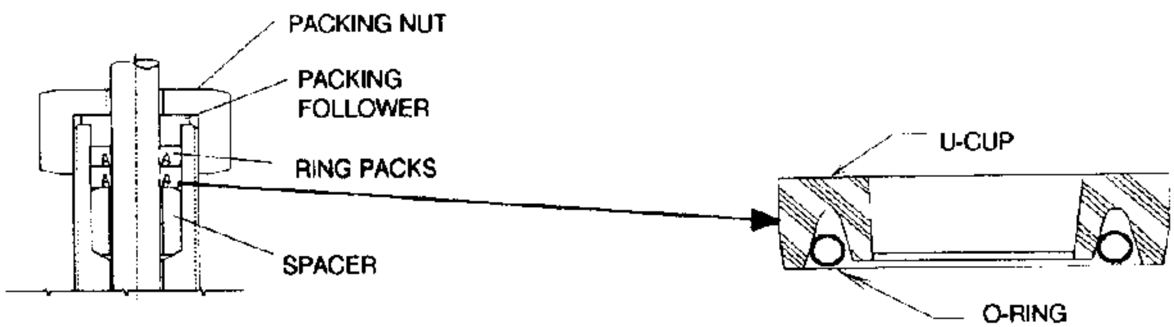


Figure 4: Standard Valve Packing

The **Actuator** consists of either pneumatic or electric means to provide the force to stroke the valve. Consult *Section Va: Valve Actuator* in the *Engineering Data Book* for further discussion.

Valve Parameters

Valve Flow Characteristic

The factor that is most useful in selecting a valve type for a given application is the flow characteristic. This characteristic is the relationship that exists between the flow rate through the valve and the valve stem travel as the latter is varied from zero to 100 percent. Different valves have different flow characteristics, depending primarily on internal construction. This flow relationship is usually shown in the form of a graph as in Figure 7. The characteristic that is usually graphed is the **Inherent Flow Characteristic** that is found under laboratory conditions with constant pressure drop across the valve. The inherent equal percentage characteristic can be described by the following equation:

$$Q = Q_m R^{[(x/T)-1]}$$

Where:
- Q = Flow rate (GPM)
- x = Valve Position (in.)
- T = Maximum Valve Travel (in.)
- Q_m = Maximum Flow rate (GPM)
- R = Valve Rangeability (see Table II)

These inherent flow characteristics are valuable for specifying a type of valve to be supplied by a manufacturer, but they do not reflect the actual performance of the valve once installed within a system. The pressure drop across the valve in the system is not constant; it varies with flow and other changes in the system. As the valve closes the pressure drop shifts to the valve and away from the other system components. 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).

$$N = \Delta P_{valve} \div \Delta P_{system}$$

where: N = Valve Authority

The actual characteristic when installed is known as the **Installed Flow Characteristic.** The installed flow characteristic can be described by the following equation which is a function of valve authority and the inherent valve flow characteristic.

$$Q_{installed} = \sqrt{\frac{\frac{1}{N}}{\frac{1}{N} - 1 + \frac{1}{k^2}}}$$

:

$Q_{installed}$ = Actual Installed Flow rate, Decimal Percentage (0.0-1.0)

N = Valve Authority, Decimal Percentage (0.0-1.0)

$k = \frac{Q}{Q_M}$ = Inherent Flow rate, Decimal Percentage (0.0-1.0)

Pressure Shift at Valve

This 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 but the advantages and disadvantages of the many varieties of pumps are beyond the scope of this article.

This point where the system curve crosses the pump characteristic curve shows the operating conditions (flow and head) that will exist for this particular pump for a given system resistance (see Figure 5a). The system resistance is the combination of the pressure drop across the control valve and the other system components (coils, piping, balancing valves, etc.) pressure drop. As the valve is closed on a system in full flow, the resistance to the system flow that the valve provides (valve pressure drop) will increase by shifting from point A towards point B (See Figure 5b). This increasing resistance will use more of the head in the system, as well as decrease system flow. The decrease in system flow will result in a decrease in pressure drop across every other component (coils, piping, balancing valves, etc.) and leave additional pressure drop for the control valve. This is because the resistance of the components is proportional to the square root of the flow through them.

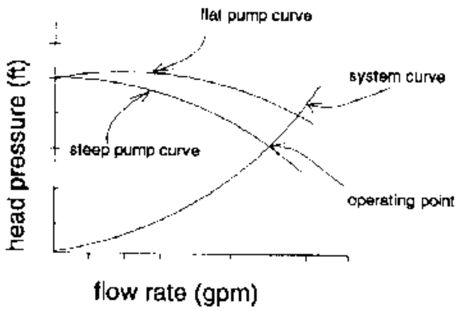


Figure 5a: System Operating Point.

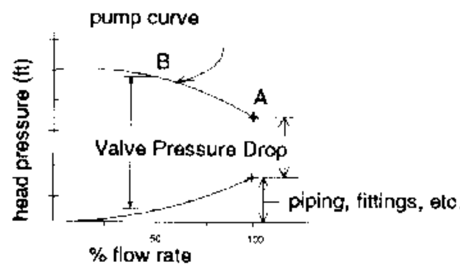


Figure 5b: Valve Pressure Shift

The effect of these system variables can be minimized by keeping the relative change in valve pressure drop as small as possible. Because the total pump head will appear across the valve when it is closed, the best way to keep the relative change as small as possible is to size the valve for as large a pressure drop as is permissible for the system. The larger percentage this initial pressure drop is of the total pump head, the smaller the relative change in pressure will be and the closer the valve installed flow characteristic will resemble its inherent flow characteristic.

The desired result is to match a particular valve to a certain system. This could involve a very detailed analysis of the control loop. However, with a basic knowledge of valves and a few generalizations the process can be greatly simplified.

Valve Gain

Valve gain is the incremental change in flow rate produced by an incremental change in plug position. This gain is a function of valve size and type, plug configuration and system operating conditions. The gain at any point in the stroke of a valve is equal to the slope of the valve flow characteristic curve at that point.

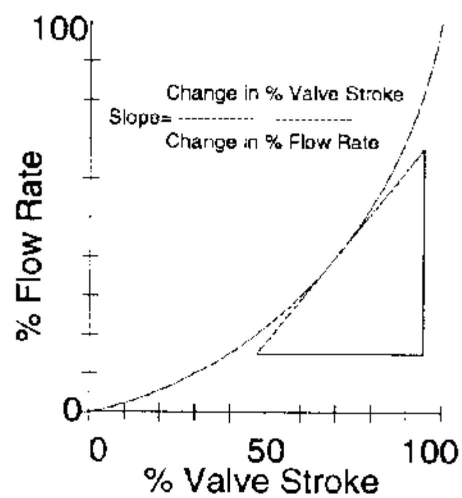


Figure 6: Equal Percentage Valve Gain

Valve Plugs

The shape of the valve plug determines the flow characteristic of the valve. (See Figure 7) Matching this plug flow characteristic to a particular control loop required that valve gain change in such a way as to compensate for the gain changes of the other elements (coil, balancing valve, piping, etc.) in the control loop. The valve gain is equal to the slope of the flow characteristic and is of primary significance in establishing the compatibility of the plug with the process. This will be shown graphically when valve and coil combinations are considered.

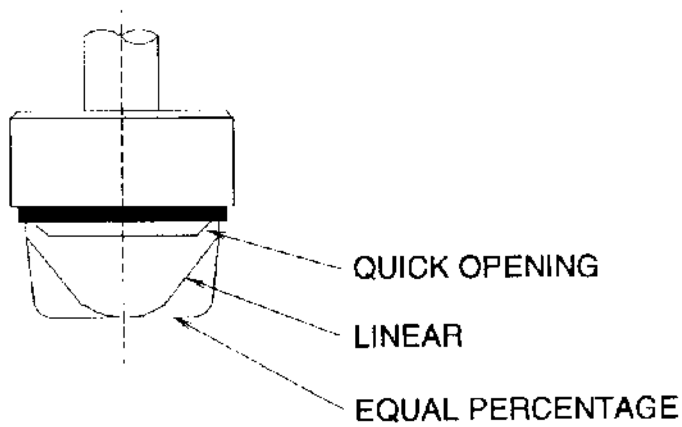


Figure 7: Valve Plug Types

The most common types of plugs are the equal percentage, linear, and quick opening plug. Typically JCI offers the equal percentage characteristic. The idealized flow characteristics for these are shown in Figure 8.

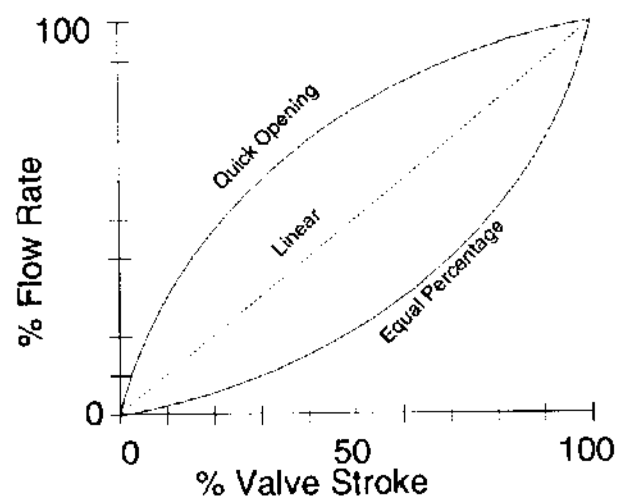


Figure 8: Typical Valve Inherent Flow Characteristics

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. (see Table I below.)

Table I: Comparison of Equal Percentage Change Between Lift and Flow

Stem		Flow	
Lift (%open)	Change	Flow Rate	Change
30%		5 gpm	
	10%		60%
40%		8 gpm	
	10%		60%
50%		12.8 gpm	

The flow through a linear valve plug varies directly with the position of the valve stem. This type of valve plug is normally utilized in process control applications. They can be useful where it is desirable to control mass flow rates into and out of a process such as liquid level control.

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 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.

Rangeability

Another valve parameter which can be considered at this point is rangeability. Rangeability is defined as the ratio between maximum and minimum *controllable* flow through the valve. Large values for rangeability are desirable because it will allow for control across a larger portion of the valve stroke.

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

The rangeability for the current JCI valves are listed below in Table II.

Table II. JCI Globe Valve Rangeabilities

Valve Size (in.)	Globe Valve Rangeability
*1/2 0.7Cv	18:1
*1/2 1.9Cv	22.0:1
*1/2 4.7Cv	34.0:1
3/4	40.0:1
1	44.0:1
1-1/2	50.0:1
2	60.0:1
2-1/2	6.5:1
3	7.7:1
4	9.3:1
5	10.7:1
6	10.4:1

*** - Rangeability values apply to VT valves only. For old 1/2 inch Cage Trim style valve rangeabilities refer to appropriate product data bulletin**

All valves have some amount of uncontrollable flow. This occurs when the plug is initially lifted off the seat and is due to the matching tolerances between the plug and seat. Valves with high rangeabilities will benefit from lower uncontrollable flow rates for a given size valve plug. This uncontrollable flow rate can be approximated as shown in the following example.

Example

Determine the uncontrollable flow rate through a 6 in. globe valve where C_v equals 350 and rangeability equals 10.4:1. Assume the full flow (wide open) differential pressure across the valve equals 5 psig.

$$\text{Uncontrollable Flow Rate (Q)} = \left(\frac{C_V}{R}\right)\sqrt{\Delta P} = \left(\frac{350}{10.4}\right)\sqrt{5} = 75\,gpm$$

It should be noted that in reality the pressure drop across a control valve will normally rise due to pressure shifts within the hydronic system. These effects were not considered in the example. The pressure shifts are discussed in Engineering Report H110 and H112. The net effect of the pressure shifts is to increase the uncontrollable flow rate.

Cavitation

Cavitation is a two-stage phenomenon which can greatly shorten the life of the valve trim in a control valve. Whenever a given quantity of liquid passes through a restricted area such as an orifice or a valve port, the velocity of the fluid increases. As the velocity increases, the static pressure decreases. If this velocity continues to increase, the pressure at the orifice will decrease below the vapor pressure of the liquid and vapor bubbles will form in the liquid. This is the first stage of cavitation. (See Figure 9)

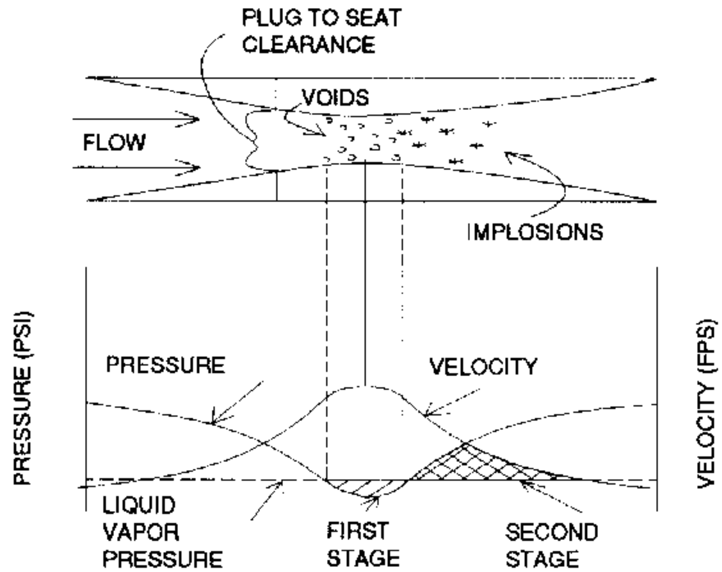


Figure 9: Variations of Pressure and Velocity for Points Along a Flow Stream Through a Restriction.

As the liquid moves downstream, the velocity decreases with a resultant increase in pressure. If the downstream pressure is maintained above the vapor pressure of the liquid, the voids or cavities will collapse or implode. This is the second stage of cavitation. (See Figure 9)

The second stage of cavitation is detrimental to valve. Because of the tremendous pressures created by these implosions (sometimes as high as 100,000 psi), tiny shock waves are generated in the liquid. If these shock waves strike the solid portions of the valve they act as hammer blows on these surfaces. Repeated implosions on a minute surface will eventually cause fatigue of the metal surface and chip a portion of this surface off. Tests show that only those implosions close to the solid surfaces of a valve act on the valve in this manner.

Low degrees of cavitation are tolerable in a control valve. Minimum damage to the valve trim and little variation in flow occur at these levels. However, there is a point where the increasing cavitation becomes very detrimental to the valve trim and possibly even the valve body. It is at this point that the cavitation is beginning to choke the flow through the valve resulting in the flow rate staying the same regardless of increases in pressure drop.

The point at which cavitation becomes damaging can be expressed by the following:

$$\Delta P_{allowable} = K_M * (P_1 - P_v)$$

K_M = Valve Recovery Coefficient

P_1 = Absolute Inlet Pressure (psia)

$\Delta P_{allowable}$ = Maximum Allowable Pressure Drop (psi)

P_v = Absolute Vapor Pressure (psia)

The Valve Recovery Coefficient differs among various types and sizes of valves. The following values of K_M are recommended for Johnson Controls globe valves:

0.7	1/2 to 2 inch - Brass Body
0.5	2-1/2 to 6 inch - Cast Iron Body

P_v is based on temperature and can be found in Table III below or in any steam tables book.

Table III: Water Vapor Pressure in psia

Vapor Pressure of Water			
Water Temp. (°F)	Vapor Pressure (psia)	Water Temp. (°F)	Vapor Pressure (psia)
40	0.12	140	2.89
50	0.18	150	3.72
60	0.26	160	4.74
70	0.36	170	5.99
80	0.51	180	7.51
90	0.70	190	9.34
100	0.95	200	11.53
110	1.28	210	14.12
120	1.69	220	17.19
130	2.22	230	20.78

The following is an example of calculating the maximum allowable pressure drop $\Delta P_{allowable}$.

Given: 1 inch valve with an inlet pressure of 30 psig and 180 degree water flowing through it

Find: The Maximum Allowable Pressure Drop (ΔP)

Solution: The valve recovery coefficient (K_M) is 0.7. The absolute vapor pressure (P_v) from Table III is 7.51 psia.

$$\Delta P = 0.7 * \{(30.0 + 14.7) - 7.51\} = 26.0 \text{ psi}$$

It would not be recommended based on the example above to size for a full flow pressure drop of greater than 26.0 psi.

Coil Theory

Water Coils

The relationship between flow rate through the coil and heat output of the coil is nonlinear and based on several factors. Some of the factors that influence the coil curve are entering air temperature, entering water temperature, water flow rate, and coil surface area. As these factors vary so does the shape of the coil curve. Figure 10 shows the typical shape of the curve assuming entering air and water temperature are held constant. As the flow rate decreases from the design point to 50 percent, the coil capacity only decreases to 90 percent. As the flow rate is reduced the water remains in the coil for a longer period of time and more energy is transferred. To compensate for this non-linearity a valve with an equal percentage characteristic can be selected. When the non-linear coil characteristic is combined with an equal percentage valve the combined curve will approach a linear characteristic. The combined characteristic curve is arrived at by combining the individual characteristics of the coil and the equal percentage plug. The inherent equal percentage characteristic is used to convert percent valve stroke into gpm. These values of gpm are then located on the coil characteristic curve, and the corresponding percentage of total capacity is observed. Plotting these values of percent valve stroke versus percentage of total capacity gives the combined characteristic. This gives the combined curve when the inherent valve characteristic is used which considers a constant pressure drop as the valve modulates. By using the installed characteristic instead of the inherent, the pressure shift to the valve is added and the resulting combined curve will shift as shown in Figure 11. The degree of shift will depend upon the valve authority. The lower the authority the larger the pressure shift will be. The combined characteristic will be considered linear from the controllers point of view.

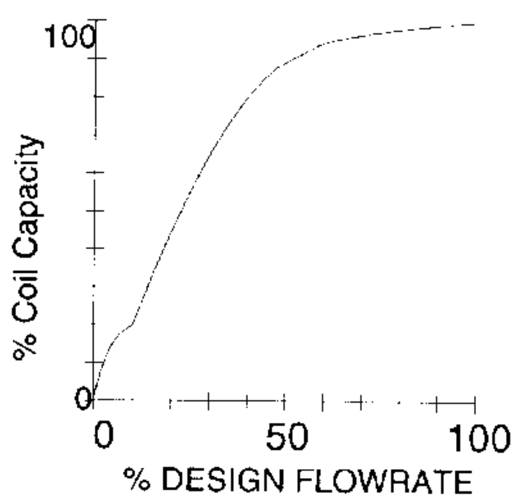


Figure 10: Typical Coil Characteristic

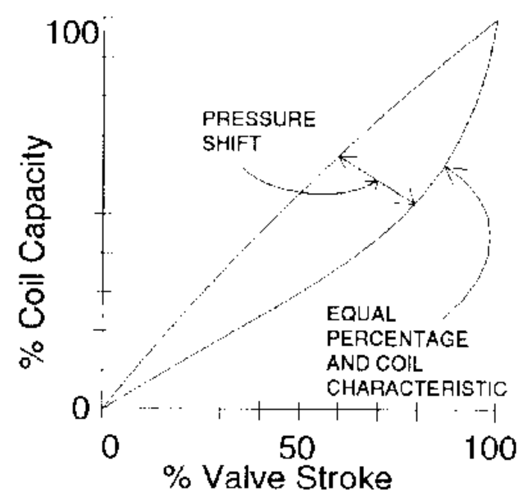


Figure 11: Combined Valve and Coil Characteristic

Steam Coils

The capacity of the steam coil is based upon the entering air temperature, steam supply pressure, the quantity of air passing of air passing through the coil, and the steam flow rate. At design conditions the coil has sufficient capacity to meet the heat requirements of the space. Since design conditions seldom occur the coil capacity must be reduced. Assuming that the entering air temperature, steam supply pressure and air quantity are held constant the steam flow rate must be varied in order to reduce the heat output of the coil. The purpose of the control valve is to regulate the steam flow rate by creating a varying resistance. If the valve closes part of the way, it momentarily passes less steam. The coil is still condensing the same amount of steam which causes the valve outlet pressure to decrease. Since the supply pressure is constant and the outlet pressure decreases the valve pressure drop increases as does the valve capacity. This will continue until the critical pressure drop is attained across the valve. The critical pressure drop is the point at which any further pressure drop will not result in an increase in steam velocity. The approximate value at which the critical velocity occurs is 45 percent of the absolute inlet pressure. Steam quantity by volume can be expressed by Q=VA where A is port area and V is velocity. It would be desirable to always select the valve size so that the pressure drop, when the valve is wide open, equals the critical pressure drop. Then the velocity through the valve would not increase as the valve closes, and the steam quantity would be proportional to the port area.

The ideal characteristic between the coil heat output and valve stem movement would have a linear relationship. There are two common cases when selection of the valve with an equal percentage characteristic would be more desirable than linear characteristic.

The first situation is when the valve cannot be sized for the critical pressure drop because the coil requires a higher steam supply pressure. For example, a coil that requires 12 psig steam when the supply of steam is only 15 psig. In this situation the valve pressure drop is 3 psi well below the critical pressure drop of 13.4 psi {.45*(15+14.7)=13.4}. The result is that the pressure will shift to the valve and the equal percentage characteristic will shift closer to a linear characteristic as shown in Figure 12. A valve with a linear characteristic would also shift and produce a curve similar to Figure 13. This is far from the desired inherent characteristic because the slope of the major portion of the curve is steeper than the equal percentage characteristic. The result is the valve will try to control a large amount of the coil capacity with a small amount of the valve stroke and wider controller throttling ranges will have to be used to produce stability.

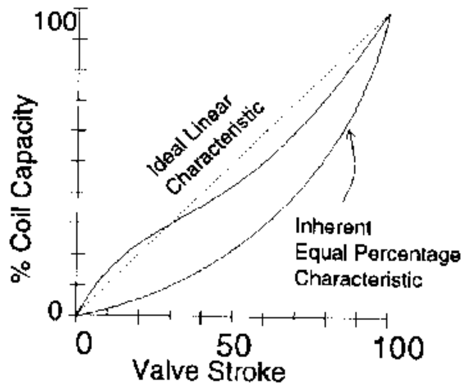


Figure 12: Shift of Equal Percentage Characteristic Due to Changing ΔP at Valve

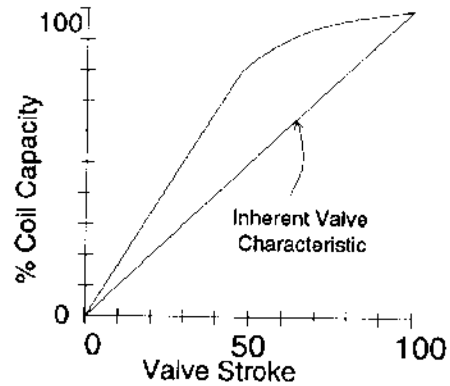


Figure 13: Shift of Linear Valve Characteristic Due to Changing ΔP at Valve

The second situation where equal percentage characteristics would be beneficial is sizing valves for use with an oversized coil. Oversizing of coils may occur for any of the following reasons. The first is because coils are only manufactured in certain sizes and this makes it difficult to match coil capabilities to exact loads. A second reason is the coils must be selected for design loads which very rarely occur, coils under normal operation are much too large. A third reason for oversized coils is the safety factors which are introduced into the design. Figure 14 shows how a valve with an equal percentage characteristics applied to an oversized coil utilizes a greater percentage of the valve stroke to produce the maximum capacity compared to the percentage of valve stroke if a linear characteristic is used.

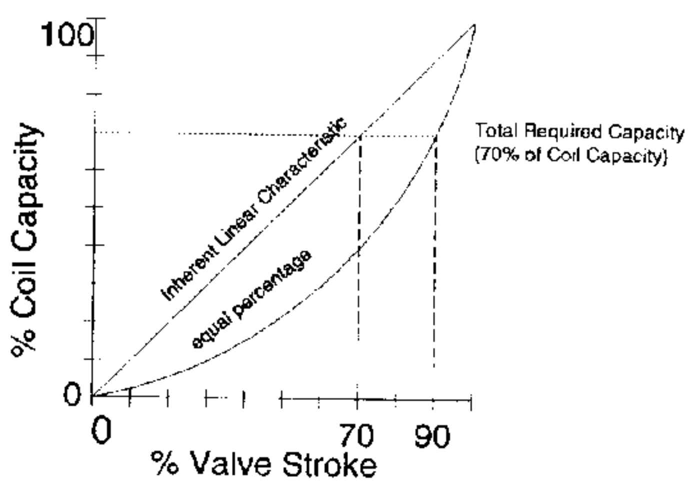


Figure 14: Comparison of Total Valve Stroke Used on Oversized Coils.

Valve Sizing

Valves must be sized correctly to perform the job for which they were intended. Undersized valves cannot deliver sufficient quantities for maximum load conditions, and oversized valves attempt to perform correctly but must do so at the very end of their strokes where hunting or cycling is hard to avoid. Oversizing is definitely the most prevalent in industry because safety factors are used when designing the system which may result in oversizing, control valves included. Sizing, however, is not complicated. It is typical that the specifications supplied by the consultant will indicate the required flow and pressure drop of the valve. If this is the case with a few simple equations the desired flow coefficient for sizing the valve can be determined and a valve can be selected.

Valve Flow Coefficient

The first step in finding the size of a valve is to determine the flow coefficient (Cv) that is required for the system. Cv factor is defined as "the number of US, gallons per minute of 60F water that will flow through a fully open valve with a 1 psi drop across it". This factor is determined by the construction of the valve and will not change. Identical valves sizes may have different Cv's if the body style or valve trim is different. **This value of Cv is probably the most useful piece of information necessary to size a valve.**

Table IV: Cv Factors - Johnson Controls Valves

Code No.	style	group	connect	VALVE (inches)															Notes
				1/2			5/8	3/4	1	1-1/4	1-1/2	2	2-1/2	3	4	5	6		
VT	**	IV	**	0.7	1.9	4.7													
V-3754	NO	IV	SC					8.6	13.9		27.5								
V-3766	NO	IV	FR	1.0	1.7	3.2													A
V-3854	NO	IV	SC	1.2	2.2	4.4													
V-3966	NC	IV	FR		1.7	3.2													A
V-3974	NC	IV	SC					8.6	13.9		27.5								
V-4324	MX	IV	SC					8.6	13.9		27.5								
V-4334	MX	III	FR				4.7												B
V-4440	NO	III	FR	1.4	2.4		4.7												B
V-5252	NO	I	FL										51	83	150	240	350		
V-5254	NO	IV	SC								27.5	41							
V-5462	NC	I	FL										54	83	150	237	344		
V-5464	NC	IV	SC								27.5	41							
V-5842	MX	I	FL										54	80	157	238	347		
V-5844	MX	IV	SC								27.5	41							
V-7216	NO	V	SC	0.7	1.2	2.9	4.7		7.0	12	19	29	47						C
V-7416	NC	V	SC	0.7	1.2	2.9	4.7		7.0	12	19	29	47						C

Notes: (A) ANSI standards do not apply to flare valves.
V-3766 and V-3966 Flare Valves exceed the requirements for ANSI B16.15, Class 250.
(B) V-4332, V-4334 and V-4440 Flare Valves meet the requirements for conformance with ANSI B16.15, Class 125.
(C) V-7216 and V-7416 are manufactured in the Lomagna Facility

Pressure Drop Across the Valve

A valve and coil should be sized to produce a combined linear characteristic so the controller can do an efficient job of controlling. A valve is matched with a coil based on the inherent characteristic and the flow coefficient of the valve. These valve parameters are determined at constant pressure drop and consequently, the valve should be operated as close to a constant pressure drop as is possible. However, as the valve closes, the total system pressure drop shifts to the valve. The best that can be done is to keep the relative change in pressure as low as possible.

For example, a system with a total branch pressure drop of 20 psi (ΔP_2) including valve pressure drop and a wide open valve pressure drop of 7 psi (ΔP_1) would have the following change in ΔP as the valve closes.

$$[\Delta P_2 / \Delta P_1] \text{ X } 100 = \Delta P$$

$$[20 / 7] \text{ X } 100 = 286\%$$

A valve with an initial drop of 3 psi would have a total percent change in ΔP of:

$$[20 / 3] \text{ X } 100 = 667\%$$

would produce a much larger pressure shift. Therefore, the valve pressure drop at maximum flow should be as large as is practical for the system. What this also means is that a valve with a large authority (50%) will shift away from the inherent characteristic less than a valve with a small authority (10%). Figure 15 shows the various authorities for an equal percentage valve.

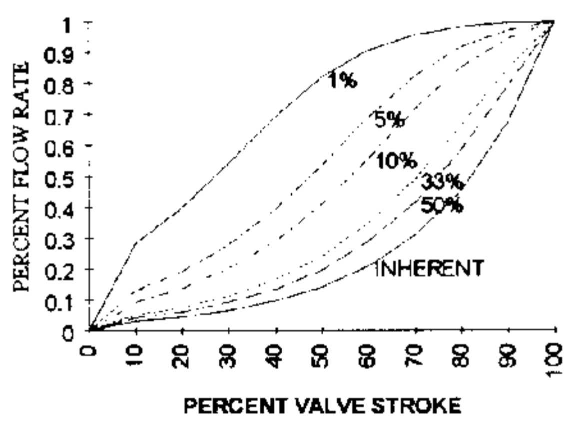


Figure 15: Installed Flow Characteristic of Equal Percentage Valve

Sizing Water Valves

The first step in sizing a water valve is to determine the required Cv factor through the use of the following formula:

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

Q = Flow in gallons per minute (gpm)

C_v = Valve Flow Coefficient

ΔP = Difference in pressure between inlet and outlet (psi)

The required flow (Q) for a coil should be available in the specifications; however, if it is not, formulas for calculating the flow requirements of a coil, based on other requirements such as temperature drop and total heat output, are found in the "x" Section (Ref. Data) of the Johnson Controls Engineering Data Book (Fan 347)

The sizing pressure drop (ΔP) across the valve is measured in the valve's full open position. For the sake of controllability, this pressure drop should be as large as possible, but other system parameters prevent an excessive drop from being selected, such as available pump head, and maximum allowable pressure drop. This is true because other components in the system require certain values of pressure drop to operate efficiently. Often a maximum valve pressure drop is stated in the specifications and cannot be exceeded. This maximum pressure drop does not ensure controllability. When it is permissible to choose the pressure drop for the valve, a value equal to 50% of the pressure between the supply and return mains for that branch should be selected.

Examples

The basic valve sizing equation $Q = Cv\sqrt{\Delta P}$ can be used to calculate pressure drop, flow rate, or the flow coefficient.

Example 1

Given: Flow Rate (Q) = 90 gpm
Flow Coefficient (C_v)=51

Find: Valve Pressure Drop (ΔP)

Solution

$$\Delta P = \left(\frac{Q}{C_v}\right)^2 = \left(\frac{90}{51}\right)^2 = 3.1 psi$$

Example 2

Given: Valve Pressure Drop (ΔP) = 10 ft
Flow Coefficient (Cv) = 51

Find: Flow Rate

Solution

10 ft of head * 0.433 *psi/ft* = 4.33 psi; 1 ft of head = 0.433 psi

$Q = Cv\sqrt{\Delta P} = 51\sqrt{4.33} = 106$ gpm

Example 3

Given: Flow Rate (Q) = 90 gpm
Valve Pressure Drop = 12 ft

Find: Valve Flow Coefficient (Cv)

Solution

$$Cv = \frac{Q}{\sqrt{\Delta P}} = \frac{90}{\sqrt{12 * 0.433 = 5.2}} = 39.5$$

Solutions Other Than Water

For solutions other than water, a correction for a difference in specific gravity of the solution is necessary. This revised formula would be:

$Q = Cv[\sqrt{\Delta P/Sg}]$

with *Sg* = specific gravity of the liquid.

Table V: Specific Gravity for Various Liquid

Specific Gravity of Liquids	
Liquid	Sg
Alcohol, methyl	0.79
Alcohol, ethyl	0.79
Ethylene Glycol (50%)	1.07
Propylene Glycol (50%)	1.04
Brine (10% by weight)	1.07
Brine (20% by weight)	1.15
Water	1.00

Example

Given: Flow Rate (Q) = 90 gpm
Valve Pressure Drop (ΔP) = 9 ft
Fluid Medium = Ethylene Glycol (50% concentration)

Find: Flow Coefficient (Cv)

Solution

$$Cv = \frac{Q}{\sqrt{\frac{\Delta P}{Sg}}} = \frac{90}{\sqrt{\frac{(9*0.433)}{1.07}}} = 47$$

Sizing Steam Valves

There are three important factors to consider in arriving at the correct steam valve size for a coil:

1. Maximum amount of heat which the coil must provide.
2. Pressure of steam supplied to the valve.
3. Pressure drop across the valve.

When the coil is sized, auxiliary heating devices and internal heat gains from people, lights, and the sun are generally not considered. The heat loss calculations used to size the coil are normally based on conservative transmission coefficients and coil manufacturers can only offer a limited number of sizes. When all of this is factored in, the result is an oversized coil. To maintain stable control it is recommended that the valve capacity be sized for the actual heat requirements.

Since the density of steam increases with the pressure, the steam supply pressure directly affects the valve capacity. For example, a valve supplied with steam at 5 psig has approximately 10 percent more capacity than one supplied at 2 psig using the same pressure drop. The steam pressure supplied to the valve should be constant. If the pressure switches between two settings then the average of the steam pressure, should be used in determining the valve size.

Modern practice in sizing low pressure steam valves is to select a valve on the basis of a pressure drop equal to the supply pressure when the supply pressure is 10 psig or below. However, for supply pressures above 10 psig, the critical pressure drop can be used. The critical pressure drop is equal to 45 percent of the absolute inlet pressure. The pressure drop is then:

$\Delta P = 0.45 * P_i$

ΔP = Critical Pressure Drop (psi)

P_i = Absolute Inlet Pressure (psia)

When the specification calls for a pressure drop that is less than the 45 percent of the inlet pressure or the steam supply pressure to the valve is less than 10 psig then the following equation should be used:

$$Cv = \frac{Q}{2.11\sqrt{P_i^2 - P_o^2}}$$

Cv = Valve Flow Coefficient

Q = Flow in lbs. of steam / hour

P_i = Absolute Inlet Pressure (psia)

P_o = Absolute Outlet Pressure (psia)

When the inlet pressure is above 10 psig then the critical pressure drop equation was substituted into the above equation. The resulting equation requires only the inlet pressure and steam flow rate to calculate the required flow coefficient (Cv) for critical pressure drop of the wide open valve.

$$Cv = Q / [1.76 * P_i]$$

Cv = Valve Flow Coefficient

Q = Flow in lbs. of steam / hr

P_i = Absolute Inlet Pressure (psia)

Examples

Example 1

Given: Flow Rate (Q) = 1220 lbs/hr
Steam Supply Pressure (P_i) = 20 psig
Valve to be sized for critical pressure drop

Find: Flow Coefficient (C_v)

Solution

$$Cv = \frac{Q}{1.76 * P_i} = \frac{1220}{1.76*(20 + 14.7)} = 20$$

Example 2

Given: Flow Rate (Q) = 1220 lbs/hr
Steam Supply Pressure (P_i) = 20 psig
Outlet Pressure (P_o) = 15 psig

Find: Flow Coefficient (C_v)

Solution

First determine what the critical pressure drop is

$\Delta P = 0.45 * P_i = 0.45*(20 + 14.7) = 15.6$ psi

Since the specified pressure drop of 5 psi is less than the critical pressure drop of 15.6 psi the following equation is used to determine the proper Flow Coefficient (C_v).

$$Cv = \frac{Q}{2.11\sqrt{P_i^2 - P_o^2}} = \frac{1220}{2.11\sqrt{(20+14.7)^2 - (15+14.7)^2}} = \frac{1220}{2.11\sqrt{(34.7)^2 - (29.7)^2}} = 32$$

Gases Other Than Steam

Where ΔP is .1 P_o (less than 1/10 of upstream pressure) the following equation is used to calculate C_v.

$$C_V = \frac{Q}{963}\sqrt{\frac{S_g T}{P_i^2 - P_o^2}}$$

Q= Flow Rate in SCFH
S_g= Specific Gravity (Table)
T = Temperature in Degrees Rankine (460+F)
P_i= Inlet Pressure in PSIA
P_O = Outlet Pressure in PSIA

Table VI : Specific Gravity of Gases

GAS	Sg
AIR	1.00
CARBON DIOXIDE	1.52
CARBON MONOXIDE	.97
OXYGEN	1.11
WATER VAPOR	0.62
AMMONIA	0.59

Example

Given: Medium - Air

Flow Rate = 500,000 scfh
P_i = 110 psig = 14.7 + 110 psig = 124.7 psia
P_o = 106 psig = 14.7 + 106 psig = 120.7 psia
Temperature = 510°F = 460 + 510°F = 970°F Rankine

Find: Flow Coefficient (C_v)

Solution:

$$C_V = \frac{500,000}{963}\sqrt{\frac{1.0*970}{(124.7)^2 - (120.7)^2}} = 519.2\sqrt{.988} = 514$$

Three Way Valves

There are two basic types of three-way valves; the mixing valve with two inlets and one outlet, as shown in Figure 16, and the bypass valve with one inlet and two outlets as shown in Figure 17. There are also two types of applications to which these valves may be applied, a mixing application or a bypass application. The mixing valve can perform either application depending upon the piping arrangement but the bypass valve can only be used in a bypass application. Since Johnson Controls no longer supplies a bypass valve many of the new and existing applications can be accomplished with a mixing valve. These various combinations of mixing valve piping arrangements are shown in Figure 18.

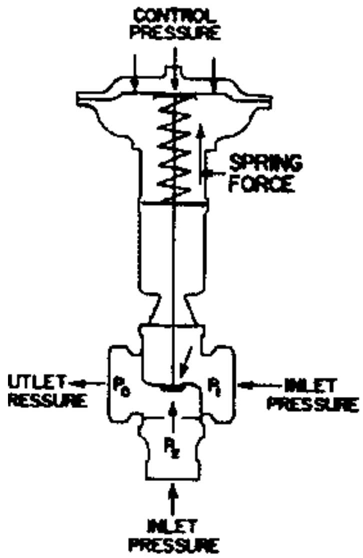


Figure 16: Three-Way Mixing Valve

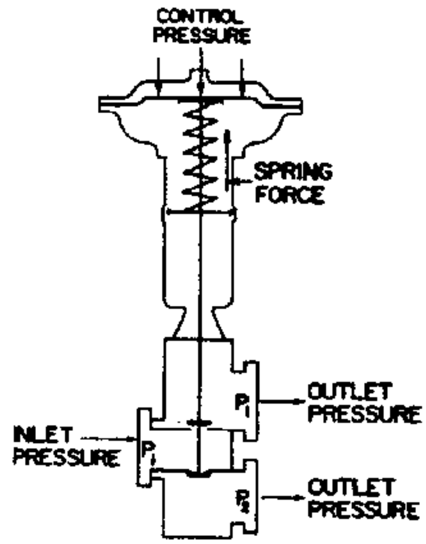


Figure 17: Three-Way Bypass Valve

The type of application that is chosen for a certain job will depend upon the required fail-safe conditions and the way in which the rest of the system is piped. It is desirable to maintain as closely as possible, a constant system loss from balancing valves, coils, fittings, etc. and constant pump head in a system. This is possible if constant flow and constant frictional losses from piping are maintained.

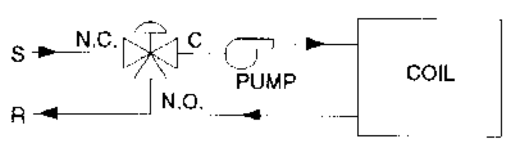


Figure 18a: Mixing Valve in a Mixing Application Piped NC. to Coil

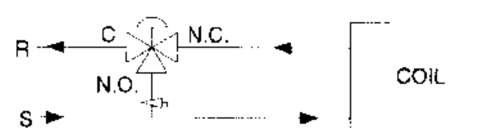
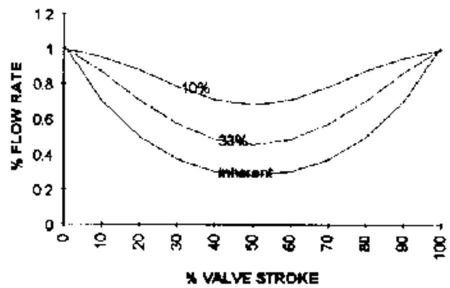


Figure 18b: Mixing Valve in a Bypass Application Piped NC. to Coil

Constant flow across the equal percentage three way valve will depend upon the valve authority. The combined flow characteristic which is the total flow from both inlet ports is shown in Figures 19 and 20 for a 2 inch and 4 inch valve respectively with authorities of 10% and 33%. The smaller the authority the closer the combined flow characteristic approaches the 100% flow condition. This 100% flow condition is the total flow from either of the individual inlets. The difference that occurs between the valve sizes is due to the individual valve rangeability.



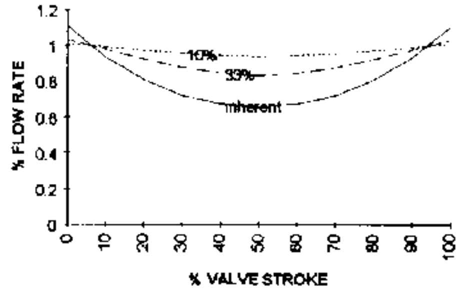


Figure 19: Installed Flow Characteristic for a 2" Brass Body Mixing Valve

Figure 20: Installed Flow Characteristic for a 4" Iron Body Mixing Valve

Two items that should be considered when applying three way valves are 1) The valve should be selected so that its installed characteristic, when combined with the coil performance characteristic, will allow a linear combined lift versus capacity relationship. 2) The valve should produce a relatively constant system flow rate regardless of its stem position. These two traits are not necessarily mutually exclusive. As can be seen with the figures, an equal percentage three way valve with an authority of ten percent can meet both of these performance constraints.

The reasons for selecting a particular flow characteristic for a three-way valve are similar to that of the two-way valve and can be summarized by the following. A linear inherent flow characteristic provides an equal change in flow for an equal change in valve stroke with a constant pressure drop. This would appear to be the most desirable valve characteristic because the valve gain remains constant throughout the valve stroke. Once installed in a system other factors (i.e. piping equipment, control loop, etc.) must be considered which generally make the equal percentage the most widely applied characteristic. The equal percentage characteristic produces a change in flow, with a change in lift, that is a constant percentage of the flow before the change was made.

Valve Selection Summary

This manual contains a few of the basic valve theories and their applications in systems. The topics covered in this manual should provide a better understanding of valves and also aid in their selection. Unfortunately, it is very seldom that the perfect valve for a certain application is available and the next best thing must be selected for a compromise. As a general rule of thumb, because most system components are oversized, the next smaller C_v valve will provide satisfactory results. Good judgment must be used, however, when selecting a smaller valve so that the maximum capacity of the coil is not greatly reduced.

Table VII: Valve Sizing - Steam Capacity in Pounds per Hour

Cv	Inlet Pressure (psi)													
	2		5		10			15	25	35	50	75	100
	Differential Pressure (psi)													
	1	2	2	5	2	5	10	13	18	22	29	39	52
0.2	2.4	3.3	3.6	5.5	4.1	6.3	8.4	10	14	18	23	32	44
0.4	4.8	6.7	7.3	11	8.2	13	17	21	28	35	46	63	85
0.6	7.2	10	11	17	12	19	25	31	42	53	68	95	121
0.9	11	15	16	25	19	28	38	47	63	79	103	142	190
1.0	12	17	18	28	21	32	42	52	70	88	114	138	202
1.2	14	20	21	33	25	38	50	62	84	105	136	179	242
1.4	17	23	25	39	29	44	59	73	98	123	159	221	283
1.6	19	26	29	44	33	50	67	83	112	140	181	252	323
1.8	22	30	33	50	37	57	75	94	126	158	205	284	363
2.0	24	33	36	55	41	63	84	105	140	175	228	316	404
2.2	26	37	40	61	45	69	92	115	154	193	251	347	444
2.4	28	40	43	66	49	75	100	125	168	210	273	379	485
2.6	31	43	47	72	54	82	109	136	182	228	296	411	525
2.8	34	47	51	78	58	88	117	146	196	245	319	474	565
3.0	36	51	55	83	62	95	126	157	210	263	342	474	606
3.2	38	55	58	89	66	101	134	167	224	280	364	505	646
3.4	41	58	62	94	70	107	139	178	238	296	387	537	686
3.6	43	62	66	100	74	113	151	188	252	315	410	568	727
3.8	46	66	69	105	78	120	159	199	266	333	433	600	767
4.0	48	69	73	110	82	126	168	209	280	350	456	632	808
4.5	54	73	82	125	93	142	189	235	315	394	513	711	909
5.0	60	82	91	139	103	158	210	262	350	438	570	790	1010
5.5	66	91	100	152	113	173	230	288	384	481	626	868	1110
6.0	72	100	109	166	124	189	251	314	419	525	683	947	1211
6.5	78	109	118	180	134	205	272	340	454	569	740	1026	1312
7.0	84	118	127	194	144	221	293	366	489	613	797	1105	1450
7.5	90	127	137	208	155	236	314	392	524	656	854	1184	1514
8.0	96	137	146	222	165	252	335	418	559	700	911	1263	1615
8.5	102	146	155	235	175	268	356	444	594	744	965	1342	1709
9.0	108	155	164	249	185	284	377	471	629	788	1025	1421	1803
9.5	114	164	173	263	195	299	398	497	644	831	1090	1500	1900
10	120	173	182	277	206	315	419	523	699	875	1139	1579	2019
11	132	182	200	250	226	346	461	575	768	962	1252	1736	2221
12	144	200	218	332	247	378	503	628	839	1050	1367	1895	2600
13	156	218	237	360	268	410	545	680	909	1100	1481	2052	2625
14	168	237	255	388	288	441	587	732	979	1225	1595	2211	2827
15	180	251	273	416	309	473	629	785	1049	1313	1709	2369	3029
16	192	267	291	443	330	504	670	837	1118	1400	1822	2526	3230
17	204	284	309	471	350	536	712	889	1188	1488	1936	2684	3432
18	216	301	328	499	371	567	754	941	1258	1575	2050	2842	3634

Table VII: Valve Sizing - Steam Capacity in Pounds per Hour

Cv	Inlet Pressure (psi)												
	2		5		10			15	25	35	50	75	100
	Differential Pressure (psi)												
	1	2	2	5	2	5	10	13	18	22	29	39	52
15	180	251	273	416	309	473	629	785	1049	1313	1709	2369	3029
16	192	267	291	443	330	504	670	837	1118	1400	1822	2526	3230
17	204	284	309	471	350	536	712	889	1188	1488	1936	2684	3432
18	216	301	328	499	371	567	754	941	1258	1575	2050	2842	3634
19	228	317	346	526	391	598	796	994	1328	1665	2164	3000	3836
20	240	334	364	554	412	630	838	1046	1398	1750	2278	3158	4038
22	264	367	400	609	453	693	899	1150	1538	1925	2506	3474	4422
24	288	400	436	664	494	756	1006	1252	1678	2100	2734	3790	4846
26	312	434	473	720	536	819	1089	1360	1817	2275	2961	4105	5249
28	336	468	510	776	577	882	1173	1464	1979	2450	3189	4421	5653
30	360	501	546	831	618	945	1257	1569	2097	2625	3417	4737	6057
32	384	534	582	886	659	1008	1341	1674	2237	2800	3645	5053	6461
34	408	567	619	942	700	1071	1425	1778	2377	2975	3873	5368	6865
36	432	601	655	997	742	1134	1508	1883	2516	3150	4100	5684	7268
38	456	635	692	1053	783	1197	1592	1987	2625	3325	4328	6000	7672
40	480	668	728	1108	824	1260	1676	2092	2900	3600	4785	6631	8479
45	540	751	819	1246	927	1417	1885	2363	3225	4000	5240	7262	9286
50	600	835	910	1385	1030	1575	2095	2615	3495	4375	5695	7895	10095
55	660	919	1001	1524	1133	1733	2305	2877	3845	4812	6265	8685	11104
60	720	1002	1092	1662	1236	1890	2514	3138	4194	5250	6834	9474	12114
65	780	1086	1183	1801	1339	2048	2724	3400	4544	5688	7404	10264	13124
70	840	1169	1274	1939	1442	2205	2933	3661	4893	6125	8354	11580	14806
80	960	1335	1456	2215	1648	2520	3351	4184	5591	7000	9304	12896	16488
90	1080	1503	1638	2493	1854	2835	3771	4707	6291	7875	10251	14211	18171
100	1200	1669	1820	2770	2063	3150	4190	5230	6990	8750	12339	17106	21872
120	1440	2004	2184	3324	2472	3780	5028	6276	8388	10500	14427	20001	25573
140	1680	2338	2548	3878	2884	4410	5866	8322	9786	12250	16515	22896	29274
160	1920	2672	2912	4432	3296	5040	6704	9034	11184	14000	18603	25791	32975
180	2160	3006	3276	4986	3708	5670	7542	9746	12582	15750	20691	28686	36676
200	2400	3340	3640	5540	4120	6300	8380	10460	13980	17500	22780	31580	40380
220	2640	3674	4004	6094	4532	6930	9128	11511	15378	19250	25058	34738	44418
240	2880	4008	4368	6648	4944	7560	10056	12552	16776	21000	27366	37896	48608
260	3120	4342	4732	7202	5356	8190	10894	13598	18174	22750	29614	41054	52794
280	3360	4677	5096	7757	5768	8820	11732	14644	19572	24500	32057	44447	56982
300	3600	5010	5460	8310	6180	9450	12570	15690	20970	26250	34500	47840	61170
320	3840	5344	5824	8864	6592	10080	13408	16736	22370	28000	37707	52284	66853
340	4080	5678	6488	9418	7004	10710	14246	17782	23770	29750	40914	56728	72536
360	4320	6012	6552	9972	7416	11340	15084	18828	25170	31500	44121	61172	78219
380	4560	6346	6916	10536	7828	11970	15922	19874	26570	33250	47328	65616	83902
400	4800	6680	7280	11080	8240	12600	16760	20920	27970	35000	50535	70060	89585
450	5400	7515	8190	12465	9270	14175	18855	23535	31465	39375	53742	74504	95268
500	6000	8350	9100	13850	10300	15750	20950	26150	34950	43750	56950	78950	10000
550	6594	9176	10000	15221	11319	17309	23024	28738	38410	48081	59000	84000	10500
600	7188	10002	10900	16592	12338	18868	25098	31326	41870	52417	64000	88000	11000

Table VIII: Valve Sizing - Water Capacity in US. Gallons per Minute

	Differential Pressure (psi)								Differential Pressure (psi)						
Cv	3	5	7	9	12	15	20	Cv	3	5	7	9	12	15	20
0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	26	45	58	69	78	90	101	118
0.4	0.7	0.9	1.1	1.2	1.4	1.5	1.8	28	48	63	74	84	97	108	125
0.6	1.05	1.35	1.6	1.8	2.05	2.3	2.7	30	52	67	79	90	104	116	135
0.8	1.3	1.7	2.1	2.4	2.7	3.0	3.5	32	55	72	85	96	111	124	144
1.0	1.7	2.2	2.6	3.0	3.5	3.9	4.5	34	59	76	90	102	118	132	152
1.2	2.0	2.6	3.1	3.6	4.1	4.6	5.25	36	62.5	80	95	108	125	140	161
1.4	2.4	3.1	3.7	4.2	4.8	5.4	6.1	38	66	85	101	114	132	147	170
1.6	2.8	3.6	4.2	4.8	5.5	6.2	7.1	40	69	89	106	120	139	155	180
1.8	3.1	4.0	4.7	5.4	6.2	6.9	8.1	45	78	101	119	135	156	—	—
2.0	3.4	4.4	5.2	6.0	6.9	7.7	9.0	50	87	112	132	150	173	—	—
2.2	3.8	4.9	5.8	6.6	7.6	8.5	9.75	55	95	125	145	165	190	—	—
2.4	4.1	5.3	6.2	7.1	8.2	9.25	10.8	60	104	134	159	180	208	—	—
2.6	4.5	4.5	5.8	6.8	7.8	9.0	11.9	65	113	145	172	195	225	—	—
2.8	4.8	6.3	7.4	8.4	10	11	12.5	70	121	157	185	210	242	—	—
3.0	5.2	6.7	7.9	9.0	10	12	13.5	80	139	179	212	240	277	—	—
3.2	5.5	7.1	8.4	9.6	11	12	14.2	90	156	201	238	270	312	—	—
3.4	5.9	7.6	9.0	10	12	13	15.2	100	175	225	265	300	350	—	—
3.6	6.2	8.0	9.5	11	12.5	14	16	120	208	268	318	360	416	—	—
3.8	6.5	8.4	10	11.5	13	15	17	140	242	313	370	420	485	—	—
4.0	6.9	9.0	11	12	14	15	18	160	280	350	425	475	560	—	—
4.5	7.7	10	12	14	16	17	20	180	313	400	475	540	625	—	—
5.0	8.6	11	13	15	17	19	22.5	200	346	447	529	600	693	—	—
5.5	9.5	12	15	17	19	21	24.2	220	381	492	582	660	762	—	—
6.0	10	13	16	18	21	23	27	240	416	537	635	720	831	—	—
6.5	11	14	17	19	23	25	29	260	450	580	680	775	900	—	—
7.0	12	16	19	21	24	27	31.9	280	485	626	741	840	970	—	—
7.5	13	17	20	23	26	29	34	300	520	671	794	900	1039	—	—
8.0	14	18	21	24	28	31	36	320	550	720	840	950	1100	—	—
8.5	14.5	19	22.5	25.9	29	33	38	340	590	755	900	1000	1175	—	—
9.0	15.5	20	24	27	31	35	40	360	625	800	950	1100	1250	—	—
9.5	16.5	21	25	28.5	33	36.5	42.5	380	660	850	1000	1150	1350	—	—
10	17	22	26	30	35	39	45	400	700	890	1075	1200	1400	—	—
11	19	25	29	33	38	43	48	450	780	1000	1200	1375	1580	—	—
12	21	27	32	36	42	46	54	500	866	1118	1323	1500	1732	—	—
13	23	29	34	39	45	50	58	550	950	1230	1450	1650	1900	—	—
14	24	31	37	42	48	54	62.5	600	1039	1342	1587	1800	2078	—	—
15	26	34	40	45	52	58	68	650	1125	1475	1700	1950	2250	—	—
16	28	36	42	48	55	62	72	700	1212	1565	1852	2100	2425	—	—
17	29	38	45	51	59	66	75	750	1300	1675	2000	2250	2600	—	—
18	31	40	48	54	62	70	80	800	1400	1800	2250	2400	2800	—	—
19	33	42	50	57	66	74	85	850	1475	1900	2400	2575	2950	—	—
20	34	44	52	60	69	77	89	900	1559	2012	2381	2700	3117	—	—
22	38	49	58	66	76	85	98	950	1645	2124	2514	2850	3291	—	—
24	42	54	64	72	83	93	108	1000	1750	2250	2650	3000	3450	—	—

Maximum Temperature and Pressure Ratings

The maximum body pressure and temperature limits of Johnson Controls valves are grouped below. The ratings comply with American National Standards Institute (ANSI) specifications. The grouping numbers are designations assigned by Johnson Controls to classify valves and have no other significant meaning.

JOHNSON CONTROLS VALVE GROUPINGS

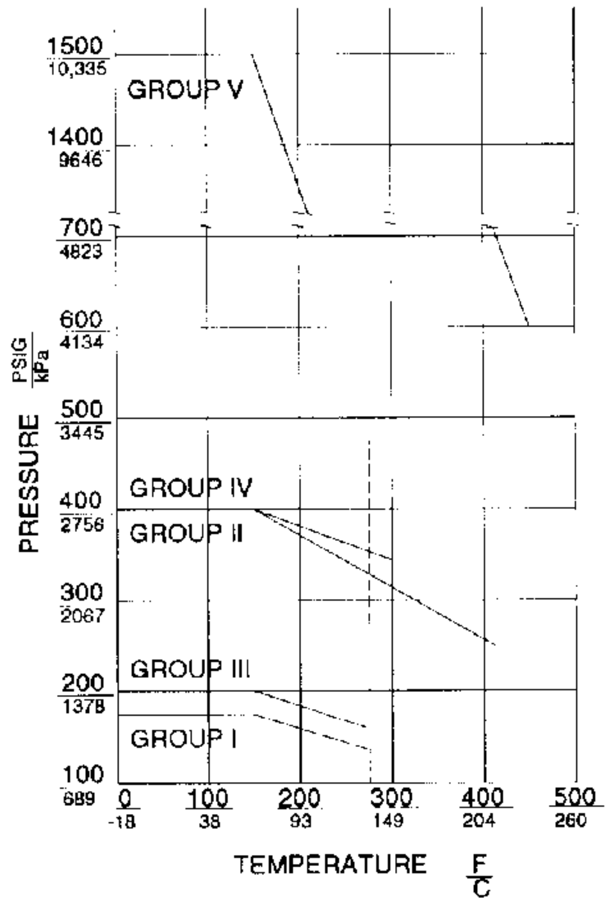
GROUP # I ANSI B16.1 CLASS 125
(Cast Iron - Flanged)
175 psig to 150°F
142 psig at 281°F

GROUP # II ANSI B16.1 CLASS 250
(Cast Iron - Flanged)
400 psig to 150°F
250 psig at 406°F

GROUP # III ANSI B16.15 CLASS 125
(Cast Brass - Threaded)
200 psig to 150°F
160 psig at 281°F

GROUP # IV ANSI B16.15 CLASS 250
(Cast Brass - Threaded)
400 psig to 150°F
345 psig at 281°F

GROUP # V ANSI B16.3 CLASS 300
(Malleable Iron - Threaded)
1500 psig to 150°F
600 psig at 450°F



Glossary

Authority, Valve — The ratio of valve pressure drop to total branch pressure drop at design flow. The total branch pressure drop includes the valve, piping, coil, fittings, etc.

Cavitation — The forming and imploding of vapor bubbles in a liquid due to decreased, then increased, pressure as the liquid flows through a restriction.

Control Loop — Chain of components which makes up a control system. If feedback is incorporated it is a closed loop; if there is no feedback, it is an open loop system.

Controlled Fluid — When applied to a valve, this term refers to whatever fluid is being regulated. For heating-cooling systems, this fluid can be hot or chilled water, steam or refrigerant.

Critical Pressure Drop — This applies to gases and vapors. It is the pressure drop which causes the maximum possible velocity through the valve. Higher pressure drops will not increase the flow velocity.

Dynamic Pressure — The pressure of a fluid resulting from its motion. Total Pressure - Static Pressure = Dynamic Pressure (Pump Head)

Flow Characteristic — Relation between flow through the valve and percent rated travel as the latter is varied from zero to 100 percent.

Flow Characteristic, Inherent — Flow characteristic when constant pressure drop is maintained across the valve.

Flow Characteristic, Installed — Flow characteristic when pressure drop across valve varies as dictated by flow and related conditions in system in which valve is installed.

Flow Coefficient (C_v) — Number of US. gallons per minute of 60F water that will flow through a fully open valve with a 1 psi drop across it.

Rangeability — Ratio of maximum to minimum controllable flow at which specified flow characteristic prevails.

Rated Flow — For a coil this is the flow through the coil which will produce full rated heat output of the coil.

Spring Range — Control pressure range through which the signal applied must change to produce total movement of the controlled device from one extreme position to the other.

Actual Spring Range — Control pressure range that causes total movement under actual conditions to overcome forces due to spring force, fluid flow, friction etc.

Nominal Spring Range — Control pressure range that causes total movement when there is no external force opposing the actuator.

Static Pressure — The pressure with respect to a surface at rest in relation to the surrounding field.

Stroke — This is synonymous to lift, travel, and percent open. These are terms used when referring to the amount a valve has moved from either extreme of fully open or fully closed.

Total Pressure — The sum of the Static Pressure and the Dynamic Pressure.

Three Way Valve — Valve with three connections, one of which is a common and two flow paths.

Bypass or Diverting Valve — Common connection is the only inlet: Fluid entering this connection is diverted to either outlet.

Mixing Valve — Two connections are inlets and the common is the outlet. Fluid from either or both inlets is selected to go out the common connection.

Two Way Valve — Valve with two connections and a single flow path.

Uncontrollable Flow — The flow rate at low load conditions that causes the valve to hunt or cycle. Typically occurs within the first 10% of valve stroke.

Valve Pressure Drop — Portion of the system pressure drop which appears across the valve. For valve sizing this drop is across a fully open valve.

Notes

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