

## Section Vb2: Butterfly Valves

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# Butterfly Valves

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## **Introduction**

The two types of control valves most commonly utilized in the commercial Heating, Ventilating and Air Conditioning (HVAC) industry are the globe and butterfly styles. Johnson Controls has been installing globe style valves in hydronic and steam systems for many years, and therefore, have a substantial amount of application experience with globe style valves. Globe valve construction and characteristics are covered in *Section Vb1* of this manual.

This section will cover the construction and application of exclusively butterfly style valves.

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## **Advantages of Butterfly Valves**

Compared to Globe Valves selected for the same design flow rate requirement:

1. Butterfly valves are more compact. They require less space and are lighter.

For example a 6 in. V-5252-19 with a  $C_v = 350$  weighs approximately 200 pounds. In contrast a 4 in. VF series butterfly valve with a  $C_v = 496$  (at 70° Rotation) weighs only 19 pounds including a VA-909X series actuator.

2. Butterfly valves are less expensive.
3. Butterfly valves have fewer parts and are easy to maintain.

Furthermore:

4. Butterfly valves are available in sizes up to 20 in. and with  $C_v$  ratings as large as 22,339.
5. Practically speaking; actuator sizing is **not** dependent on the differential pressure across the system (i.e., pressure developed by the pump). Therefore, problems with the valve being unable to close off against the system differential pressure are eliminated.
6. Butterfly valves are bubble-tight in the closed position. They don't leak.
7. When sized properly (probably not line size) butterfly valves are capable of providing accurate, stable, modulating flow control.

Many of these points will be discussed in more detail later in this section.

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### **Disadvantages of Butterfly Valves**

1. Butterfly valves have lower valve recovery coefficients,  $K_m$ , than globe valves. The value of  $K_m$  relates to cavitation potential. Large values are desirable.
2. Butterfly valves have a greater potential for water hammer than globe valves.
3. Butterfly valves are not as well understood in the HVAC industry as are globe valves.

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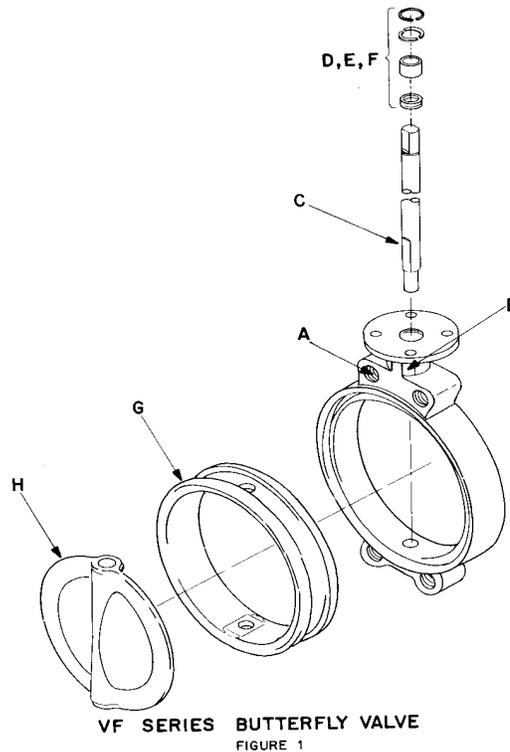
### **Construction of Butterfly Valves**

The body of a butterfly valves (see Figure 1) consists of a circular casting with lugs (A) and a neck (B). The neck encloses the valve stem (C), a stem bushing (D), a stem seal (E) and a stem retaining ring (F). The stem bushing insures proper stem alignment within the valve by absorbing actuator side thrusts. The other end of the stem is secured within a recess machined in the bottom of the body. In the case of the VF series valve the stem seal prevents contaminants on the **outside** of the valve from entering the valve bore. This can be important in outdoor applications or corrosive environments. The stem retaining ring stabilizes the valve stem in the body.

On the inner surface of the body is the valve seat (G). This seat performs two functions. First, it provides an elastic surface which will insure a tight interference fit with the valve disc. This tight interference fit allows the VF series valves to provide **bubble-tight** shutoff. In the case of the VF series valves the seat also provides a tight seal between the valve body and the face of the surrounding pipe flanges. No separate flange gasket is required.

The final component of the VF series butterfly valve is the disc (H). The disc is the component of the valve which actually performs the liquid throttling function. As the actuator is modulated the disc is rotated within the valve body. Its operation is similar to that of a blade inside a round damper.

The primary seal which prevents the leakage into the valve neck is an interference fit between the valve stem and the seat. The diameter of the stem is larger than the hole cut in the seat through which it passes. Since this is a dry stem type seal the stem is not exposed to the media in the piping system.



## Undercut Discs

The features and options template in the VF series butterfly valve product data bulletin shows two different types of valves. They are low and high pressure respectively. The difference between these valves is that the low pressure series valves have an undercut disc. The diameter of an undercut disc is slightly less than the diameter of the disc found on the high pressure series valves. The purpose of reducing the disc diameter is to decrease the seating/ unseating torque requirements and to prolong the seat life in low pressure applications. Another benefit of an undercut disc is that it generally allows the use of a smaller actuator for a specific valve size.

The high pressure valves do not leak (are bubble-tight) with a differential pressure of up to either 150 psig (14 in. - 20 in.) or 175 psig (2 in. - 12 in.). Since the low pressure valves have an undercut disc, they have less of an interference fit between the disc and the seat. Therefore, their bubble-tight rating is only valid for up to a 50 psig differential pressure across the valve.

Keep in mind that these bubble-tight pressure ratings are a function of **differential** pressure across the valve not the magnitude of the system pressure. The magnitude of the system pressure is related to both the pressure developed by the pump and the height of the building. In the worst case situation, the differential pressure across the valve would equal the shutoff pressure developed by the pump.

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## **Materials of Construction**

### **Valve Body Material**

The valve body is made of cast iron and complies with ASTM A-126 Class B Specification.

### **Valve Stem Material**

The valve stem is made of one of the following optional materials:

1. Phosphate coated carbon steel (ASTM A-108). The phosphate coating provides increased surface lubricity; reduces friction, galling, and wear; reduces high temperature oxidation; and increases corrosion resistance. The first two items help to reduce the torque requirements of the valve. Remember: the series VF butterfly valve has a dry stem design. Therefore, the potential for stem corrosion is very small since the stem is not exposed to the media in the pipe.
2. 416 Stainless Steel (ASTM A-582 Type 416). 416SS offers the advantage of having a higher yield strength than carbon steel (90,000 psi vs. 36,000 psi). However, 416SS offers very little additional corrosion resistance over carbon steel. Generally speaking corrosion resistance is a function of the amount of Nickel contained within the alloy. 416SS does not contain enough Nickel to substantially increase its corrosion resistance.
3. 304 Stainless Steel (ASTM A-276 Type 304). 304SS has less than 1/2 the yield strength of carbon steel, but it is significantly more corrosion resistant.
4. 316 Stainless Steel (ASTM A-276 Type 316). 316SS has less than 1/2 the yield strength of carbon steel. It is also significantly more corrosion resistant. 316SS is very similar to 304SS except that it has more molybdenum and nickel than 304SS.

**Note:** The 304SS, 316SS and 416SS stems are provided to meet specification requirements. Practically speaking they offer very little advantage over the phosphate coated carbon steel stems. This is true because the VF series valves utilize a dry stem design. Thus the increased corrosion resistance provided by 304SS or 316SS is not required. Also the strength of carbon steel is more than adequate for 2 in. through 20 in. size valves, and the additional strength of 416SS is not required.

### **Valve Seat Material**

EDPM is the abbreviated name for Ethylene Propylene Diene Monomer. It also goes under other abbreviations or trade names such as EPT, Nordel, ECD, or EPR. All of these are the same material as EDPM. EDPM has excellent abrasion resistance. It is resistant to and recommended for the following media: Alcohols, Acidic Salts, Alkaline Salts, Alkaline Solutions, Beverages, Bleach, Inorganic Acids (Dilute), Neutral Salts, Water (cooling, brackish or salt).

EDPM is **not** resistant to Hydrocarbons, Petroleum based oils, or Turpentine. If you have questions concerning other media contact your local Johnson Controls Representative.

The temperature range of EDPM is minus 40°F to 250°F. However, durometer hardness increases when temperature is consistently below 0°F (torque requirements will consequently increase). Consult your local Johnson Controls representative for applications with media temperatures less than 0°F.

### **Valve Disc Material**

The disc is made of ductile iron and is coated with Nylon 11. Nylon 11 is a thermoplastic produced from a vegetable base. It is very corrosion and abrasion resistant. Nylon 11 coatings are resistant to and recommended for: Inorganic salts, alkalis, glycol solutions, organic acids, most solvents, water (cooling, brackish or salt). The continuous service temperature range of Nylon 11 is -20°F to +200°F, with intermittent service up to +250°F.

Nylon 11 may not be resistant to inorganic acids, phenols and certain chlorinated solvents. If you have any questions concerning other media contact your local Johnson Controls representative.

### **Actuator Options**

There are several actuator options available for the VF series of butterfly valves. Pneumatic options include standard Johnson Controls piston actuators factory installed on mounting plates, high pressure double acting rack and pinion actuators (V-909x series) and high pressure spring return rack and pinion actuators (V-919x series). Electric actuator options include electric two position (switched 120 VAC) and electric modulating (4-20 MA) actuators. The piston actuators are standard Johnson Controls. D-3153, D-3244, or D-3246 actuators. They can be used on several different two and three-way valve sizes. Refer to the *VF Series Butterfly Valve Product Bulletins* to determine which size valves can utilize the piston actuators. The maximum valve disc rotation which can be obtained for a butterfly valve driven by a Johnson Controls piston actuator is 70°.

The high pressure pneumatic rack and pinion and electric actuators can be utilized to modulate any size of VF series butterfly valves. When these actuators are utilized, up to 90° of valve disc rotation can be obtained; in contrast to the 70° maximum rotation of valves driven with the piston actuators.

When butterfly valves with pneumatic actuators are utilized for modulating control, positioners must be provided. The reasoning for this requirement will be elaborated upon later when torque requirements are discussed.

The VF series butterfly valve product data sheets contain the necessary actuator sizing sheets. The actuator selection charts incorporate a 25% safety factor for 2 in. - 12 in. sizes and 10% safety factor for 14 in. - 20 in. sizes to insure smooth trouble free operation.

### Butterfly Valve Torque Requirements

The amount of total torque ( $T_T$ ) required to modulate a butterfly valve disc is actually the sum of several torques which occur within the butterfly valve. Specifically:

$$T_T = T_{su} + T_d + T_{bf} + T_{ss} + T_e + T_h$$

Where:

$T_{su}$  = Seating and Unseating Torque

$T_d$  = Dynamic Torque Resulting from lift effect of the fluid flow on the disc.

$T_{bf}$  = Bearing Friction Torque

$T_{ss}$  = Stem Seal Friction Torque

$T_e$  = Eccentricity Torque resulting from disc offset from centerline of stem

$T_h$  = Hydrostatic Torque

The overall torque requirement for a butterfly valve is primarily a function of  $T_{su}$ ,  $T_d$  and  $T_{bf}$ . The magnitude of the other torque components are generally insignificant in comparison.

### Seating/Unseating Torque

The magnitude of the required seating/unseating torque ( $T_{su}$ ) for the VF series butterfly valves has been determined by actual testing. Its value is largest in the first 20° of rotation while the disc and seat are in contact. After the disc clears the seat material the value of  $T_{su}$  will drop to zero. The magnitude of  $T_{su}$  is a function of the pressure differential across the valve, the seat material's coefficient of friction, the finished surface of the disc edge, and the amount of interference between the seat I.D. and disc O.D. when flanged in the piping and the seat thickness.

If a butterfly valve sits in the closed position for an extended period of time (over 5 days) the seating material will take a compression set. The effect of compression set is to further increase the value of  $T_{su}$ . The effect of compression set **has** been considered in the actuator selection charts for the VF series of butterfly valves.

### Bearing Friction Torque

Bearing friction torque ( $T_{bf}$ ) occurs because the differential pressure across the valve disc generates a force which is applied against the disc and subsequently is transmitted to the stem. As the stem is forced against the bearing supports, bushing and interior body, friction forces are created between the stem and the stem supports.

Bearing friction forces can be determined by using the following equation:

$$T_{bf} = 0.21 (D_v)^2 (d/2) \Delta P$$

Where:

$D_v$  = Valve Diameter, inches

$d$  = Diameter of Shaft, inches

$\Delta P$  = Differential Pressure Across Valve, psi

### Dynamic Torque

Dynamic torque ( $T_d$ ) occurs when the position of the disc is between the closed position  $0^\circ$  and the wide open position  $90^\circ$ . With the disc in the partially open position, velocity of the fluid passing the leading disc edge is less than the velocity passing the trailing edge. This variance in velocity past the leading disc edge and trailing disc edge results in an unbalanced distribution of forces across the face of the disc. The total forces acting perpendicular to the disc face on the leading edge half of the disc are greater than the total forces acting perpendicular on the trailing half of the disc. This uneven distribution of forces acting on the disc face results in a torsional moment which tries to turn the disc to the closed position. The magnitude of  $T_d$  is greatest when the disc is between  $75^\circ$  and  $85^\circ$  of rotation. To determine dynamic torque, the following equation is applied:

$$T_d = C_{dt} \times D^3 \times \Delta P$$

Where:

$T_d$  = Dynamic Torque, in-lbs

$C_{dt}$  = Coefficient of Dynamic Torque (obtain value from Figure 2)

$D$  = Diameter of Disc, inches

$P$  = Differential Pressure Across The Valve, psi

Dynamic torque may be minimized by proper installation of the valve with regard to orientation of the shaft, distance in the pipeline from elbows, other valves, etc. Review the installation instructions for the VF series butterfly valves for details.

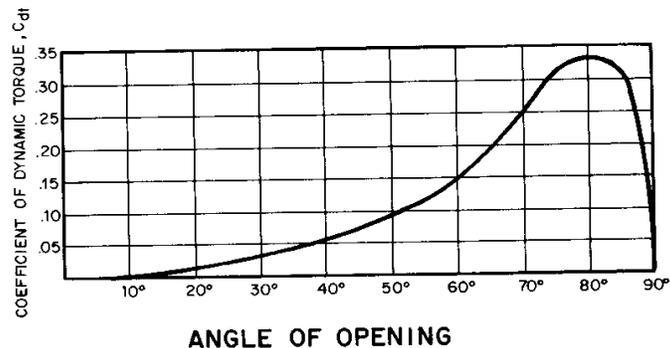
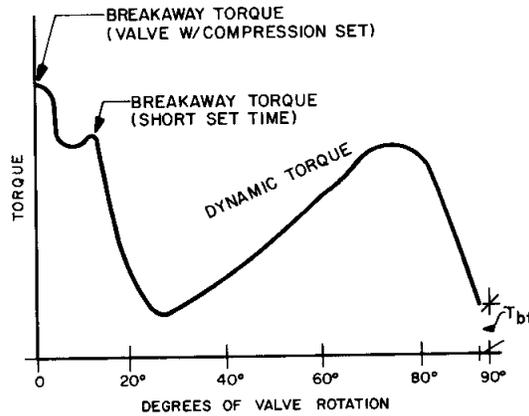


FIGURE 2

Figure 3 shows the combined effects of  $T_{su}$ ,  $T_{bf}$  and  $T_d$  as a function of valve rotation for a butterfly valve in a typical HVAC installation. In almost all HVAC applications the magnitude of  $T_{su}$  has the largest effect and will determine the sizing of the actuator.



TYPICAL OPERATING TORQUE

FIGURE 3

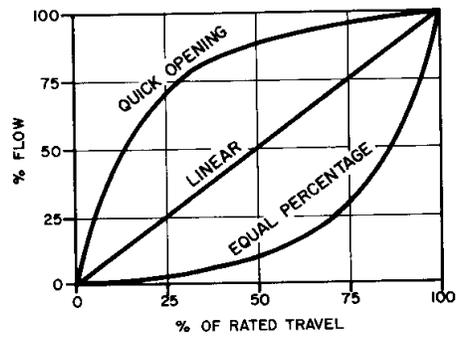
## Recommendations

Butterfly valves utilized for proportional control (throttling) applications should be selected on the basis of their  $C_v$  rating at  $70^\circ$  rotation. This recommendation is based on the fact that the dynamic torque increases very rapidly at approximately  $75^\circ$  rotation. It then subsequently drops suddenly at approximately  $85^\circ$  rotation. These rapid changes in dynamic torque will cause a throttled valve to become unstable. When smaller than line size butterfly valves are installed (throttling applications) concentric reducers and fittings are recommended.

## Butterfly Valve Parameters

### Butterfly Valve Flow Characteristics

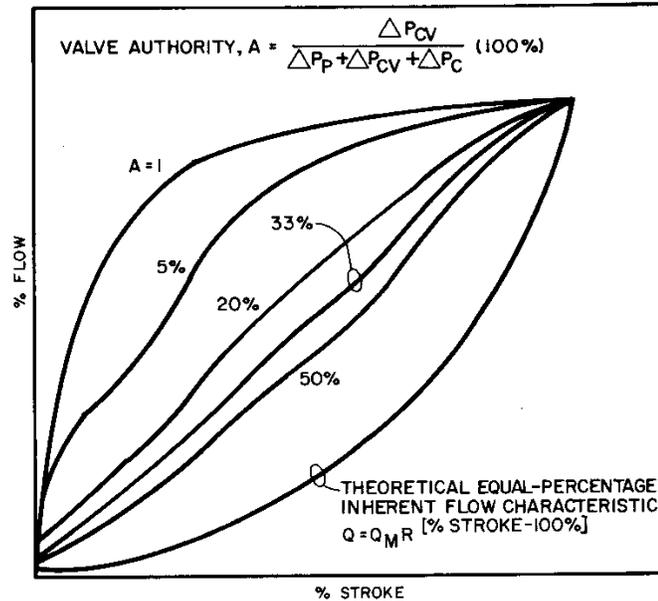
The valve flow characteristic represents the relationship between the flow rate through a valve and the degrees of rotation of the valve disc. This relationship is usually illustrated in the form of a graph. The characteristic that is usually graphed is the **Inherent Flow Characteristic**. This relationship is determined in a laboratory using a constant pressure drop across the valve regardless of the flow rate. There are three generic types of inherent flow characteristics. They are: **quick opening**, **linear**, and **equal percentage** (see Figure 4).



CONTROL VALVE FLOW CHARACTERISTICS

FIGURE 4

In a real hydronic system the pressure drop across a valve cannot be held constant. Therefore, the inherent valve characteristic will no longer be valid. The resulting valve flow characteristic is normally called the **Installed Flow Characteristic**. Figure 5 shows how valve authority affects the flow characteristic of a equal percentage type valve. This relationship between the authority of a valve and the resulting installed flow characteristic is true for both globe and butterfly style valves. As discussed in *Engineering Report H111*, valve authority is the ratio of the wide open pressure drop in the valve to the full flow pressure drop through the branch.



INSTALLED FLOW CHARACTERISTICS OF EQUAL % VALVE

FIGURE 5

(FROM ISA HANDBOOK OF CONTROL VALVES-2nd EDITION)

Where:  $\Delta P_{CV}$  = Pressure Drop through Control Valve at Design Flow  
 $\Delta P_P$  = Pressure Drop through Pipe and Fittings at Design Flow  
 $\Delta P_C$  = Pressure Drop through Coil at Design Flow

Figure 6 shows the inherent flow characteristic for a typical butterfly valve. Through the first 70° of rotation it exhibits an equal percentage type flow characteristic. The flow characteristic through the last 20° of rotation exhibits more of a linear or slight quick opening type flow characteristic.

### Typical Butterfly Valve Applications

Butterfly valves are typically utilized in three different applications. First, they may be utilized as a simple two position (on/off) valve. Second, they may typically be used to vary the capacity of a coil or heat exchanger. And third, the butterfly valve may be used for mixed water temperature control.

### Two Position Control Applications

Currently, the majority of butterfly valves utilized in the HVAC industry are used as two position control devices to isolate non-operating equipment or, if sequenced with other valves, to reconfigure piping systems to meet other job specific requirements. When butterfly valves are used in two position applications the shape of the valve flow characteristic is not important.

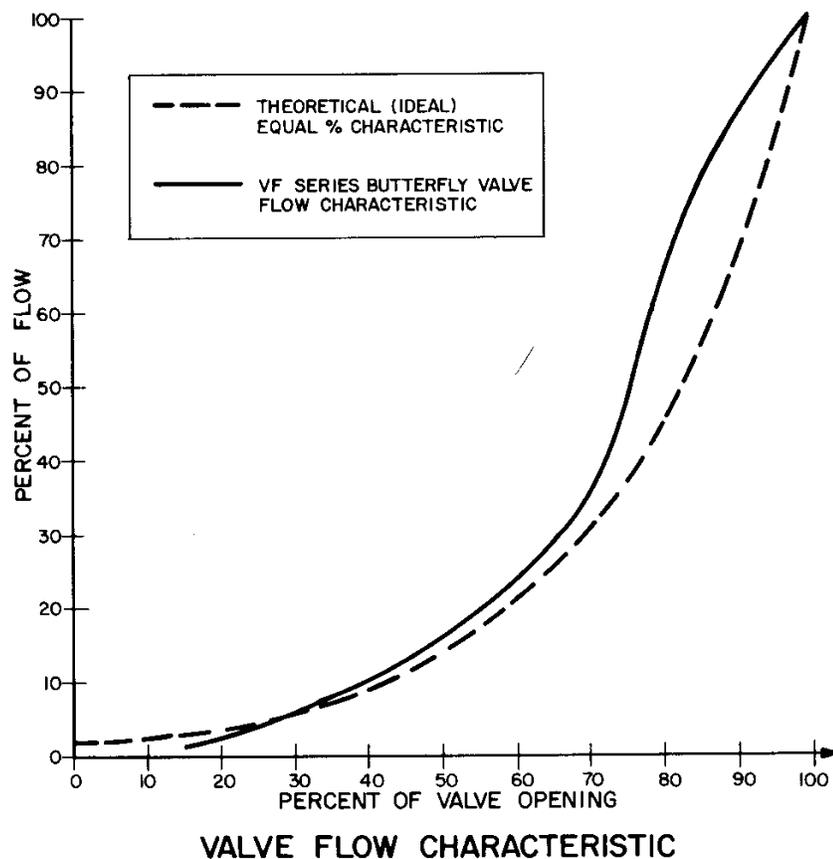


FIGURE 6

From a performance perspective, sizing a butterfly valve to pass design flow at 70° or 90° rotation is of no consequence. In fact, in two position applications, a line size butterfly valve is almost always installed. This is a good practice since modulating control is not required, and a line size valve will lower the overall system pressure drop.

Thus for two position applications, it would be more cost effective to utilize the VF series butterfly valves with Johnson Controls piston actuators (D-3153, D-3244, and D-3246) whenever possible. These actuators are significantly less expensive than the VA-90XX and VA-91XX actuators. The Johnson Controls piston actuators also offer the advantage of easy replacement usually from branch stock.

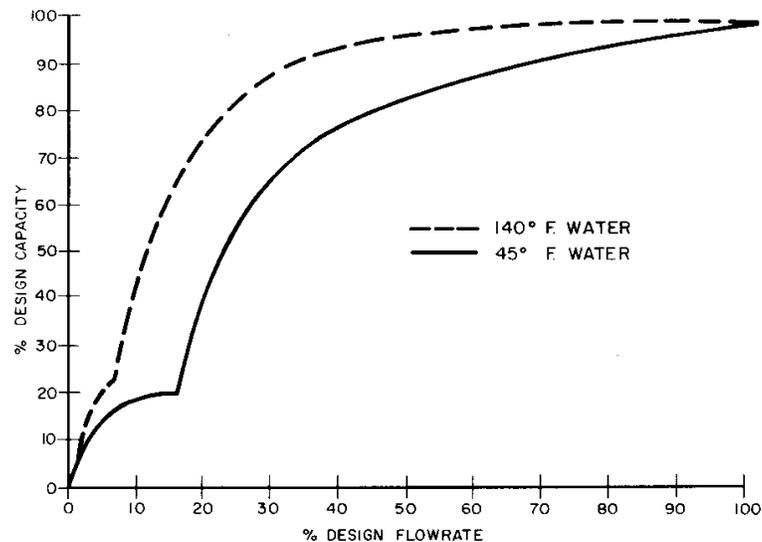
**Guideline**

For two position control applications utilize a line sized VF series butterfly valve, and whenever possible use Johnson Controls piston actuators.

## Control of Coils and Heat Exchangers

Stable, accurate control of coil or heat exchanger capacity is a function of two independent constraints. The first constraint relates to how well the flow characteristic of the valve complements the performance characteristic of the coil or heat exchanger. The second constraint, which is **much** more important, determines what percentage of the design capacity of the coil or heat exchanger will be uncontrollable. The effect each of these constraints have on controllability will now be covered.

As discussed in *Engineering Report H111*, an equal percentage type flow characteristic is useful for control of the flow rate through a coil or heat exchanger. For a coil or heat exchanger the relationship between capacity and flow rate is basically logarithmic. The exact shape of this curve will be a function of coil construction, face velocity, entering air conditions and the water supply temperature.

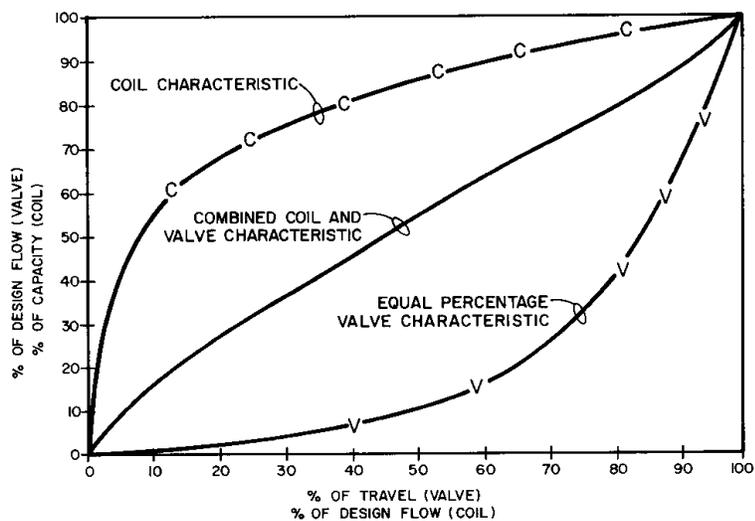


COIL PERFORMANCE CHARACTERISTIC

FIGURE 7

Figure 7 shows the flow versus capacity relationship for a typical coil supplied with 140°F water in one case and 45°F water in the other. As mentioned previously, the shape of each curve is basically logarithmic. However, there is a visible difference in the coil characteristics at values less than 20% of the design flow rate. This difference is caused by the onset of laminar flow which occurs at different flow rates as a function of media temperature.

Ideally, when a coil performance characteristic is combined with an equal percentage valve flow characteristic, the resulting relationship between the degrees of disc rotation and coil capacity will be relatively linear (see Figure 8).



COMBINE COIL & VALVE CHARACTERISTICS  
FOR EQUAL PERCENTAGE TYPE VALVES

FIGURE 8

Considering the large number of possible coil characteristic curves and the many **installed** flow characteristics of a valve, it is almost impossible to exactly match the coil performance and valve flow characteristic curves. Therefore, the desired linear relationship shown in Figure 8 is seldom achieved. Fortunately, this is not as great of a problem today as it was a few years ago.

When simple analog proportional action controllers were the only type of controller available, maintaining this linear relationship between valve stroke and coil capacity was important. Controllers which have only proportional control capabilities do not do a very good job of dealing with a nonlinear process. The controller gain must be kept quite low to provide stability whenever the system gains are high. In most processes, the system (process) gains are the highest when the controller device (i.e., fan inlet vanes or control valves) first begins to open. Objectional control offset often occurred as a result of the low controller gains, which were necessary to provide stability.

Today we have both pneumatic and direct digital controllers which are capable of compensating for nonlinear processes. As a result, the shape of the valve flow characteristic does not have nearly the importance it once had. In the case of coil control, it is still beneficial to have a valve with an installed flow characteristic which is close to the inherent equal percentage flow characteristic, but it is by no means critical. As discussed, today's Proportional Integral (PI) controllers are able compensate for most nonlinear processes.

The second constraint, mentioned above, deals with the ability of a valve to proportionally control the capacity of a coil or heat exchanger. All valves have some amount of flow which is uncontrollable when the valve is first opened. In the case of a globe valve, it occurs when the plug is initially lifted from the seat. The magnitude of the uncontrolled flow rate is related to the machining tolerances between the valve plug and the orifice through which it moves. In the case of a butterfly valve this uncontrollable flow occurs when the disc first clears the seat material. Depending on the size of the valve this occurs somewhere between 10° and 20° of rotation. Just as in the case of the globe valve, there is no flow before the disc (plug) clears the seat. However, after the disc (plug) does first clear the seat, an uncontrollable amount of flow will occur.

The amount of this uncontrolled flow can be determined if the **rangeability** of the valve is known as well as the differential pressure across the valve. By definition **valve rangeability** is the ratio of the maximum to minimum controllable flow rates through the valve. To make things simpler rangeability is normally calculated as the ratio of the maximum to minimum controllable  $C_v$  values of the valve. Thus the differential pressure across the valve no longer needs to be considered. Large values for rangeability are desirable.

$$\text{Rangeability} = (\text{Maximum } C_v) \div (\text{Minimum controllable } C_v)$$

If you refer back to Figure 7, it should be evident that it is extremely important to minimize the amount of uncontrollable flow through a valve. This is particularly true in the case of a heating coil! Remember, in coil or heat exchanger applications very small percentages of uncontrollable flow correspond to very large changes in coil capacity. If the load served by a coil falls between 0% and the percent capacity which is associated with the valve uncontrollable flow rate, it may be difficult, if not impossible, to maintain the control setpoint. Since the flow cannot be modulated proportionally below the uncontrollable flow rate associated with a particular valve, the capacity associated with this uncontrolled flow must be controlled in a two position manner.

Rangeability values for Johnson Controls butterfly and globe valves are listed below in Table 1.

Valve Size	Rangeability Values	
	Butterfly Valves 70° Rot.	Globe Valves
2"	7:1	50:1
2½"	9:1	6.5:1
3"	18:1	7.7:1
4"	25:1	9.3:1
5"	32:1	10.7:1
6"	39:1	10.4:1
8"	48:1	N.A.
10"	155:1	N.A.
12"	92:1	N.A.
14"	174:1	N.A.
16"	68:1	N.A.
18"	68:1	N.A.
20"	52:1	N.A.

Table 1

The magnitude of the uncontrollable flow rate through a valve can be calculated as shown in Examples 1 and 2. For both examples it is assumed the valve will be sized large enough to pass 750 gpm of water at a pressure drop of less than 5 psig.

**Example 1:**

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

$$\text{Uncontrollable flow rate} = (350 \div 10.4) (5)^{1/2} = 75 \text{ gpm}$$

**Example 2:**

Determine the uncontrollable flow rate through a 4 in. butterfly valve where  $C_v$  equals 496 (sized for 70° rotation) and rangeability equals 25:1. Assume the differential pressure across the valve equals 5 psig.

$$\text{Uncontrollable flow rate} = (496 \div 25) (5)^{1/2} = 44 \text{ gpm}$$

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 preceding examples. These pressure shifts are discussed in *Engineering Reports H110 and H112*. The net effect of the pressure shifts is to increase the uncontrollable rate.

In the case of Example 1, the uncontrollable flow rate is 10% of the design flow rate of 750 gpm. Referring back to Figure 7, this uncontrollable flow rate corresponds to approximately 40% of the capacity of a heating coil. Therefore, the first 40% of the heating coil design capacity will be controlled in a two position manner. The last 60% of capacity will be controlled proportionally. In the case of a cooling coil approximately 20% of the design capacity would be controlled in a two position manner.

In Example 2, the uncontrollable flow rate is 5.9% of the design flow rate of 750 gpm. This corresponds to approximately 20% of the capacity of a heating coil being controlled in a two position manner. In the case of a cooling coil approximately 15% of the design capacity would be controlled in a two position manner.

As illustrated by these examples, it is extremely important to minimize the uncontrollable flow rate through a coil, especially in the case of a heating coil. Here are several suggestions to assist in this effort. First, select a valve with a full flow  $C_v$  value which comes the closest to the  $C_v$  required for the application. Second, whenever possible utilize the style of valve which has the highest rangeability for the required  $C_v$  of the application. The next suggestion is a very proactive solution to minimizing the uncontrolled capacity of a coil or heat exchanger. It involves installing two or more control valves piped in parallel. The valves should be sequenced so that as one valve fully opens the next valve will just start to open. Generally, when two valves are used, the first valve to open is sized for approximately 30% of the design flow rate of the coil. The second valve is sized for the remaining 70% of the design flow rate. This procedure can substantially reduce the magnitude of the uncontrolled coil capacity.

In the past, it was not uncommon for globe valves to provide two-position to control for up to 40% of the coil capacity. Considering this limitation, how were globe valves able to fill the customer's demand for control? The response to this question is two fold. First, consider that until the very recent past most building owners did not have the ability to call up and trend in a digital format how well a setpoint was being maintained. Thus unless the deviation from setpoint was severe, the system was controlled well enough to be deemed satisfactory. Secondly, in most buildings, unless the cooling coil is grossly oversized, the constant lighting and interior loads account for as much as 20% to 50% of the total cooling load depending on the facility. Thus if a building has a large sustained cooling load, the problem of the uncontrollable flow rate through the valve are minimized because the load is generally above the uncontrollable rate.

Historically when customer's complained about controllability, it was usually a case of oversized coils and/or systems utilizing outdoor air economizers. In either of these cases, the capacity associated with the uncontrollable flow rate through the valve can be larger than the percent load on the coil. An outside air economizer utilizes the cool outdoor air to provide most of the cooling required for the space. The remainder of the cooling requirements are made up at a cooling coil. Thus even in buildings with large interior and lighting loads, the load at the cooling coil may still be quite small.

### Guidelines for Coil and Heat Exchanger Control

The following guidelines are based upon the previous examples and discussion.

1. For applications with  $C_v$  requirements greater than 160; the uncontrolled flow rate through a valve will be minimized by utilizing a butterfly valve sized for 70° stem rotation.
2. For applications with  $C_v$  requirements of less than 160; the uncontrolled flow rate through a valve will be minimized by utilizing a globe style valve.
3. Where possible size the control valves for at least a 50% authority.
4. When systems are encountered which have significantly oversized coils, it is generally best to utilize two or more valves piped in parallel. In many cases, of course, it will not be known that the coil is oversized until the system is started up. By that time, it is too late to change the piping arrangement. However, keep the following in mind. If the job has one or more large air handling units, sized to include future expansion of an area, it is very likely that the coil is oversized for the area it will initially serve. Act accordingly.

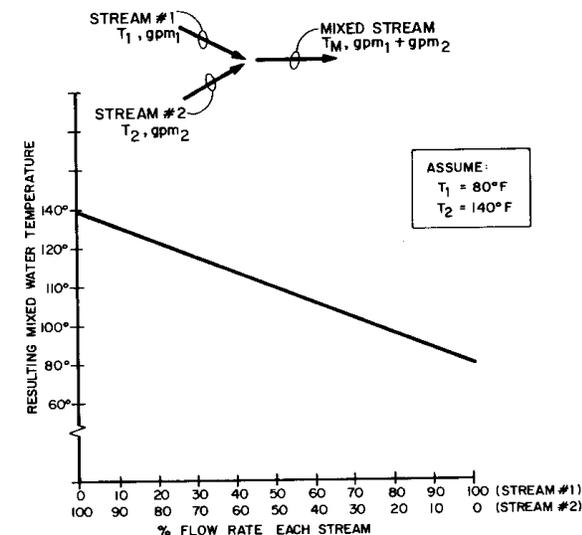
### Control Of Mixed Water Systems

Butterfly valves are frequently utilized to control the temperature of a mixed water stream. This application can be accomplished with either two-way, three-way mixing or three-way diverting valves. Two common examples are hot water supply temperature control and condenser water control via the cooling tower bypass valve. In a mixed water system, because the mixed water temperature is directly proportional to the ratio of the flow rate of each inlet stream, a **linear** valve flow characteristic is optimal. While it is useful to have a valve with an **equal percentage** flow characteristic for the control of coils and heat exchangers, it is not desirable in mixed water temperature control applications.

$$T_m = \frac{T_1(GPM_1) + T_2(GPM_2)}{(GPM_1 + GPM_2)}$$

Where:  $T_m$  = Temperature of Mixed Water Stream  
 $T_1$  = Temperature of Inlet Stream #1  
 $T_2$  = Temperature of Inlet Stream #2  
 $GPM_1$  = Flow Rate Inlet Stream #1, gpm  
 $GPM_2$  = Flow Rate Inlet Stream #2, gpm

Figure 9 depicts this relationship in a graphic format. Since the relationship shown in Figure 6 is a straight line, a valve with a **linear** type characteristic would be desirable.



MIXED WATER TEMPERATURE vs % FLOW RELATIONSHIP  
FIGURE 9

At this point in time Johnson Controls does not manufacture a valve with an inherent linear flow characteristic. However, if the actual installed flow characteristic of an equal percentage valve is considered it is possible to come close to a linear characteristic (see Figure 5). Notice a equal percentage style valve with an authority of approximately 33% has a nearly linear relationship between % stroke and % flow.

The relationship between the mixed water temperature and the flow rate of each inlet stream is directly proportional. Thus for mixed water temperature control, an uncontrollable flow rate equal to 5% effect on the resulting mixed water temperature. In contrast, this same 5% uncontrolled flow rate can constitute up to 25% of the design capacity in a coil application. Therefore, the larger uncontrollable flow rates associated with valves sized for lower authorities does not have nearly the negative effect in a mixed water temperature control application that it does in a coil application.

### Guidelines for Mixed Water Temperature Control Applications

1. To minimize the uncontrollable flow rate through the valve use a globe style valve for applications with a  $C_v$  requirements of less than 100. Use a butterfly valve sized for the design flow rate at 70° rotation for all other applications.
2. Utilize either a globe or butterfly style valve sized for approximately a 33% authority.

## Valve Sizing

The sizing procedure for butterfly valves is very similar to the procedure used for globe style valves. Generally the design flow rate (Q) is provided by the Consulting Engineer in either the job plans or specifications. If not, formulas for calculating the flow rate requirement of a coil as a function of temperature drop/rise and total heat output, are found in the X section of this *Data Book*.

The sizing pressure drop ( $\Delta P$ ) across the valve is measured in the valve's full open position. Often a maximum valve pressure drop is stated by the Consulting Engineer and should not be exceeded. When permissible, choose the pressure drop for a valve using the valve authority guidelines listed in the coil/heat exchanger or mixed water temperature control application sections of this report.

The following generic valve sizing equation can be used to find the required  $C_v$  once the design flow rate (Q) and the sizing pressure drop ( $\Delta P$ ) are known.

$$\text{GPM} = C_v \sqrt{\Delta P}$$

Where:

Q = Design Flow Rate, gallons per minute

$C_v$  = Valve Flow Coefficient

$\Delta P$  = Pressure Difference Across Valve at Design Flow Rate, in psig

After determining the valve  $C_v$  requirement from the preceding equation, the valve size required can be obtained from Table 2.

For butterfly valves, the  $C_v$  factor is also influenced by the diameter of the piping located both immediately upstream and downstream of the butterfly valve. This is especially important when sizing butterfly valves for throttling applications. Remember, line size valves should not be used for throttling applications. Use Table 2 to select the appropriate size of valve for the design  $C_v$  requirement.

Table 2				
Inlet Dia.	Valve Size	Outlet Dia.	C <sub>v</sub> 70° Throttling Application	C <sub>v</sub> 90° 2 Position Application
2	2	2	84	144
2½	2	2	73	103
2½	2	2½	80	127
3	2	2	69	93
3	2	2½	75	110
3	2	3	76	111
2½	2½	2½	163	282
3	2½	2½	136	186
3	2½	3	155	245
3	3	3	267	461
4	3	3	201	254
4	3	4	236	339
4	4	4	496	841
5	4	4	380	483
5	4	5	451	664
6	4	4	348	442
6	4	5	400	528
6	4	6	405	539
5	5	5	775	1376
6	5	5	611	805
6	5	6	722	1132
8	5	5	533	647
8	5	6	602	785
8	5	8	612	809
6	6	6	1025	1850
8	6	6	784	1016
8	6	8	913	1359
10	6	6	729	904
10	6	8	828	1120
10	6	10	821	1101

Table 2 (Continued On Next Page)

Table #2 Continued:				
Inlet Dia.	Valve Size	Outlet Dia.	C <sub>v</sub> 70° Throttling Application	C <sub>v</sub> 90° 2 Position Application
8	8	8	1862	3316
10	8	8	1462	1922
10	8	10	1711	2633
12	8	8	1347	1682
12	8	10	1535	2099
12	8	12	1552	2142
10	10	10	2948	5430
12	10	10	2367	3205
12	10	12	2765	4488
14	10	10	2174	2768
14	10	12	2470	3475
14	10	14	2536	3667
12	12	12	4393	8077
14	12	12	3565	4869
14	12	14	4169	6893
16	12	12	3261	4168
16	12	14	3703	5239
16	12	16	3853	5690
14	14	14	5939	10538
16	14	14	4923	6756
16	14	16	5702	9360
18	14	14	4509	5790
18	14	16	5084	7192
18	14	18	5330	7942
16	16	16	7867	13966
18	16	16	6597	9149
18	16	18	7605	12639
20	16	16	6042	7818
20	16	18	6788	9679
20	16	20	7163	10872

Table 2 (Continued On Next Page)

Table #2 Continued:				
Inlet Dia.	Valve Size	Outlet Dia.	C <sub>v</sub> 70° Throttling Application	C <sub>v</sub> 90° 2 Position Application
18	18	18	10065	17214
20	18	18	8529	11745
20	18	20	9782	15902
24	18	24	7410	9239
24	18	20	8187	10897
24	18	24	8789	12454
20	20	20	12535	22339
24	20	20	9840	12945
24	20	24	11666	18296

Table 2

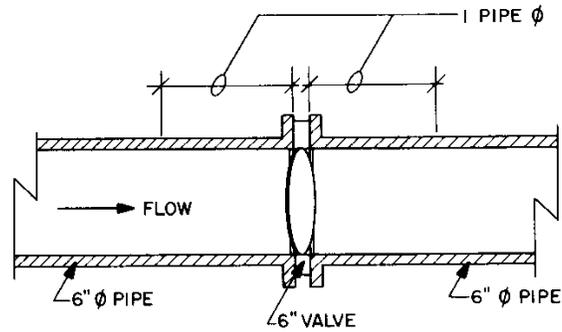
### Sizing Two-Way Valves

With regard to Table 2, if a reducer is installed within 1 pipe diameter upstream of the valve, the number in the first column should reflect the size of the piping **before** it is reduced. If the size of the piping located within 1 pipe diameter downstream of the valve is not the same size as the valve, Column 3 should reflect the size of the larger pipe size. Column 2 of Table 2 should reflect the actual valve size.

If the valve is line size, the numbers in all three columns of Table 2 should reflect the size of the valve (see Examples 3 and 4).

**Example 3:**

Determine the 70° C<sub>v</sub> factor for a 6 in. butterfly valve installed as shown in Figure 10.



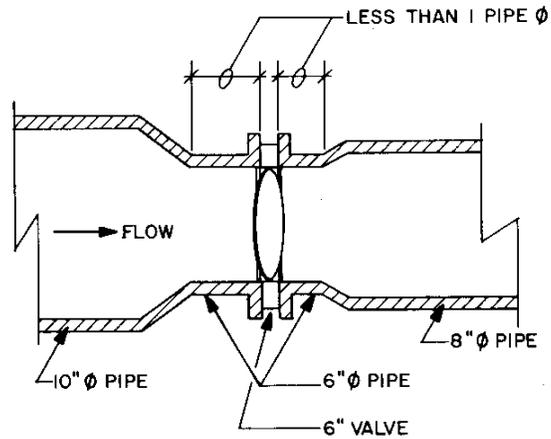
**LINE SIZED TWO-WAY VALVE**

FIGURE 10

From Table 2: the C<sub>v</sub> rating of this valve sized for 70° rotation is 1025.

**Example 4:**

Determine the 70° rotation C<sub>v</sub> factor for a 6 in. butterfly valve installed as shown in Figure 11.



**INLET & OUTLET PIPE Ø ≠ VALVE SIZE**

FIGURE 11

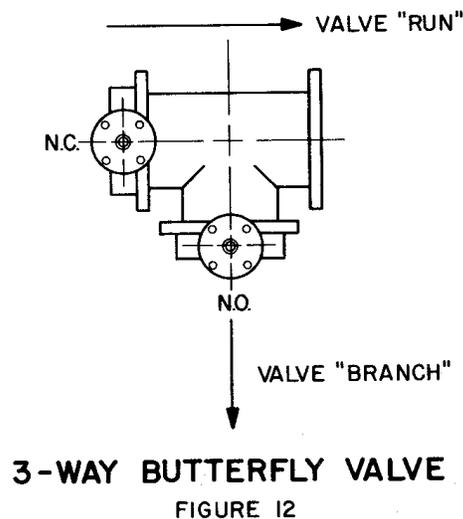
From Table 2: the C<sub>v</sub> rating of this valve sized for 70° rotation is 828.

## Sizing Three-Way Valves

Figure 12 shows a three-way butterfly valve. The designation **run** indicates a path through the valve where a straight line could be drawn between two flanges. The designation **branch** indicates the path to the third flange which is located at a 90° angle to the run. The procedures for determining the  $C_v$  factor for mixing and diverting valves are different.

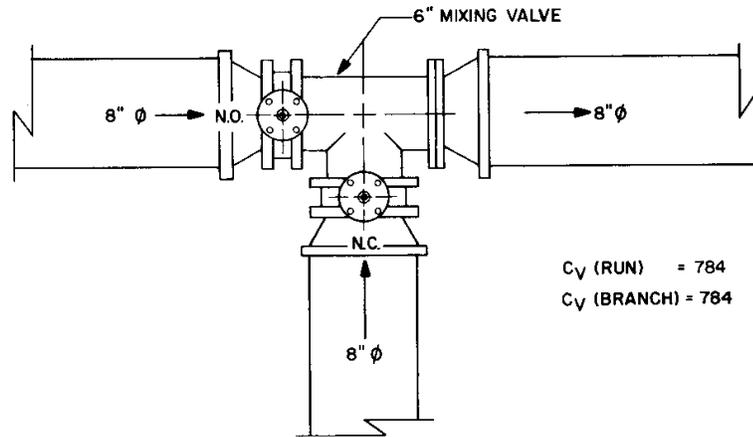
To determine the  $C_v$  factor for a diverting style valve, use the valve size in Columns 1, 2, and 3 of Table 2. This procedure is contingent on the adjacent downstream pipe size of both the run and the branch being either the same size or larger than the valve size. This will be true 99% of the time. Normal piping practices preclude the case where the adjacent downstream pipe size is smaller than the valve size. Contact the Technical Support Group if this last configuration is encountered.

Sizing three-way mixing valves is similar to sizing two-way valves except that the sizing procedure must be done twice. Once for the valve run and once for the valve branch. The lower of the run or branch  $C_v$  values is used select the valve. To determine the run  $C_v$  factor for a mixing style valve, use the adjacent upstream pipe size of the run in Column 1 and the valve size in both Columns 2 and 3 of Table 2. To determine the branch  $C_v$  factor for a mixing style valve, use the adjacent upstream pipe size of the branch in Column 1 and the valve size in both Columns 2 and 3 of Table 2.



**Example 5:**

Determine the 70°  $C_v$  factors for a 6 in. three-way butterfly valve installed as shown in Figure 13.



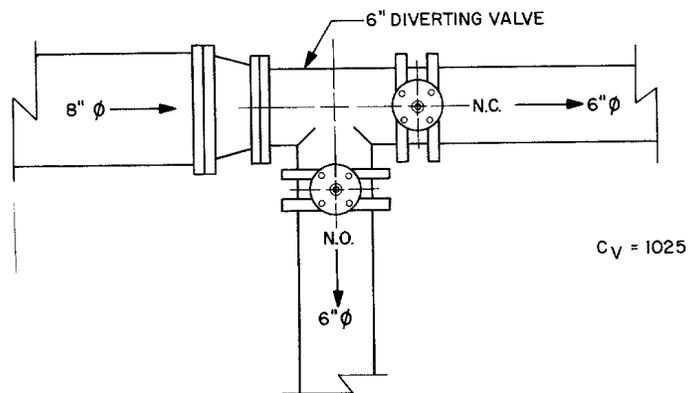
**THREE-WAY MIXING VALVE**

FIGURE 13

From Table 2: the 70° rotation  $C_v$  rating of the valve **run** is 784. The 70° rotation  $C_v$  rating of the **branch** is 784. Therefore, the 70° rotation  $C_v$  rating for this three-way mixing valve is 784.

**Example 6:**

Determine the 70°  $C_v$  factors for a 6 in. three-way butterfly valve installed as shown in Figure 14.



**THREE-WAY DIVERTING VALVE**

FIGURE 14

From Table 2: the 70° rotation  $C_v$  for this three-way diverting valve is 1025.

## Solutions Other Than Water

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

$$\text{GPM} = C_v \times \sqrt{\Delta P / \text{SG}}$$

Where: SG = Specific Gravity Of The Liquid

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## Cavitation

From the preceding discussion it should be well understood that selecting valves with relatively large design pressure drops will enhance control in most throttling applications. However, there is a pressure drop limit ( $\Delta P_{\max}$ ) which should not be exceeded or cavitation inside the valve and downstream piping will occur. Cavitation occurs when the local velocity of the water becomes so high that the water vaporizes (flashes). As the water vapor continues to move past the valve the velocity drops, and the vapor bubbles collapse causing very large pressure changes on the inside walls of the valve and downstream piping. Cavitation can destroy a valve or the piping immediately downstream from the valve. The maximum allowable pressure drop for a butterfly valve be determined from the following equation:

$$\Delta P_{\max} = K_m (P_i - .93P_v)$$

Where:

- $\Delta P_{\max}$  = Maximum Allowable Pressure Drop, psi
- $K_m$  = Valve Recovery Coefficient,
- $K_m (90^\circ) = 0.32$
- $K_m (70^\circ) = 0.5$
- $P_i$  = Inlet Pressure, in psia
- $P_v$  = Water Vapor Pressure, in psia from Table 3

The value of  $P_i$  is in terms of absolute pressure. Therefore, its value would be equal to the reading (in psig) obtained from a pressure gauge installed immediately upstream from the valve plus 15 psi.

When sizing valves, determine the value of  $\Delta P_{\max}$  and compare it to the design pressure drop of the valve. If the design pressure drop of the valve is greater than  $\Delta P_{\max}$ , the valve size must be increased until the value of  $\Delta P_{\max}$  is less than the design pressure drop of the valve. Otherwise the valve will cavitate.

To help prevent cavitation in chilled water systems, two-way control valves should be installed in the coil supply piping to take advantage of the slightly higher inlet pressures. This logic may not be applicable in hot water systems, however, because the difference in the water vapor pressure across the coil may be higher than the static pressure drop through the coil.

VAPOR PRESSURE OF WATER (PSIA)			
Water Temp. °F	Vapor Press. (psia)	Water Temp. °F	Vapor Press. (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

Table 3

### ***Water Hammer***

Water hammer is a pressure surge in a pipeline which can result from the opening or closing of a valve too quickly. The magnitude of the pressure wave is related to the time of valve closing or opening, the length of the pipe and the velocity change of the water in the pipe.

When a valve closes a pressure wave is sent from the valve back to the tank or pump. After it reaches the tank or pump, it is reflected back to the valve. The pressure wave travels at a speed of between 2000 to 4000 ft/sec depending primarily on the pipe size. If the valve closes before this pressure wave has had a chance to return to the valve, the magnitude of the pressure change attributed to the water hammer can be severe. It can be determined by the following equation:

$$\Delta P = (a \times \Delta V) \div 74$$

### **Rapid Valve Closure (Where $T_c < 2L/a$ )**

Where:

- $\Delta P$  = Increase in Pressure, psi
- L = Pipe length from tank or pump to the automated valve in question, ft
- $\Delta V$  = Change in water Velocity in Pipe, ft/sec  
(In HVAC systems usually < 10 ft/sec max.)
- $T_c$  = Time of Valve Closing, sec.
- a = Velocity of Pressure Wave, ft/sec  
(Assume Worst Case, a = 4000 ft/sec)

The pressure increase attributed to a slower closing valve can be determined by the following equation:

**Show Valve closure (Where  $T_c > 2L/a$ )**

$$\Delta P = (L \times \Delta V) \div (37 \times T_c)$$

The water hammer effect caused by a sudden valve opening is different than that associated with a valve closing. When the valve is initially opened, the pressure in the piping between the tank or pump and the automated valve will drop. This pressure drop is generally much smaller than the pressure rise associated with a sudden valve closure. After the initial pressure drop, the pressure will rise quickly to a level between its pressure and 1.25 times its initial pressure. These effects can be predicted mathematically. Contact your local Johnson Controls representative if additional information is required.

The negative effect of water hammer can be minimized if compression tanks (air chambers) are installed in the piping system. Retarding valve opening and closing times is also an effective method of minimizing the effect of water hammer. For most HVAC systems, if the minimum valve opening and closing times are retarded to approximately 5 seconds, water hammer will normally not be a problem. The VF series butterfly valves have a factory installed resistor or fitting which retards their opening and closing times.

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## Notes

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# Notes



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