6.19 Valve Types: Globe Valves


Types:
A. Single-ported with characterized plug
B. Single-ported, cage-guided
C. Single-ported, split body
D. Double-ported, top-bottom-guided or skirt-guided plug
E. Angle
F. Y-type
G. Three-way
H. Eccentric plug, rotary globe

Sizes:
A. Typically NPS ⅜ to 16 in. (DN 15 to DN 400); available up to NPS 48 in. (DN 1200)
B. Typically NPS ⅜ to 16 in. (DN 15 to DN 400); available up to NPS 48 in. (DN 1200)
C. NPS ⅜ to 10 in. (DN 15 to 250)
D. NPS ½ to 16 in. (DN 15 to DN 400)
E. Typically NPS ⅜ to 16 in. (DN 15 to DN 400); available up to NPS 48 in. (DN 1200)
F. NPS 1 to 16-in. (DN 25 to DN 400)
G. Typically NPS ⅜ to 6 in. (DN 15 to DN 150); available up to NPS 24 in. (DN 600)
H. NPS 1 to 12 in. (DN 25 to DN 300)

Design Pressure Ratings:
DN = diameter, nominal—mm assumed.
Typically all ratings are available from ANSI Class 150 (PN 20) to Class 2500 (PN 420) with special designs up to Class 4500; types C and H are limited to ANSI Class 600 (PN 100)
PN = Pressure, nominal—bar assumed.

Maximum Pressure Drop:
Up to maximum allowed by body pressure rating depending on limitations of actuator size and trim design and materials

Design Temperature:
Depends on material properties. Generally from −20 to 1200°F (−29 to 538°C). Cryogenic designs for temperatures down to −423°F (−253°C). Special valves have been designed for operation up to 1600°F (871°C).

Materials of Construction:

Body and bonnet materials: Most cast and forged grades of carbon steel, low-alloy steel, stainless steel, Alloy 20, duplex stainless steel, nickel and nickel alloys, bronze, titanium, and zirconium. See Table 6.19ww. Fluoropolymer lining also available for corrosion protection.

Trim materials: Generally available in stainless steel, nickel, nickel alloys, bronze, titanium, and zirconium. Hard facing is available for erosive applications. See Table 6.19j.

Seal and soft seat materials: FEP, PFA, PTFE, PCTFE, ETFE, EPT/EPDM, Fluoroelastomers, Nitrile, polyethylene, polyurethane, UHMWPE, compressed graphite, and soft metals.
Leakage: (See Table 6.1gg for FCI leakage classes.) Metal seats in double-ported designs are Class II, while in single-seated designs they can meet Class IV or Class V. Soft seats in double-ported designs can meet ANSI Class IV or V, while in single-seated globe valves they can give Class VI performance.

Characteristics: Refer to Section 6.7 for details; see Figure 6.19a.

Rangeability: Based on Instrumentation, Systems, and Automation Society-75.11 or IEC 60534-2-4, it seldom exceeds 30:1. Special designs can achieve 50:1 or higher by increasing precision of control at small valve openings. See the discussion under Rangeability below and Section 6.7 for details.

Capacity: \( C_{vd} = 10 \) to 15 with single-ported designs closer to the bottom of the range and with double-ported and eccentric disc designs closer to the top of the range (see Table 6.19c).

Cost: See Figure 6.19b.

Partial List of Suppliers: (Includes both manual and control valves)
- ABB Control Valves (www.abb.com/controlvalves)
- American Valve, Inc. (www.americanvalve.com)
- ARI-Armaturen Richter (www.ari-armaturen.com)
- Asahi-America (www.asahiamerica.com)
- Cashco Inc. (www.cashco.com)
- Collins Instrument Co. (www.collinsinst.com)
- Control Components Inc. (www.ccivalve.com)
- Conval Inc. (www.conval.com)
- Crane Valves (www.cranevalve.com)
- Curtis Wright Flow Control (www.cwfc.com)
- Dresser Flow Solutions (www.masoneilan.com)
- Emerson Process Management (www.emersonprocess.com/home/products)
- Flowserve Corporation (www.flowserve.com/valves)
- GE-Nuovo Pignone (www.gepower.com/prod_serv/index.htm)
- Invalco (www.invalco.com)
- Kitz Corp. (www.kitz.com)
- Koso Hammel Dahl (www.kosoamerica.com)
- Metso Automation (www.neles.com)
- Milwaukee Valve Co. (www.milwaukeevalve.com)
- Nibco Inc. (www.nibco.com)
- Powell Valves (www.powellvalves.com)
- Richards Industries Valve Group, Inc. (www.jordanvalve.com)
- Samson AG (www.samson.de)
- Severn Glocon Ltd. (www.severnglocon.com)
- Spirax Sarco, Inc. (www.spiraxsarco.com/us)
- SPX Valves and Controls (www.dezurik.com)
- Tyco Flow Control (www.tycovalves.com)
- Velan Valve Corp. (www.velan.com)
- Warren Controls Corporation (www.warrencontrols.com)
- Weir Valves & Controls (www.weirvalve.com)
- Welland & Tuxhorn (www.wellandtuxhorn.de)
- Yamatake Corp. (www.yamatake.com)

**VALVE TRENDS**

When this handbook was first published some 35 years ago, the overwhelming majority of throttling control valves were the globe types, characterized by linear plug movements and actuated by spring-and-diaphragm operators. At that time, the rotary valves were considered to be on/off shut-off devices. Globe valves are still widely used, but their dominance in throttling control applications has been diminished by the less expensive rotary (ball, butterfly, and plug) valves as a result of improvements in rotary valve and actuator designs. Generally, globe valves use a linear-motion stem connected to a plug head that controls the flow area through a stationary seat ring. One exception to this is the rotary globe valve, which rotates an eccentric spherical plug into the seat ring; this type of rotary stem valve will be discussed later. Unless otherwise noted, the discussion of globe valve characteristics will apply to the linear-stem globe valve.
The main advantages of the traditional globe design include:

1. The simplicity of the pneumatic actuator designs
2. The availability of a wide range of valve characteristics
3. The relatively low likelihood of cavitation and noise
4. The availability of a wide variety of specialized designs for corrosive, abrasive, and high-temperature or high-pressure applications
5. Relatively small amounts of dead band and hysteresis

The main reason for the increasing popularity of rotary valves is their lower manufacturing cost and higher capacity ($C_v/d^2 = 20–40$ for rotary vs. $C_v/d^2 = 10–15$ for globe). They generally weigh less, some designs can act as both control and shut-off valves, and they can be easier to seal at the stem to meet clean air requirements.

The limitations of globe valves, in addition to their higher cost per unit $C_v$, include their greater weight and dimensional envelope relative to their flow capacity. For the valve coefficients of globe valves, refer to Table 6.19c.

One major disadvantage of rotary valves is their higher tendency to cavitate and produce excessive amounts of noise (Section 6.14). They are also more likely, due to their smaller size per unit $C_v$, to have larger pipe reducers with the associated waste of pressure drop and distortion of characteristics. Their control quality can suffer from the linkages, which can introduce substantial hysteresis and dead band.

As a result of advances in distributed control system (DCS) technologies, both rotary valves and globe-style (linear) valves generally benefit from the use of positioners with either single-acting or double-acting pneumatic actuators (diaphragm or piston types). Previous problems with positioners in fast processes are largely relics of old-fashioned control systems, but much misinformation has perpetuated an aversion to positioner use on fast processes, even though DCS technology overcame these issues decades ago.

For more information about control theory in general and controller tuning in particular, consult Chapter 2, and about DCS systems refer to Chapter 4. For conventional and for intelligent positioners, refer to Sections 6.2 and 6.12 respectively, in this chapter.

TRIM DESIGNS

The valve trim consists of the internal parts contained within the body and wetted by the process fluid. The main components are the plug and stem and the seat ring(s). Some globe valve body designs also incorporate other parts such as cages or seat retainers, spacers, guide bushings, and special elements. The trim parts create the flow restriction or throttling action responsible for most of the pressure loss dissipated in the valve. The trim design also serves to determine the inherent flow characteristics of the valve. The various aspects of trim design, construction, and selection will be discussed.
### TABLE 6.19c

Valve Coefficients (Cv) for Single-Ported, Equal-Percentage, Unbalanced Globe Valves with Flow under the Plug. *

<table>
<thead>
<tr>
<th>Valve Size (in.)</th>
<th>Trim Size (in.)</th>
<th>Stroke (in.)</th>
<th>C, At Percent Open</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>0.81</td>
<td>0.33</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>0.72</td>
<td>0.23</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>0.62</td>
<td>0.15</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.10</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>0.38</td>
<td>0.065</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>0.31</td>
<td>0.040</td>
<td>0.079</td>
</tr>
<tr>
<td>0.25A</td>
<td>0.75</td>
<td>0.030</td>
<td>0.059</td>
</tr>
<tr>
<td>0.25B</td>
<td>0.75</td>
<td>0.0071</td>
<td>0.014</td>
</tr>
<tr>
<td>0.12A</td>
<td>0.5</td>
<td>0.0070</td>
<td>0.014</td>
</tr>
</tbody>
</table>

* For each valve size, the values given in the first line correspond to full-area trim; the values for reduced trims follow in descending order.

Courtesy of Flowserve Corporation.

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Typical components that make up a globe valve are shown in Figure 6.19d. Globe valve trims are available in many design variations, depending upon manufacturer and the intended application of a particular valve. A complete discussion of every trim design variation is impossible, but those with the most general application use will be covered, including special trims for severe services such as noise, cavitation, and erosion. See Sections 6.1 and 6.14 for discussions of low-noise control valves.

**Trim Flow Characteristics**

All control valves are pressure-reducing devices; in other words, they have to throttle the flowing fluid in order to achieve control. The most widely used form of throttling is with a single-stage orifice and plug assembly. Multiple-stage orifice elements are usually found in trim designs for combating noise, erosion, and cavitation (Figure 6.19g). In all cases, the valve trim is the heart of the valve and operates to give a specific relationship between flow capacity and valve plug lift. This relationship is known as the valve flow characteristic and is achieved by different cage orifice patterns (Figure 6.19e) or valve plug contours (Figure 6.19f).

The term “flow characteristic” usually refers to the “inherent” characteristic, which is a function of a number of valve design and manufacturing parameters. The inherent characteristic is determined by testing the valve flow vs. valve lift using a constant differential pressure across the valve throughout the test. These types of tests are standardized by ANSI/ISA-75.02-1996 and IEC 60534-3-2: 1997.

Therefore, the manufacturers’ trim characteristic curves or tables should not be confused with the installed flow characteristic in the actual process fluid flow loop. In actual service, the differential pressure across the valve varies throughout the valve lift and flow range as a function of the system characteristics. This variation is due to such factors as pump head changes with flow, piping friction losses, and the hydrostatic resistance of pipe fittings, block valves, flow measurement devices, heat exchanges, and other system elements.
Control valve inherent characteristic data are expressed in graphs or tables, such as shown in Table 6.19c, where a flow coefficient \( C_v = K_v / 1.17 \) is expressed as function of the percentage of valve opening. It is important to understand the meaning of these flow coefficients. A detailed discussion of control valve sizing is provided in Section 6.15, which discusses control valve sizing. In its simplest form, the valve capacity coefficient, \( C_v \) (or \( K_v \)), for liquids can be expressed as

\[
C_v = Q \sqrt{\frac{G_f}{\Delta p}}
\]

where \( Q \) is volumetric flow rate in gpm (or m\(^3\)/h for \( K_v \)), \( G_f \) is specific gravity relative to water, and \( \Delta p \) is the pressure differential (the lesser of the actual \( \Delta p \) or the choked \( \Delta p \)) across the valve in lbf/in.\(^2\) (or bar for \( K_v \)). Important observations should be made from this simplified expression.

1. \( C_v \) and \( K_v \) are not dimensionless coefficients. They have units of \((\text{volume/time}) \times (\text{area/force})^{1/2} = (\text{length})^3 / [(\text{time})(\text{force})^{1/2}]\).
2. Valve manufacturers publish valve inherent characteristic in terms of \( C_v \) (or \( K_v \)) vs. lift (or percentage open).
3. Valve users need to know flow rate vs. lift for the installed characteristic. They must determine the system pressure differential allocated to the valve for the full range of flow rates in order to calculate the flow rate vs. lift.

Control valve manufacturers commonly furnish three types of inherent characteristic valve trims along with some minor variations (Figure 6.19a). These are idealized curves and do not accurately reflect the actual characteristic as determined by test. Examination of actual test data will show deviations in lift vs. flow of 10% or more, slope variations, and other distortions from the ideal curve.

This is due to a number of factors; in order of their significance, they include a) the trim type and design, b) valve body geometry effects, c) test variations and repeatability, and d) manufacturing variations. For practical purposes, these distortions, if kept within reasonable limits, do not materially affect the valve in actual service. Allowable limits on variations in flow characteristic are established in industry standards ANSI/ISA-75.11 and IEC 60534-2-4.

The typical inherent characteristic (i.e., \( C_v \) or \( K_v \) vs. lift) test data and pressure loss vs. flow rate data for the static elements of the process system can be used to approximate the valve characteristic behavior in the installed system. This can be used to select the best valve trim for the controlled process, which will keep the control loop gain constant or optimized for process control (see Figure 6.7a in Section 6.7).

A traditional rule of thumb is to use a linear trim if the control valve pressure drop is relatively constant (such as in pure pressure reducing). Where there is significant system and valve pressure drop variation as flow changes, the equal-percentage trim is recommended.

### Rangeability

Rangeability can be expressed in different ways with different meanings. Inherent rangeability is the ratio of the largest controllable flow coefficient \( C_v \) or \( K_v \) to the smallest controllable flow coefficient within specific deviation allowances.\(^1\)

Valve flow rangeability, referred to as turndown, is the ratio between the valve’s maximum and minimum controllable flow rate at stated operating pressures. Generally, the minimum controllable flow is considered to be about twice the minimum clearance flow as the plug lifts off the seat. For single-seated contoured plug control valves, manufacturers often state inherent rangeability from 30:1 to 50:1 based on \( C_v \) vs. lift tests.

In practice, these numbers are merely benchmarks. When applied to processes with high system pressure losses, the installed flow rangeability of the control valve is more likely to be in the order of 7:1 to 15:1. This is usually enough because most processes do not operate much over 5:1 turndown. Some processes can require flow rangeability beyond the capability of one valve and will require parallel valves with split-ranging. For more details, see Figures 6.1i and 6.1j.

While linear and equal-percentage trims are designed to throttle essentially over the full valve travel, the quick-opening characteristic is designed to act more like a “bath stopper” plug. The flow characteristic develops approximately 80% of its \( C_v \) capacity in a nearly linear manner over the initial 20–30% of valve lift. The remaining capacity is added over the balance of the lift. This plug can be used for on/off service, for short-stroke valves such as self-contained pressure regulators, or in some process applications where a decreasing valve gain is required as the load increases.

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\(^1\) See ANSI/ISA-75.11-1985 and IEC 60534-2-4: 1989.

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Standard Trim Configurations

The valve plug configurations used on modern control valves include the contoured plug, ported plug, or piston plug (see Figure 6.19e). The turned or contoured plug is probably the most common, followed by the piston and ported plugs. The contoured plug is simple to machine out of bar stock from stainless steels and special alloys and can be hard-faced easily for erosive services. The contoured plug is usually used with single-seat valves, but it is also available in double-seat designs.

The ported plugs usually have cast or forged stainless steel or special alloy heads mechanically attached to a similar stem material. They are more difficult to hard-face than designs with uninterrupted control surfaces. This plug is most common in double-seat valves, but it is also available in single-seat designs. Both the contoured and ported plugs are shaped to obtain the desired flow characteristic as they move in and out of the seat ring.

The piston plug is relatively easy to fabricate and is usually made from a hardenable type of stainless steel such as 410, 440, or 17-4PH®. Other materials such as nickel alloy 718, alloy K-500, and austenitic stainless steel with hard-facing are also available. Plug heads are usually a hardened material, or hard-facing must be done, because these plugs are normally guided in a cage assembly. The flow characteristic for this trim design is incorporated into the cage.

Special Trim Configurations

There are severe applications that may require special trim configurations. These applications usually involve noise, cavitation, erosion, or combinations of these problems. The special trim designs for all of these are often similar in concept although they will differ in design detail. Because noise is an especially difficult and complex problem to deal with, it is covered in depth in Section 6.14. The following discussion will touch upon the noise reduction trims, but will primarily concentrate on cavitation and erosion services.

Cavitation

Liquid cavitation is a complex fluid dynamic reaction to pressure change, which is also discussed in Sections 6.1, 6.14, and 6.15. It has many aspects that have not been successfully explained, but the fundamentals are relatively simple. The basic process of cavitation is related to the conservation of energy and Bernoulli’s theorem, which describe the pressure profile of a liquid flowing through a restriction or orifice (Figure 6.19g).

In order to accelerate the fluid through the restriction, some of the pressure head is converted into velocity head. This transfer of static energy is needed to push the same mass flow through the smaller passage. The fluid accelerates to its maximum velocity, which is also the point of minimum pressure (vena contracta). The fluid velocity gradually slows down as it again expands back to the full pipe area. The static pressure also recovers, but part of it is lost due to turbulence and friction.

If the static pressure at any point drops below the liquid vapor pressure ($P_v$) for that temperature, then vapor bubbles will form. As the static pressure recovers to a point greater than the vapor pressure, the vapor bubbles collapse back into their liquid phase. The cavitation process includes the vapor cavity formation and sudden condensation (collapse) driven by pressure changes. The growth and collapse of the bubbles produce high-energy shock waves in the fluid. The collapse stage of the process (the bubble implosion) produces more severe shock waves.

These implosions generate noise, fluid shock cells, and possible microjets that impinge upon the trim parts. This generates highly concentrated impact forces that cause surface fatigue and localized fractures that destroy the metal. This erosion process gives cavitation damage a very distinctive appearance, like that of cinder block or sandblasting.

No known material will withstand continuous, severe cavitation without damage and eventual failure. The length of time it will take is a function of the fluid, metal type, and severity of the cavitation. Without special trim geometry, some of the possible mitigating actions include the use of extremely hard trim materials or overlays, increasing the downstream back-pressure, or limiting the pressure drop by installing control valves in series to reduce the pressure drop in each valve.

Another mitigating effect in some processes is a result of the fluid thermodynamic properties and operating conditions. As liquid operating temperature approaches its critical temperature, heat transfer effects become increasingly significant relative to the dominant inertial effects, which causes the growth and collapse rates of cavities to slow down. This can greatly reduce impingement stresses on the valve parts. Some cryogenic and hydrocarbon applications are thought to behave this way, which may partly explain why cavitation damage in these cases is minimal or absent even when cavitation is present in the valve. Further information about cavitation and predicting its effects on valve performance can be found in Section 6.15 of this text and in the Instrumentation, Systems, and Automation Society (ISA) Recommended Practice RP75.23.01, “Considerations for Evaluating Control Valve Cavitation.”

Some of the special trim designs for combating cavitation are the Drag®, Cavitrol®, Turbo-Cascade®, VRT®, Hush®, ChannelStream®, and various other staged or step-type plugs and orifices, which are shown in Figures 6.1y, 6.1z, and 6.1aa. The multihole Cavitrol-style trims are designed to break the flow into multiple fluid jets and force the jets to impinge upon themselves with extreme turbulence. This turbulence converts part of the upstream energy (static pressure) into heat energy. Bubbles from the many small fluid jets are small and tend to implode within the turbulent fluid core away from the internal surfaces, which greatly reduces trim damage. However, these trims are suitable for only moderate cavitation and moderate pressure drops.

The balance of the trims listed can be considered variations of staged trims. These trims reduce the total valve
Erosion of the valve trim can also be caused by high-velocity liquid impingement, abrasive particles, and erosive-corrosive combination action. Erosion damage is roughly proportional to some power (e.g., $1.4 \leq n \leq 6$) of velocity, which depends on the erosive environment and the boundary material. As in cavitation, one major key to the solution is to reduce the velocity through the trim. It is no surprise that the valve and trim designs discussed above are also useful on most erosion problems, although there may be some variations of design and materials of construction needed to better cope with a particular problem.

A properly chosen and specified control valve and trim type can be one of the most reliable pieces of equipment in process service. Indeed, many companies no longer use control valve bypasses, except in some unique situations. However, it is a requirement that there be close consultation with the control valve manufacturer in specification of special trims. High-velocity liquid impingement erosion is usually associated with high pressure drop coupled with undesirable valve geometry. High-velocity fluid jets developed through the seat area will often result in erratic flow patterns that allow the liquid to impinge directly on the valve trim and body. Such damage is often confined to specific areas in the valve. Liquid droplets in a vapor stream can also cause impingement erosion, but it is generally spread over a greater area. Impingement damage is characterized by relatively smooth grooves and pockets worn into the metal.

Abrasive erosion occurs when the fluid stream contains solid particles that are harder than the trim surface and are traveling at sufficient velocity. This erosion can be likened to a type of scouring action that wears away metal, similar to a file or grinder. Solutions to the problem involve the use of harder trim materials, streamlining the flow pattern, and reducing velocity. However, abrasive erosion can only be reduced in magnitude and not entirely eliminated.

Good valve and trim service life can be obtained in some cases, but in severe problems other alternatives should be considered. If the fluid and operating conditions are compatible with elastomers, it might be better to consider pinch valves (see Section 6.20). With high velocities or corrosive fluids, ceramic-lined valves or chokes can be used.

**Erosion-Corrosion**

Metals in most ambient and process environments resist corrosion by means of a protective metal-oxide film. Rust is a form of protective film on iron and steel, even though it has some undesirable characteristics. If the protective film is damaged, worn, or dissolved, the base metal is exposed to further corrosive action and a new oxide film is formed at the expense of the base metal. Protective films can be damaged by particle abrasion, mechanical wear, cavitation, chemical attack, and fluid velocity or turbulence.

Common rust is a relatively weak film that is easily disturbed chemically or mechanically. Small additions of alloys, such as copper, to the steel can increase the stability of the iron oxide against atmospheric corrosion, such as in "weathering" steel. Substantial additions of chromium to steel create a "stainless" steel that forms a relatively strong protective chromium oxide film instead of iron oxide, which protects against further attack in a wide range of chemical environments and is referred to as the passive layer or film.

The flow of fluid through a piping system and especially through valves and fittings can have both electrochemical and mechanical effects on protective films. Velocity, turbulence, and impingement can increase the polarization rates of the oxidation and reduction reactions at the metal-electrolyte interface, which can weaken or dissolve metal-oxide films.

The mechanical effects of fluid velocity can more easily remove a weakened or thinned protective film, leaving the base material exposed to further corrosion. When these effects are combined in a way that accelerates the rate of corrosion from a static state, it is called erosion-corrosion or flow-accelerated corrosion. This is a complex phenomenon, and actual service experience may be needed to determine which alloys and trim configuration will give the best service.

Depending on the actual metal, chemical, and velocity characteristics of a specific application, erosion-corrosion may appear in different ways. In some cases, the eroded surface may appear like a sandy beach with wave-like ripples or ridges. When there is more direct impingement or severe turbulence, the surface might have deep gouges, undercuts, or gullies. Some cases exhibit a pattern of elongated pits. Erosion-corrosion has been observed in the following applications.

- Deoxygenated water (condensate and boiler feedwater) or wet steam in the temperature range of $212–480°F$ (100–250°C) in carbon steel valves and fittings of fossil-fueled and nuclear power plants
- Polluted or silty, salt or brackish waters with dissolved or entrained gases with low levels of sulfur compounds in copper, bronze, or brass systems of oilfields and wastewater applications
- Slurry flow or cavitation in stainless steel systems

Users should consult experienced corrosion specialists or metallurgists regarding alloy selection, system design, and process chemistry (or water treatment) to prevent or correct these situations.
Trim Materials

The most popular general service trim material is austenitic type 316 stainless steel, which is commonly used with and without hard-facing up to about 800°F (427°C) and in special cases up to 1200°F (649°C). Other harder materials are frequently required in special trims, higher temperatures, and trim parts that might gall because of close tolerance metal-to-metal sliding action (cage guiding and guide bushings). Among these materials are 17-4PH, 410, 416, and 440C stainless steels; hardenable Ni-Cr-Fe-Mo alloys (e.g., Inconel® 718); cobalt-chromium alloys (e.g., Stellite®); nickel-boron alloys (e.g., Colmonoy® and Deloro® hard-facing); tungsten carbide; and ceramics.

For very corrosive services, more noble or high alloy metals are used to advantage. Among these are Alloy 20 stainless steel, nickel, titanium, tantalum, zirconium, 70Ni-30Cu alloys (e.g., Monel® 400, Monel K-500), Ni-Cr-Fe-Mo alloys (e.g., Inconel), Ni-Cr-Fe alloys (e.g., Incoloy®), Ni-Mo alloys (e.g., Hastelloy®-B/B2), and Ni-Cr-Mo alloys (e.g., Hastelloy-C/C276, -C22). It is difficult to generalize on recommended materials or material combinations for valve trims because of the wide range of valve designs and process application requirements.

The specifying engineer should utilize not only his or her own knowledge, but also enlist the experience and expertise of the manufacturer and material specialists and metallurgists when needed. Fortunately, many applications are reasonably straightforward, and standard trim material combinations set forth by the manufacturer can be used.

Some general guidelines can be given for specifying trim. When specifying hard-faced plugs and seats, the plug can be supplied with hard-facing alloy on the seat surface only (Figure 6.19h). This may be sufficient if the valve is subject to high pressure drop primarily during shut-off. However, for continuous high pressure drop throttling, the full face or contour of the plug should be completely overlaid with hard-facing alloy, unless the base material is already hardened.

If the plug is stem-guided or post-guided, the lower guide area should also be hard-faced for high pressure drop throttling or if the fluid temperature is above 750°F (400°C). As with the plug, the seat ring can be hard-faced only on the seating surface or over the entire bore surfaces, depending on the severity of the pressure drop and temperature. A variety of cobalt-chromium and nickel-chromium-boron alloys are available for hard-facing. In some cases, coating techniques such as flame or plasma spraying will be used. The valve manufacturer’s recommendations are valuable guidance.

Commonly used hardenable alloys for trim materials include

- 410 and 416 stainless steels hardened up to about 38 Rockwell C (HRC)
- 440C stainless steel with hardness up to 60 HRC
- 17-4PH stainless steel, a precipitation-hardened material combining good corrosion resistance with a range of tensile properties and hardness between 28 and 42 HRC depending on heat treatment

The 400-series (martensitic) stainless steels have limited corrosion resistance suitable for most water and steam service up to about 700°F (371°C). They are generally used for trim parts that can be made from bar stock or forgings, but some types are available as castings. Stainless steel 17-4PH is available in cast and wrought forms and is a usable general-purpose alloy up to 750°F (400°C). It is not as corrosion resistant as austenitic 316 stainless steel, but it is significantly better than most common 400-series types. Where 316 or other soft alloys are indicated as the proper alloy for a cage-guided trim, hard-facing will be required to minimize metal-to-metal galling problems.

Leakage

Control valves have varying degrees of shut-off capability, depending upon the valve and internal trim design, material, and manufacturing methods. Tight shut-off is not always a requirement, especially for throttling control valves. However, as reliability of control valves has increased, more applications are requiring tight shut-off for control valves in order to minimize the number of isolation valves and bypass loops. Another consideration should be the cost of lost or contaminated product and wasted energy resulting from leakage through valves. Users should consider all of these factors along with the cost and operating requirements of the valve before specifying the shut-off requirements.

Shut-off requirements are usually specified as an allowable volumetric leakage rate measured in a standardized test.
6.19 Valve Types: Globe Valves

While it is permissible for a user to specify any value for the allowable leakage at a specified pressure drop, it is more common to specify one of the standard leakage classes defined by industry standards. The two most commonly applied standards, FCI 70-2 (formerly ASME B16.105) and IEC 60534-4, define several classes, with Classes II, III, IV, V, and VI being most commonly used for globe valves. Class V and Class VI represent the smallest allowable leakage depending on the pressure drop and test method specified. Refer to Section 6.1 for information about determining allowable leakage in each class.

Good single-seated valve trims can give Class IV or V shut-off in nonbalanced plug designs. Leakage Classes III or IV are typical for balanced plugs, but elastomer seals and special pilot-operated balanced trims have been used to achieve Class V shut-off. Figure 6.19g gives the seat leakage class tabulation. Typically, Class VI shut-off is specified for soft seat inserts such as polytetrafluoroethylene (PTFE) or Teflon® (ETFE (Tefzel®), or other plastics.

Figure 6.19i shows two typical configurations where the soft insert can be located in either the plug or the seat ring. Class VI leakage is also achievable with special lapped-in or precision-fit metal plugs and seats.

Note that operating service temperatures, high or low, will limit the use of soft seat materials. The pressure drop across the valve is another limiting factor, although some “protected insert” designs (Figure 6.19j) will operate at very high pressure drops.

Seat leakage tests and classes are defined only for new valves, and it should not be assumed that the same level of tightness can be maintained in service. When a valve is placed in service, the seating surfaces can be worn or damaged by high velocity, pipe scale, process solids, corrosion, or vibration, which cause leakage to increase over time. Wear-resistant materials and careful installation and start-up practices can minimize wear and damage to seating surfaces.

Plugs

The valve stem connects the plug head to the actuator stem or coupling. It has several requirements as part of a carefully balanced mechanical system consisting of the plug head and stem, seat ring, cage, bonnet, stem bushings, stem packing, and actuator. It must be strong enough to transfer the load from the actuator to plug and bear the seat loading forces without cyclic fatigue. It must be stiff enough under maximum actuator loading to prevent buckling or significant deflections that promote packing wear and leakage. Yet it cannot be so big as to generate excessive packing friction or unnecessary static pressure forces that make actuation and control difficult.

The proper function of the valve also requires precise alignment of the plug and stem with the seat, bonnet, and actuator in order to prevent excessive friction and binding and to ensure minimal leakage at the seal or through the packing. Materials, design, and surface finish of the stem and bushings must prevent galling and minimize friction and packing wear. Material selection of the stem includes consideration of the process environment inside the valve, the range of environmental conditions outside the valve, and a mixture of those environments in the packing interface. In some unusual corrosive services, moisture or chemicals in the atmosphere can react with process chemicals to create a more corrosive mixture in the stem-packing interface. This situation may require a stem material with more corrosion resistance than the plug head that is exposed only to the process fluid.

Valve stems are normally the same material as the plug head, but they can be different based on the design criteria discussed above. Depending upon the type of valve design, the valve stem may be integral (one piece) with the plug, or it can be threaded into the plug and then pinned to prevent unscrewing. Because the manufacturer does a number of things to insure proper alignment and a solid, vibration-resistant threaded connection, good maintenance practice may dictate replacement as a unit rather than separate pieces.

Stem guides in one form or another are an integral part of the trim assembly. Metal stem guide or bushing material is selected to minimize metal-to-metal wear and galling...
against the stem. For lower temperatures and light duty, non-metallic guide bushing materials, such as reinforced PTFE fluoroplastic or compressed graphite, are common choices. Metal guides may be of such materials as 17-4PH, 440-C, Stellite, or hard-chrome plated or nitrided stainless steel, bronze, and aluminum-bronze. For the main characteristics of the common trim materials refer to Table 6.19k.

### Bonnet Designs

The valve bonnet is the top closure assembly for the globe valve, as well as for several other valve body design types. In addition to closing the valve body, the bonnet also provides the means for mounting the actuator assembly to the valve body and sealing the valve stem against process fluid leakage. The various bonnet designs will be discussed along with the subject of stem sealing utilizing packing materials, lubricants, and special seal designs.

In addition to considerations of pressure containment, manufacturers design bonnets to provide features that predominate in their particular philosophy of valve design. The depth of the stuffing box and surface finish, provision of guides, method of operator attachment, packing design flexibility, and packing follower design are all details that vary from manufacturer to manufacturer or even among various body designs offered by one manufacturer.

Some low-pressure valves, especially in sizes below 2 in. (DN 50), can be provided with a threaded bonnet. This reduces the weight and is more economical in first cost than the flanged and bolted design. Depending on the materials of construction, it can be difficult to remove a threaded bonnet after extended service in high temperature or corrosive service, making this type more costly to maintain in these types of applications. Economic justification for using a valve with a threaded bonnet is sometimes based on a life-cost model of “discard and replace,” whereas larger valves, bolted bonnet valves, and control valves typically require a “maintain and repair” cost analysis. In special cases the bonnet-to-body joint can be seal welded to prevent leakage of highly reactive, lethal, or radioactive fluids.

### Bolted Bonnets

The most common valve bonnet design is the bolted bonnet, like the one shown in Figure 6.19I. It is usually fastened to the valve body by high-strength stud bolts and heavy nuts. Removal of the bonnet gives complete access to the valve trim for maintenance purposes. Because the bonnet is a pressure-retaining part of the overall fluid containment system,
the design and materials are determined in accordance with an applicable pressure vessel standard. For example, the ASME Pressure Vessel Codes, ASME B16.34, API 6D, AD Merkblätter, European norms, ISO standards, and numerous individual nations’ pressure vessel standards give material requirements and design criteria for flanges, wall thickness, and flange bolting.

**Bonnet Gaskets** The seal between the valve bonnet and body can take several forms depending upon the valve design and application range, including containment pressure and fluid temperature. Fluid corrosion is also a factor that must be considered. The most common seal is a contained gasket, either a flat or spiral-wound composite design (Figure 6.19l).

Other designs that may be found are the API ring joint (oval or octagonal cross-section), lens type, delta gasket, and Bridgeman gasket (Figure 6.19m). These latter designs are metal gaskets. The flat gasket is usually either graphite-based or a reinforced PTFE. The spiral-wound gasket usually consists of graphite ribbon or PTFE wound between thin metal strips. The metal windings of a spiral-wound gasket are usually stainless steel, but they are available in a variety of corrosion resistant and high-temperature alloys.

Asbestos fillers were commonly used in gaskets until the late 1970s, largely due to the lack of effective substitutes for many high-temperature or corrosive sealing applications. Since then, sealing materials and technologies have improved to the point where there should be no further requirement for using this potentially hazardous material in gaskets. Proper handling and disposal are required if very old valves are encountered in order to reduce the risks of asbestos exposure.

**Pressure Seal Bonnets**

Another typical bonnet seal is called the pressure seal, and it is used in high-pressure valves Class 900 (PN 150) and higher to minimize size and weight of the bonnet-to-body connection. The pressure-sealed bonnet does not rely on heavy bolting and a thick flange to retain pressure, like the bolted bonnet. Instead, a wedge-shaped graphite-composite gasket is installed on top of a bonnet sealing lip and is compressed between the bonnet and a set of antieextrusion or spacer rings and heavy retaining ring segments that are indexed into the body. During assembly, the bonnet is pulled up tightly against the seal, spacer ring, and gasket retainer segments by the pull-up bolting and bonnet retainer to create a radial seal between the body neck and bonnet, as shown in Figure 6.19n.

When the valve is pressurized in service, the upward force from pressure under the bonnet further energizes the radial sealing. The design and materials of pressure-sealed
gasket joints are especially important. If the gasket material bonds so tightly in service to the inside bore of the body that it becomes difficult to remove for maintenance, it may be time-consuming or impossible to free the bonnet without damage to the body. Fortunately, recent design and material improvements have minimized these types of maintenance problems. Pressure-sealed bonnet joints have advantages in high-pressure, high-temperature applications, because they permit more uniform body wall thickness at the body neck opening, which minimizes thermal stresses in the body during temperature transients. The valves are frequently lighter in weight than comparable bolted bonnet valves, and they are relatively easy to assemble.

**Bonnet Classification**

Bonnets fall into basically three classifications. These are standard, extended for hot or cold service, and special designs such as cryogenic extensions and bellows seals. These classifications along with the stem seal systems, guides, and bushings will be discussed in more detail later in this section.

**Standard Bonnet** The standard or plain bonnet (Figure 6.19d) is the normal bonnet design furnished on most valves. It covers the range of pressures and temperatures compatible with standard seal gaskets and stem packing materials. Generally, this includes valves designed for ANSI Pressure Classes 150 (PN 20) through 2500 (PN 420) and temperatures from −20 to 600°F (−30 to 315°C). Above 450°F (230°C) graphite-based packing or extended bonnets are recommended. The reason for setting a temperature limit for standard-length bonnets is to limit the temperatures to which the packing and actuator are exposed. Over 90% of all control valve applications can be handled by the plain bonnet design. It may or may not incorporate stem guides or bushings and may have very broad or very limited packing configurations available, depending upon the specific manufacturer and valve design.

**Extended Bonnet** The extended bonnet (Figure 6.19o) is usually required when the fluid temperature is outside the plain limitations of the standard bonnet temperature. Even when normal process temperatures are within the plain bonnet limits, it may be necessary to use the extended bonnet to protect the packing and actuator against temperature excursions during occasional process upsets.

Originally, the extended bonnet used different designs for hot and cold service. The hot service extended bonnet was provided with “cooling fins,” while the cold service extended bonnet was a plain casting without fins. Over many years it was demonstrated that fins on the bonnet added only marginal capability to heat dissipation in the packing area. It made a costly and complex casting and has been largely abandoned in favor of the plain extension.

In most modern control valve designs, the bonnet extension is similar for hot or cold service, except where deep cryogenic temperatures under −150°F (−100°C) are encountered. Some manufacturers offer two standard bonnet extension

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FIG. 6.19n
Pressure seal bonnet configuration showing composite wedge gasket. (Courtesy of Flowserve Corporation.)

FIG. 6.19o
Standard high-temperature extension bonnet. (Courtesy of Flowserve Corporation.)
lengths (other than cryogenic) depending upon the operating temperature. In general, the standard extension bonnet is suitable from $-20$ to $800^\circ F$ ($-30$ to $425^\circ C$) in carbon steel construction and from $-150$ to $1500^\circ F$ ($-100$ to $815^\circ C$) in austenitic stainless steel construction.

**Cryogenic Bonnet** The cryogenic bonnet or cold-box bonnet (Figure 6.19p) is a special design adaptation of the extended bonnet. Depending upon a manufacturer’s valve design, this style bonnet may be required with operating temperatures ranging from $-150$ to $-300^\circ F$ ($-100$ to $-185^\circ C$) down to $-425^\circ F$ ($-255^\circ C$) using a bolted bonnet. The main purpose for extending the bonnet for cold service is to keep the packing and upper plug stem warm enough to prevent icing or frost around the packing area and stem. Ice crystals on the stem can be pulled into the packing, damage the seal, and create a leak path.

The bonnet length is selected for the application based on valve body size, piping requirements, and operating temperature needs; it will generally range from 12 in. (300 mm) to 36 in. (900 mm). The standard cryogenic bonnets are distinctly different from cold-box designs or extended-neck designs (Figure 6.19q). The standard design is usually similar to the standard extension bonnet, except much longer. It can be cast or fabricated from multiple pieces by welding.

For extreme temperatures near $-454^\circ F$ ($-270^\circ C$), the body neck is often extended to remove the bonnet gasket away from the extremely low temperature and to make the bonnet joint accessible outside of the cold-box. The extended neck of the cold-box body is usually fabricated from thin-walled stainless steel tubing (to reduce cool-down weight and heat leakage into the cryogenic process). The extension is welded directly to the body casting or forging (Figure 6.19q). At the top of the extension is the flange for connecting with the bonnet. In general, these applications are limited to ANSI Pressure Class 600 or below.

Special designs are also available for high-pressure service up to ANSI Class 4500 and above. Because the extreme cold requires good impact resistance, materials of construction are limited to the austenitic stainless steels (Types 304L or 316L) and bronze. These valves incorporate a stem seal system at the plug end of the bonnet to keep the cryogenic liquid out of the bonnet and packing area. This seal may be vented or nonvented, but it must allow a pocket of vapor to exist below the bonnet as insulation against severe convective heat loss from the warmer bonnet area if exposed to cryogenic liquid.

The seal design must also allow any build-up of gas pressure in the warmer bonnet area to relieve back into the valve body. Vented designs are typically used if the valve is installed with the neck and stem oriented vertically up to within $30^\circ$ of horizontal to prevent liquid from getting to the packing area. Nonvented designs incorporate a unidirectional seal and are used when the valve neck is installed at or near horizontal. In some cases, where additional insulation is needed to reduce outside heat flow, the bonnet can be fitted with a vacuum jacket.

**Bellows Seal Bonnet** When no stem leakage can be permitted, many globe valve manufacturers provide extended bonnet designs that incorporate a bellows seal around the stem (Figure 6.19r). Bellows seals are justified in applications involving toxic or radioactive fluids, where leakage to the
outside would pose personnel safety hazards. The bellows is usually made of stainless steel or other corrosion-resistant nickel alloys such as Hastelloy C-276 and Inconel 625. They can be hydraulically or mechanically formed (as shown in Figure 6.19r), or they can be made by stacking many individual leaf segments that are welded together at their outer edges and are known as welded or nested bellows.

The bellows is attached to one end of the stem by welding; the other end is welding to a clamped-in fitting with an antirotation device. The antirotation device prevents the bellows from being twisted during assembly and disassembly or by vibration of the plug in service.

Bellows seals are usually leak-tested from atmospheric pressure to vacuum using a mass spectrometer to detect helium leakage rates below $1 \times 10^{-6}$ cc/sec. The service life of a metal bellows depends on the design, material, manufacturing processes, service pressure and temperature, corrosion effects, and stem cycle history. Failures of metal bellows usually occur by cyclic fatigue.

Bellows manufacturers that have tightly controlled production processes have cycle-tested their designs and are able to make reasonable predictions of expected cycle life. Bellows-sealed bonnets are backed up with a standard stem packing set and a leakage monitoring port between the bellows and the packing in order to prevent catastrophic release of hazardous fluid in the event of a bellows leak.

Metal bellows seals have pressure and temperature limitations. Ratings of about 150 PSIG (1030 kPa) at 100°F (40°C) or 90 PSIG (620 kPa) at 600°F (315°C) are typical. The average full stroke cycle life can vary from 50,000 cycles for size 1 in. (DN 25) and smaller valves to 8000 cycles for sizes 3–6 in. (DN 75–DN 150). In some cases, cycle life can be improved by reducing operating pressures or by using special short stroke valve plugs.

Operating pressures can be increased to as much as 2900 PSIG (20,000 kPa) and temperatures up to 1100°F (590°C) by multiple or heavy-wall bellows and selection of a high-strength metal alloy. However, this reduces cycle life considerably. As a result of these various factors, metal bellows bonnet seals are selected for relatively few applications. Improved environmental packing systems are specified for a majority of hazardous fluids, except for dangerous applications where the risks justify the additional costs of purchase and maintenance for metal bellows seals.

**Bonnet Packing**

In order to seal the valve stem against leakage of process fluid to the atmosphere, the upper part of the bonnet contains a section called the stuffing or packing box. This assembly consists of a gland flange, packing follower, packing spacer or lantern ring, lower packing retainer, and a number of packing rings. The surface finish of the stem should be very fine, on the order of 8 Ra (micro-inch roughness average), and the internal finish of the bonnet stuffing box should be 16 Ra or better. Various valve packing materials are available, but for control valves use three general groups of materials: fluoroplastics (PTFE, FEP, PCTFE), carbon graphite (compressed rings and braided yarn), and synthetic polymer fibers (PBI® and aramid).

Control valve packing must be compatible with the process fluid, seal the stem and bonnet, produce minimum starting and sliding friction, and give long service life in modulating service. The most popular material that meets all of these conditions over the broadest range of fluid applications is PTFE, used as V-rings or braided filament. As a result, the majority of control valve manufacturers provide a variety of packing configurations with this material.

**Fluoroplastic Packing**

Polytetrafluoroethylene (or Teflon) is the most common packing material in the family of fluoroplastics. It is normally formed or machined as chevron or V-rings from virgin (not reprocessed) material. For special needs, a shape variation known as “cup-and-cone” is available. Note that in V-ring and cup-and-cone configurations, the top and bottom rings are adapter rings with one flat surface. Braided packing is also formed from PTFE filament. For higher temperature or pressure applications, PTFE can be reinforced or filled with up to about 25% by volume of glass fibers, silica, carbon, or graphite and other fillers to add strength and stiffness and to improve its resistance to cold-flow or creep. PTFE braided packing can be reinforced by using PBI or aramid fiber in the corner braids. As noted earlier, PTFE is limited to a maximum exposure temperature...
of about 450°F (230°C) in a plain bonnet, depending on the service pressure.

When used in extended bonnets, some users have successfully used reinforced PTFE packing with process temperatures up to about 850°F (455°C), providing the packing box temperature remains below 450°F (230°C). Although PTFE packing has useable properties down to about −320°F (−195°C), its practical lower limit for packing in a standard length bonnet ranges from −50°F (−46°C) to −100°F (−73°C), depending on bonnet design. See Figure 6.19s for pressure-temperature limits for PTFE and other packing in standard bonnets. In order to prevent ice damage to packing at lower temperatures, extended bonnets or cold-box-style bodies are used (Figures 6.19p and 6.19q).

Contrary to some claims, PTFE packing does not require live-loading springs to be effective as a stem seal. Normal packing follower loading and adjustment is all that is required, especially with the V-ring or chevron shape (Figure 6.19r). The cup-and-cone style requires a higher loading to effectively energize the seal. Live-loading springs are beneficial in special applications, such as in temperature cycling duty and for some types of environmental seals to reduce volatile organic chemicals (VOCs) and toxic emissions.

The packing rings and stuffing box dimensions should be very accurate for proper contact with the sealing lips of the V-rings. Dimensional tolerances are even more critical for the PTFE cup-and-cone rings because of the high degree of stiffness and packing loading required. PTFE packing has extremely low friction characteristics and does not require supplemental lubrication. However, excessive overtightening of the gland bolting can transform the V-ring structure into a solid compression packing capable of transferring high radial forces and excessive friction to the stem.

**Asbestos Packing** Asbestos is one of the oldest packing materials and was in wide use until the late 1970s, even though the health hazards of airborne fibers were known before then. Health risks were generally insignificant when handling new packing with binders to keep the fibers from fraying. However, in high-temperature service, the binders disappear, and removal of old packing from stuffing boxes

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**FIG. 6.19s**

Recommended temperature-pressure limits for some common packing materials. (Courtesy of Flowserve Corporation)
had the potential of creating airborne fibers unless special dust mitigation procedures were employed. The lack of effective asbestos substitutes for many high-temperature or corrosive sealing applications made it difficult to abandon its use. Since then, sealing materials and packing technologies have virtually eliminated further need for using this potentially hazardous material. In order to reduce the risks of asbestos exposure, proper handling and disposal are required if very old valves are encountered.

**Graphite Packing**  
The improvement and optimization of graphite foil and yarn for use as valve packing came about largely out of the need to find substitutes for asbestos packing. Flexible graphite packing is available in formed rings of laminated graphite foil. Rings are formed in square, wedged, and cup-and-cone cross-sections.

A wide variety of braided constructions are available. Braided graphite can include dry lubricants to reduce friction. Braided graphite can be reinforced for high-pressure service using synthetic fibers like PBI or aramid. Reinforcing of the graphite braid with an Inconel wire core or fine wire-encapsulated yarn is common for high-temperature, high-pressure service. Several typical graphite packing configurations consist of a combination of formed laminated rings with braided rings above and below the laminated set to act as wiper rings.

Flexible graphite packing can be used in many fluids including reducing and mildly oxidizing acids (not strong oxidizers), caustics, hydrocarbons, solvents, water, steam, and gases. It has high-temperature capability up to 1200°F (649°C) in steam; and in inert, nonoxidizing media (i.e., oxygen-free environments like nitrogen or carbon dioxide) pure graphite is usable up to 4500°F (2500°C). In atmosphere and oxidizing media, the high-temperature limit can vary between 650°F (343°C) and 850°F (454°C) depending on the specific materials; consult with packing manufacturer for specific applications. If an extended bonnet is used, the upper temperature can be extended to 1200°F (650°C) on both oxidizing and nonoxidizing service. The low temperature limit for pure graphite braided packing can be as low as −400°F (−240°C).

Packing and valve manufacturers have undertaken considerable developmental work in an attempt to overcome or mitigate past problems with graphite. Among these shortcomings are the following:

- Relatively high stem friction
- Difficulty in “energizing” the packing to give an effective stem seal
- Low cycle life without leakage
- Electrolytic pitting of stainless steel stems in conductive or high-temperature services
- Shortened packing life due to graphite plateout on the stem

There are several methods that can be used to extend the life and improve the performance of graphite packing. The packing or valve manufacturer should be consulted for proper methods for their specific sealing system. Some general things that have helped to improve graphite packing performance include the following:

1. Use combination packing assemblies consisting of laminated graphite and braided graphite fiber rings. The braided graphite rings help as antextrusion or wiping rings and prevent graphite plateout on the stem.
2. Use sacrificial zinc washers where possible or hard chrome plating or stem materials resistant to pitting attack. Some packing include a zinc powder as anodic protection for the stem.
3. Carefully torque the packing flange nuts to the minimum torque recommended by the valve manufacturer. Overtorque will result in excessive valve stem friction and may even lock the stem.
4. Remove the packing while the valve is in storage or out of service for extended time periods.
5. Clean graphite plating from the stem before installing new packing.
6. Avoid trapping air between the rings during installation. Leave the ring level with the chamfer of the stuffing box cavity and install the next ring on top.
7. “Breaking in” new packing by tightening the gland in gradual steps while cycling the valve at least 10 times may help. A break-in lubricant applied to the packing rings and stem (e.g., nickel antiseize or silicone grease) is also recommended.

One of the oldest methods for reducing stem friction with graphite or any braided packing (such as asbestos) involved a lubricator fitting that was added to the bonnet. In this design, a compatible grease compound is injected into the lantern ring area by a packing lubricator assembly (Figure 6.19u). A loading
bolt is turned to force the grease sticks into the packing. An isolating valve should be used for safety. External lubrication works reasonably well, although it is cumbersome and requires constant maintenance for checking and reloading of the lubricator. Also, it is sometimes difficult to find lubricants compatible with the process fluid.

**Packing Arrangements** There are a number of packing arrangement systems in use to suit various types of packing and fluid containment problems (Figures 6.19v). In general, the arrangements are equivalent for either Teflon V-rings or square rings (braided and laminated), although the number of rings will vary for each packing type and manufacturer’s sealing system. In a standard packing arrangement, a lower set of rings serves to minimize ingress of solids from the process into the stuffing box and acts as a stem wiper. The upper set provides the primary seal and consists of several rings.

For harder-to-hold fluids or when a leak detection port, bonnet purge port, or lubricator is used, a packing arrangement known as the twin-seal is often used (Figures 6.19w). A variation of the twin seal arrangement is also recommended for vacuum service. In the twin seal, there are two full sets of packing installed. This system requires a bonnet with deeper stuffing box, because space is needed for spacers or lantern rings and a lower guide bushing as well as the primary stem seal. However, in vacuum service, the upper set is inverted with the V-opening toward the atmospheric side as the primary seal, because positive pressure is from atmosphere to the negative pressure inside of the valve.

For toxic or radioactive fluid services, the bonnet can be tapped at the lantern ring area, and this connection can be used in three different ways, depending upon specific design requirements. 1) The tap can be used for a leakage monitor connection using a pressure gauge or switch. 2) It can be used for sampling the process. 3) More commonly, the tap is used as a leak-off connection, whereby any process leakage is piped to a disposal header or nonpressurized waste container.

In cases where the fluid is a slurry or tends to solidify, the tap can be used as a purge connection to keep process media out of the bonnet. Here, an inert gas or liquid (depending upon the process) is introduced at a pressure well above the highest expected process pressure. This purge material provides an additional pressure seal, and any packing leakage will be in the direction of purge into the process or from the purge to atmosphere.

**Environmental Packing** The need for more aggressive protection of the environment against volatile organic chemicals and clean air regulations in Europe (e.g., TA-Luft standards), United States (e.g., EPA standards), and most other countries have motivated the development of special packing configurations and
overcome sliding friction, and gradual loss of this lubrication. Lubrication may be needed to minimize extrusion or blowout. Installation of O-rings requires great care to avoid cutting, and probably backup rings to minimize extrusion or blowout. Elastomers that are resistant to ED failures.

Most O-ring manufacturers now offer special grades of some elastomers. These regulations generally establish compliance below benchmark levels varying from 500–100 parts per million (ppm) of VOC. Figure 6.19x shows only two of many different environmental packing system designs.

Environmental packing systems often consist of a combination of ring designs and different materials. For low to moderate temperatures, a common packing set can have unfilled PTFE or chemically inert elastomer V-rings stacked between stiffer thermoplastic or reinforced PTFE chevrons for a tighter and more durable seal. For higher temperatures, various combinations of graphite braided rings with laminated graphite rings (square, wedged, or cup-and-cone) are used. Any of these configurations can include live-loading spring arrangements to help maintain constant packing loads and make up for consolidation or cold-flow of the packing over time. Antiextrusion rings are also used in some systems to promote longer packing life. Most valve manufacturers offer a variety of environmental packing styles to suit a wide range of applications.

Other Packing Materials Elastomeric O-rings are used for stem sealing in some globe valve designs, usually for less low-pressure, low-temperature utility services such as water. O-ring stem packing tends to be more common for rotary valves than for sliding stem valves. Proper selection of an elastomer that is compatible with the process fluid chemistry and temperature can also be a problem. In gas service or with liquids containing gases, many elastomers will absorb some gas. Depressurizing the valve will result in sudden expansion of this gas. If the gas cannot diffuse rapidly out of the elastomer, the resulting internal pressure can rupture or split the O-ring. This effect is called explosive decompression (ED). Most O-ring manufacturers now offer special grades of some elastomers that are resistant to ED failures.

The O-ring gland design requires a fully retained groove and probably backup rings to minimize extrusion or blowout. Installation of O-rings requires great care to avoid cutting, twisting, or other damage. Lubrication may be needed to overcome sliding friction, and gradual loss of this lubrication in service can cause excessive O-ring wear or sticking in dry service. A standard stem seal packing ring system is usually preferred in sliding stem valves.

Packing Temperature The relationship between the process and the packing temperature is a function not only of the type of bonnet used but also of the valve metallurgy and the valve and bonnet physical relationship. Heat is transmitted to the packing area by conduction through the metal, by convection via the process fluid, and by the relative heat radiation balance with the ambient environment. Stainless steel, for example, has a much lower heat conductivity coefficient than carbon steel and thus is about 20–30% less “efficient” in conducting heat into the packing area. This does not mean that the packing temperature rating can be increased, but it may serve to reduce some heat load and increase packing life. (See Figure 6.1o in Section 6.1 for further discussion and illustration of packing temperature determination.)

In some cases, the valve can be installed upside down so that the bonnet is below the valve body. In liquid service, this reduces convection, and heat is transferred to the bonnet mainly by conduction. In vapor service (with or without superheat), it may be possible in the stem-down orientation to condense sufficient vapor in the bonnet to create a condensate seal and lower the packing temperature to a suitable level. The potential corrosive effects of alternate wetting and drying must be considered with this approach. However, this approach to controlling packing temperature has serious disadvantages where maintenance is concerned, and the benefits generally do not justify the potential maintenance difficulties except in unusual cases.

BODY FORMS

The actual pressure containment and fluid conduit portion of a control valve is called the valve body assembly. This assembly consists of the body, a bonnet or top closure, sometimes a bottom flange closure, and the internal elements known as the trim. The body can have flanged, threaded, or welded end (butt weld or socket weld) connections for installation into the piping. The trim consists of such elements as the plug and stem, guide bushings, seat rings, cages or seat retainers, and stuffing box lantern ring.

The body configuration can be in-line, angle, offset in-line, Y-type, and three-way. Some of these will be discussed in more detail.

The shape and style of the valve body assembly is usually determined by the type of trim elements it contains, piping requirements, and the function of the valve in the process system. There are a large number of body designs on the market, including a number of special-purpose designs. The end result is a device that can be fitted with an actuator and used to modulate the flow of process fluid to regulate such things as pressure, flow, temperature, liquid
level, or any other variable in a process system. Examples of some of the more widely used body configurations are shown in Figure 6.19y.

**Double-Ported Valves**

The double-ported (double-seated) balanced valve (Figure 6.19z) was one of the first globe valves developed during the early 20th century. It is still available today, but has been replaced in most applications by single-seated globe valves. Size for size, it is much larger and heavier than its single-seated counterpart. Shut-off is poor because it is not practical to have both plugs in tight contact with the seats at the same time, but the valve was intended for throttling control rather than for tight shut-off. Some special seat designs have been developed to help overcome this, but application is limited.

The double-ported valve is considered semibalanced; i.e., the hydrostatic forces acting on the upper plug partially cancel out the forces acting on the lower plug. The result is less actuator force requirement, and a smaller actuator can be used. However, there is always an unbalanced force due to the difference between the upper and lower plug diameters required for assembly. In addition, unbalance forces are generated by the effect of dynamic fluid forces acting on the respective throttling areas of each plug. Such forces can be quite high, particularly with the smooth contoured plugs; these can reach as much as 40% of the forces of an equivalent unbalanced single-seated valve plug. Double-ported valves have been built in sizes up to 24 in. (DN 600), although most manufacturers now limit them to 12 in. (DN 300) as a maximum.

Figure 6.19z shows that the valve can be converted from the push-down-to-close configuration shown to a push-down-to-open design. This is done by removing the bottom closure flange, bonnet, and stem, and by inverting the entire assembly and reinstalling the stem, flange, and bonnet. This, coupled with the use of direct-acting (air pushes the stem down) and reverse-acting (air pushes the stem up) actuators, gives full flexibility to provide the required valve failure mode.

**Single-Seated Valves**

Single-seated valves are the most widely used of the globe body patterns. There are good reasons for this. They are available in a wide variety of configurations, including special-purpose trims. They have good seating shut-off capability, are less subject to vibration due to reduced plug mass, and are generally easy to maintain. There are three general types of seat construction.

1) The floating seat ring sits in machined bore in the body with a gasket to seal the joint between the body and seat ring. It must be retained in the body by a cage or seat retainer to maintain gasket tightness and concentricity with the plug. 2) The screwed-in seat ring is threaded into matching body threads with a special tool; a gasket may or may not be required. A separate seat retainer is not required, but some designs use a cage for guiding the plug or characterizing the flow. 3) The seating surface can be machined directly into the body; this is called an integral seat. The floating and screwed-in seat rings can be replaced after they wear out, but the integral seat requires resurfacing or machining of the body to repair wear or damage.

Single-seated valve plugs are guided in one of four ways: post-guided (Figure 6.19aa), top-and-bottom-guided (Figure 6.19bb), stem-guided (Figure 6.19cc), and cage-guided (Figure 6.19dd). The most popular globe valves are stem-, cage-, or post-guided types, which require only one body opening for the bonnet and have one less closure gasket subject to leakage than the top-and-bottom-guided configuration.

The stem-guided and post-guided designs provide more streamlined flow and are less subject to fouling in dirty service. The stem-guided valve minimizes stagnant fluid cavities and may be a better selection than the post-guided and cage-guided valves when dealing with fluids containing solids, sticky or viscous fluids, or highly corrosive fluids. The top-and-bottom single-seated valve (Figure 6.19bb), like its double-seated counterpart (Figure 6.19z), has similar limitations, but some users still prefer this design where the plug is held by two, widely spaced bushings. The top-entry single-seat globe valve is most commonly used in sizes from 1 in. (DN 25) through 12 in. (DN 300) from most manufacturers.

Some top-entry designs are manufactured with bodies suitable for slip-on flanges (Figure 6.19y) rather than with integral cast flanges. This type of flange construction is discussed in more detail below, under Split-Body Valves and Valve Connections.

**Cage Valves**

The cage valve is a variant of the single-seated valve and is the most popular design used in the process industries. The top-entry bonnet and trim design makes it extremely easy to change the trim or to do maintenance work. Cages are used with floating seat rings and with screwed-in seat rings. The design is very flexible in that it allows a variety of trim types to be installed in the body. This includes such variations as reduced trim, anticavitation, and low-noise trims (Sections 6.1 and 6.14).

The overall design is very rugged, and with proper specification of trim type and materials, cage valves provide relatively trouble-free service for extended time periods. These valves may eliminate the need for block and bypass valves in some cases, because their service life can be as good as or better than most other components in the process that require periodic maintenance.

There are two basic design configurations available for cage valves. One type uses the cage solely as a seat retainer to clamp a floating seat ring into the valve body (Figure 6.19cc). This design is usually stem-guided or post-guided, and the valve plug is characterized and does not guide or control flow through the cage.

The other type uses the cage to guide the plug head, and the cage openings are shaped to provide the desired flow characteristic as the valve plug exposes the ports (Figure 6.19dd), and it is called a cage-guided valve. In the cage-guided valve,
FIG. 6.19y
Typical globe body configurations. (Courtesy of Flowserve Corporation.)
6.19 Valve Types: Globe Valves

the cage may be used to clamp a floating seat ring, or it may be used with a screwed-in seat where the cage is part of the bonnet assembly. Both of the above cage designs are usually provided in smaller valve sizes with unbalanced plugs for best shut-off.

The stem-guided design (Figure 6.19cc) has advantages when handling fluids with solids, sticky fluids, fluids that coat or plate out onto the trim, and corrosive fluids. This is because the large plug-to-cage clearances in the stem-guided design are not sensitive to debris or build-up, and corrosion-resistant trim materials (316 stainless steel and nickel alloys) are more practical to use without special treatments to prevent metal-to-metal galling.
Tight clearances are required in the cage-guided version, which requires that metal surfaces must be hardened by heat treatment, hard-faced with Co-Cr or Ni-Cr-B alloys, plated with hard chrome or electroless nickel, or surface treated (e.g., nitriding) to eliminate metal-to-metal galling.

**Pressure-Balanced Valves** Pressure-balanced trims are also available in stem-guided (Figure 6.19ee) and cage-guided (Figure 6.19ff) versions.

Pressure-balanced designs help provide better control of high-pressure drops, reduce the magnitude of unbalanced plug forces, and help to reduce actuator size. The balanced plug designs can be provided with a variety of balance seal styles and materials to meet service conditions. These may be plastics such as PTFE, elastomeric O-rings, and metal piston rings. Generally, the use of balanced plugs will degrade the valve shut-off capability to some degree. For example, an unbalanced valve rated for Class V shut-off may drop to Class IV with balanced trim. This is due to leakage past the balance seal. (Refer to the discussions on leakage in this section and in Section 6.1.)

One variation of the pressure-balanced plug that has improved shut-off capability is shown in Figure 6.19gg. This is called the pilot-balanced plug. This design is particularly helpful when dealing with high-temperature, high-pressure drop situations when tight shut-off is difficult to achieve without the use of elastomeric seals. When the valve is shut off, the actuator has compressed the pilot spring and closed the pilot.

There is provision for a pressure path from the upstream pressure side of the plug to the area above the pilot plug, allowing upstream pressure on the upper plug area to assist the actuator in achieving a tight shut-off. In the shut-off position, there is no pressure drop across the conventional balance seals. When the actuator begins to open the valve, the stem first lifts the small pilot plug off its seat. This allows the pressure above the plug to vent to the downstream side, and the valve operates as a conventional pressure-balanced valve. The spring shown in this particular design holds the pilot valve off the pilot seat during normal operation. When the valve begins to close for shut-off, the plug first seats on the valve seat, and a small amount of additional stem travel compresses the spring and seats the pilot valve.

**Special Designs** Many customized, special-purpose designs are possible to meet unique service and operating requirements. The example in Figure 6.19hh shows a cage and seat that are installed from the bottom of the valve and supported by a bottom flange. This design was intended as a “flangeless”
6.19 Valve Types: Globe Valves

Valve for small sizes of forged or bar stock corrosion-resistant alloys such as Alloy 20, nickel, and Hastelloy C-276 for corrosive service. It allows for a bottom drain and quick inspection of the valve trim without removal of the actuator and bonnet. Similar bodies can be machined in custom configurations and may be more economical in small sizes for special alloys than other globe designs.

**Split-Body Valves** Another type of single-seated globe body is the split-body valve (Figure 6.19ii). This design was the original stem-guided chemical service valve intended for hard-to-handle services involving slurries, sticky fluids, and corrosive services. The seat ring is clamped between the body halves, and the body is easily disassembled for replacement of the seat and plug.

Another feature is the adaptability for building the body to use slip-on flanges. This results in cost savings when corrosion-resistant alloy castings or forgings are required for the wetted body. Because the flanges are not normally subject to wetting by the process fluid, they can be of carbon steel or lower alloys than the body. In small sizes, it is economical to cast or forge the body for a standard ANSI Class 600 rating and install Class 150, 300, or 600 slip-on flanges as needed. It is also possible to rotate the lower body 90 degrees to the line axis and eliminate a pipe elbow, although this is rarely done. The design of the split body makes it possible to be molded in structural plastics for low-pressure corrosive applications. Refer to the discussion on lined and thermoplastic valves below.

While still popular for some applications, split-body valves have limitations on installing special trim options. The bolted body joint may leak if exposed to large piping stresses from severe thermal cycling, and it should not be welded into the piping because maintenance requires body separation.

Split body valves are available with flanged ends up to size 10 in. (DN 250), but separable (slip-on) flanges are only available up to size 4 in. (DN 100), and threaded ends are available up to size 2 in. (DN 50). Availability is generally limited to small sizes in high-pressure classes. ANSI Class 900, 1500, and 2500 ratings (PN 150, PN 250, and PN 420) are in sizes 2 in. (DN 50) and smaller.

**Angle Valves** Angle valves (Figure 6.19y) are often used in a flow-to-close direction for high-pressure drop service. This is favorable to the valve body and trim but requires careful design of the downstream piping to avoid erosion problems in high-velocity liquid or two-phase flow. Depending on actual downstream velocities, these applications can require a larger pipe size than the valve and up to 20 diameters of straight pipe before the first elbow.

Angle valves are also used to accommodate special piping arrangements to aid drainage, on erosive services to minimize solids impingement problems, and on other special applications such as coking hydrocarbons. Figure 6.19jj shows a coking valve design with a streamlined, sweep-angle flow path and a replaceable venturi outlet sleeve. This body flow path is designed to reduce flow velocity in the body to minimize erosion.

Trim materials such as tungsten carbide and ceramics can be selected to resist erosion due to the higher trim velocities. The venturi-style outlet has high-pressure recovery and low vena contracta pressures, which makes the trim and downstream pipe highly susceptible to cavitation on liquid service, even with moderate pressure drops. In order to avoid damage to piping, these valves can be installed directly on vessel inlets or with a larger downstream pipe to mitigate the effects of cavitation or flashing.

**Y-Type Valves** The Y-type valve has application in several special areas. Among these applications are those where good drainage of the body passages or high flow capacity is required, such as in controlling molten metals or polymers, cryogenic fluids, and liquid slurries. Cast or forged Y-type valves are available up to size 16 in. (DN 400) and with pressure ratings up to Class 4500 (PN 760). The valve can be installed in
horizontal, vertical, or angled piping to suit the application requirements. Because of the simple body shape and bonnet design, they are easy to fit with thermal or vacuum jackets.

Figure 6.19kk shows a Y-type valve with a vacuum jacket that has been specially designed for low-pressure cryogenic liquid service. The vacuum jacket provides maximum thermal insulation for such applications as liquid hydrogen. This body is designed for minimum and uniform wall thickness, which enables rapid cool-down rates. The single-seated design allows good shut-off and can be provided with soft inserts for exceptionally tight shut-off. Note that the vacuum jacket is designed with a metal bellows to allow for mechanical tolerances or dimensional changes during temperature transients and has a provision for welding to a matching jacket around the adjacent piping.

**Eccentric Plug Rotary Globe Type**

The rotary globe valve (Figure 6.19ll) is mentioned here, because its design and performance combine features of conventional rotary valves with conventional globe valves. Compared to most rotary valves, the eccentric spherical segment plug valve has the advantage of lower torque requirements. The seating surface of the plug has the form of a spherical segment. The plug design makes exaggerated use of the offset center to obtain contact at closure without rubbing on the seat, like ball valves. It is capable of substantial seat contact loading for tight shut-off approaching that of conventional globe valves.

The flow characteristic approaches linear (Figure 6.19a). Changes in control characteristic can be accomplished with a cam in the positioner or by modifying the controller output signal. Capacity ($C_v$) is between that of a double-ported globe and a high-performance, double-offset butterfly valve. High-flow capacity is achieved with only moderate pressure recovery in the body, so the critical flow coefficient ($F_c$) is higher than that of a butterfly valve throughout its throttling range and therefore less likely to cavitate.

The valve is made in sizes from 1–16 in. (DN 25–400) in pressure Classes 150, 300, and 600 (PN 20, PN 50, PN 100). Flanged and flangeless versions are available in most sizes. Allowable operating pressure drops depend on the manufacturers’ designs, materials, and actuators. In most cases, the valves are rated for operating pressure differentials significantly less than the body’s maximum pressure rating, so it is necessary to consult the manufacturer’s data for specific limitations.

$C_v$ rangeability data are stated in ranges from 100:1 up to 160:1. However, these ratios are achievable in service only if the actuator and control system can control in the range of 1–5% open, which is possible but often not practical. From a practical control standpoint, assuming a control range from 5–95% open, the $C_v$ rangeability for eccentric rotary plugs is about 35:1 or lower, which is comparable with conventional globe valves.
Three-Way Valves

Three-way valves are a specialized double-seated globe valve configuration. There are two basic types. One is for mixing service, i.e., the combination of two fluid streams passing to a common outlet port (Figure 6.19mm).

The other is for diverting service, i.e., taking a common stream and splitting it into two outlet ports (Figure 6.19nn). The three-way design shown in Figure 6.19y uses an adapter to convert a conventional single-seated globe into mixing or diverting configurations.

A typical mixing valve application would be the blending of two different fluids to produce a specific outlet end product. A diverting valve might be used for switching a stream from one vessel to another vessel or for temperature control on a heat exchanger. In the latter, the valve would direct one portion of the flow through the exchanger, and the balance of the flow would bypass the exchanger. The relative split would provide the heat balance needed for temperature control.

The forces acting on the double-seated, three-way plug do not balance in the same way that a double-seated, two-way plug is balanced. This is because different pressure levels exist in each of the three flow channels. Also, there are different dynamic forces acting on each plug head. Therefore, these valves are not normally used in high-pressure drop service. The valve plugs are usually seat-guided and post- or stem-guided to maintain stability under fluctuating dynamic forces. Due to the larger size and piping complications, some users prefer to use two opposite-acting, two-way globe valves operating from one controller to do the same job as a three-way valve.

Lined and Thermoplastic Valves

For extremely corrosive services, high alloy metals such as Alloy 20, nickel, nickel alloys, titanium, and zirconium are often required where austenitic stainless steels are inadequate. However, special alloy valves are very expensive and the service life may still be limited by corrosion.

An alternative to special alloys could be the lined globe valve (Figure 6.19oo). The lined valve uses a carbon steel or stainless steel shell for retaining pressure, but the inside surfaces of the body and bonnet are bonded with a chemically inert or corrosion-resistant fluoroplastic, such as PFA or PTFE. These valves are commonly for 1 in. (DN 25) through 2 in. (DN 50) sizes with capacity from $C_v = 0.33$ to 45.

For very low $C_v$ flow capacities, the design shown in Figure 6.19pp is available in 1 in. size (25 mm) with trim selections covering a $C_v$ range from 0.001 to 1.0. These valve designs are limited to operating temperatures below 300–400°F (149–204°C) and pressure drops less than 125–250 PSI (8.5–17 bar). Lined valves are also available in various rotary valve types and pinch valves (see Section 6.20).

Conventional globe patterns and split-body designs can be molded entirely from structural thermoplastics for corrosive applications with low to moderate pressures and temperatures. Bodies can be molded in polyvinylidene fluoride (PVDF), polyvinyl chloride (PVC), polypropylene (PP), and other plastics. Allowable pressures and temperatures vary with material and body design.

Typically, PVDF is limited to 300 PSIG (21 bar) at 73°F (23°C) and 150 PSIG (10.3 bar) at 225°F (106°C). PVC has a limit of 300 PSIG (21 bar) at 73°F (23°C) and 150 PSIG (10.3 bar) at 140°F (60°C). Polypropylene can operate up to 300 PSIG (21 bar) at 73°F (23°C) and 150 PSIG (10.3 bar) at 175°F (79.4°C). End connections are available in Class 150 flanged,
flangeless (for clamping between pipe flanges with throughbolting), or threaded ends. Packing and gaskets are generally made of PTFE or perfluoroelastomer (e.g., Kalrez®) materials.

**VALVE CONNECTIONS**

Valve connections to adjacent piping can be categorized into four general types: 1) flanged, 2) welded, 3) threaded, and 4) clamped. Each style incorporates elements that contain pressure, bear piping loads, and seal the joint between the valve and piping.

As a general rule, valves smaller than 2 in. (DN 50) can use threaded connections, while sizes 2 in. (DN 50) and larger use flanged connections. In a few process systems where fugitive emissions or process leakage is not a problem (such as water systems), threaded connections up to size 4 in. (DN 100) have been used. Most applications require both ends of the valve to have identical connections, but on some vent and drain valves, the upstream port and the downstream port may require different sizes or types of connections. Typical end connections are discussed below.

**Flanged Ends**

Flanges are the most common valve connection to piping. Most countries and piping codes accept the flange design and ratings from the standard ASME B16.5, Pipe Flanges and Flanged Fittings commonly referred to as “ANSI” flanges (because the earlier standards were published by the American National Standards Institute). Some countries and applications use other flange standards, such as American Petroleum Institute (API) standard for oil production equipment and the International Standards Organization (ISO) ISO-7005 flanges (adopted from the German DIN standards).

These rating systems are different and are not interchangeable; they use different rating systems, bolting, gaskets, and flange dimensions. The ASME (or ANSI) flanges use a Pressure Class rating system (e.g., steel flanges are Class 150, Class 300, Class 400, Class 600, Class 900, Class 1500, and Class 2500). API flanges are designated by a nominal pressure system (e.g., 2,000 PSI, 3,000 PSI, 5,000 PSI, 10,000 PSI, 15,000 PSI, and 20,000 PSI). The ISO (and DIN) standards also use a nominal pressure or PN numbering with typical ratings PN 10, PN 16, PN 20, PN 40, PN 64, PN 100, PN 160, PN 250, PN 320, and PN 400, which indicate maximum nominal pressure in bar (1 bar = 14.504 PSI = 100 kPa).

Flanges may be flat face, raised face, ring-type joint (RTJ), tongue and groove, male and female, or other configuration to suit the application. Cast iron, ductile iron, and...
bronze are usually flat face; carbon steel and alloys are usually raised face; and above ANSI 600, the RTJ is fairly common.

Figure 6.19qq shows three common configurations of flanges: separable flange-raised face, integral flange-raised face, and integral flange-RTJ. Raised face and flat face flanges use gaskets from sheet stock, such as graphite or PTFE composites, or a spiral wound thin metal strip with graphite, PTFE, or other mineral filler between each metal winding. RTJ gaskets are oval or octagonal in cross-section made of any suitable metal softer than the flange.

Valves with separable (slip-on) flanges retain the flange on the valve body ends with two circular half-rings held in the body grooves. Separable flanges are used mainly on small sizes from NPS 1/2 in. up to 4 in. With separable end flanges, the body can be designed for an ANSI Class 600 rating and then adapted as needed with ANSI Class 150, 300, or 600 flanges.

Separable flanges are not wetted by the process, which permits less expensive carbon steel or stainless steel flanges to be used on high alloy valves. Separable flanged valves are easy to install with the mating piping, because the flanges can be rotated to fit mismatched line flange hole patterns. However, care must be taken during installation to prevent the valve from rotating in the line until the flange bolts are properly tightened.

Flangeless bodies (clamped between pipe flanges) are sometimes used in the small bar-stock bodies. While they permit lower cost where expensive alloys are involved, they require care with bolting, gasket, and piping alignment. The tie-rod bolting should be high tensile strength material, and the valve must be carefully centered to permit proper gasket sealing and loading. The longer the bolt studs are, the more they are affected by longitudinal thermal expansion differences with the valve body and piping, which can lead to gasket leakage in thermal shock or severe temperature cycling.

**Welded Ends**

Welded ends are not common in the chemical process industries, but they are generally recommended in power generation and other applications where high piping stresses or thermal shock conditions exist. They are also used in hazardous services when no leakage is allowed from gasketed joints. Socket-weld ends (Figure 6.19rr) are easy to align and may be used in small sizes of 2 in. (25 mm) or under.

Threaded connections with NPT (tapered pipe threads per ASME B1.20.1) threads are common on valve sizes 1 in. (DN 25) and smaller and are sometimes used on valves up to 2 in. (DN 50). Threaded connections are usually used in pressure ratings up to ANSI Class 600 (PN 100). The threaded connection normally consists of the valve body with female NPT threads; then the pipe with male NPT threads is screwed into the body end. Materials commonly used in
Control Valve Selection and Sizing

Threaded end valves are brass, bronze, and carbon steel. Stainless steel bodies usually do not have NPT threads, because they gall easily with stainless steel pipe. An antigalling thread sealant compound should be applied to the threads during installation to prevent leakage and seizing and to allow for future disassembly.

Threaded connections are not normally used with process valves because they can leak more easily, they are more difficult to make up in the piping, and they may corrode or gall together, making disassembly difficult. Threaded connections do not work well on corrosive fluids, because the corrosion attack is generally more severe in the threaded crevice, causing the threads to corrode together and making it difficult to disassemble. Accelerated corrosion in the threads also promotes leakage. Threaded joints also tend to loosen in services where the temperature fluctuates.

Threaded ends are not recommended for services with severe thermal shock or thermal cycling that occurs above 500°F (260°C) or below −50°F (−46°C). However, some small valves under size 2 in. (DN 50) are furnished with threaded end connections for utility services such as low-pressure steam, water, and gas. Where it is necessary, threaded end valves can be converted to flanges by welding a flange to a pipe nipple, threading it into the valve, and seal-welding the nipple to the body.

Special End Fittings

In very high pressures, usually above 5000 PSIG (345 MPa), some operating companies use proprietary fitting and flange designs. One widely used high-pressure connection design is the lens-ring-type fitting shown in Figure 6.19tt. This is a self-energizing type of seal; i.e., the lens-ring deforms to give a tighter seal with increase in-line pressure. (Further details are given in Section 6.1.)

In other high-pressure applications, special clamped fittings are very effective. One proprietary clamped fitting called the Grayloc fitting (developed by the Gray Tool Company) greatly reduces the bulk of the valve end as compared to the large high-pressure, bolted flanges. The Grayloc fitting utilizes a lens-ring-type seal, similar to one shown in Figure 6.19tt, but the special hub design is fastened together with a bolted clamp-type fitting instead of flanges. See Figure 6.19uu.

These fittings are also available in 10,000 and 15,000 PSIG (69 and 104 MPa) designs. The ASME Boiler and Pressure Vessel code permits the use of clamped connections and includes design rules in Section VIII, Division 1, Appendix 24.

For standards on globe valve end connections, see Table 6.19vv.

MATERIALS OF CONSTRUCTION

A valve body assembly is a pressure containment vessel. As such, design and material selection must follow guidelines of a pressure vessel code that is recognized by the country or state in which it will be operated. Some of the
prominent standards include the ASME Unfired Pressure Vessel Code (Section VIII and Section III), ASME B31.1, “Power Piping,” and ASME B31.3, “Process Piping.” Most other countries have similar standards, and the European Community has moved to harmonize and unify some of these standards under a European Pressure Equipment Directive (PED) 97/23/EC. Most of these codes recognize ASME B16.34, “Valves—Flanged, Threaded, and Welding End,” as an accepted standard for design, materials, and testing of valves.

The selection of proper materials for valves requires consideration of all factors related to the process fluid and operating conditions. This can include forces applied from actuators and piping, (wind and seismic loads, hoists and rigging, accidental loads), changes in process and ambient temperatures, and the erosive and corrosive potential of both the process fluid and the outside environment. The complex scope of material selection is outside the purpose of this text, but a few of the common globe valve materials are listed in Table 6.19ww with typical ASTM specifications and process applications.

### TABLE 6.19ww

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* Always use the current edition of any standard, unless governmental or construction specifications require otherwise.
### TABLE 6.19
Common Valve Body Materials, Specifications, and Applications

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<tr>
<td>316 SS</td>
<td>A351-CF8M</td>
<td>A182-F316</td>
<td>Class 4500</td>
<td>−425 (−254) to 1000 (538)</td>
<td>Same as 304, high temperature; fair resistance to pitting and crevice attack</td>
</tr>
<tr>
<td>316L SS</td>
<td>A351-CF3M</td>
<td>A182-F316L</td>
<td>Class 4500</td>
<td>−425 (−254) to 850 (454)</td>
<td>Same as 316, low to moderate temperature</td>
</tr>
<tr>
<td>316H SS</td>
<td>A351-CF10M</td>
<td>A182-F316H</td>
<td>Class 4500</td>
<td>−325 (−198) to 1500 (816)</td>
<td>Same as 316, high temperature, creep resistant</td>
</tr>
<tr>
<td>Alloy 20</td>
<td>A351-CN7M</td>
<td>A182-F20</td>
<td>Class 4500</td>
<td>−325 (−198) to 600 (316)</td>
<td>Sulfuric acid, organic acids, hydroxides, nonhalogenated organic chemicals</td>
</tr>
<tr>
<td>Bronze</td>
<td>B61 (C92200)</td>
<td>n/a</td>
<td>B16.24, Class 300</td>
<td>−325 (−198) to 400 (204)</td>
<td>Steam, fresh and chloride water, oxygen</td>
</tr>
<tr>
<td>Aluminum-Bronze</td>
<td>B148-C95200</td>
<td>n/a</td>
<td>B16.24, Class 2500</td>
<td>−425 (−254) to 600 (316)</td>
<td>Brine; fresh, brackish, and salt water; chlorides</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>A216-WCB</td>
<td>A105</td>
<td>Class 4500</td>
<td>−20 (−28) to 800 (427)</td>
<td>Neutral and alkaline waters, steam, dilute caustic, hydrocarbons</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>A216-WCC</td>
<td>A350-LF3</td>
<td>Class 4500</td>
<td>−20 (−28) to 800 (427)</td>
<td>Neutral and alkaline waters, steam, dilute caustic, hydrocarbons</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>A126-A</td>
<td>n/a</td>
<td>B16.1, 400 PSIG</td>
<td>−20 (−28) to 406 (208)</td>
<td>Neutral and alkaline waters, low-pressure steam, dilute caustic</td>
</tr>
<tr>
<td>Chrome-Moly WC9</td>
<td>A217- WC9</td>
<td>A182-F22</td>
<td>Class 4500</td>
<td>−20 (−28) to 1200 (649)</td>
<td>Mildly corrosive, high temperature, resists erosion by steam and flashing water</td>
</tr>
<tr>
<td>Chrome-Moly C12A</td>
<td>A217-C12A</td>
<td>A182-F91</td>
<td>Class 4500</td>
<td>−20 (−28) to 1200 (649)</td>
<td>Mildly corrosive, high temperature, resists erosion by steam and flashing water</td>
</tr>
<tr>
<td>Duplex SS 22% Cr</td>
<td>A351/A395-CD3MN (J92205)</td>
<td>A182-F51</td>
<td>Class 4500</td>
<td>−20 (−28) to 600 (316)</td>
<td>Corrosive, brine, salt water, polluted water, acid-chlorides, good against pitting and crevice attack</td>
</tr>
<tr>
<td>Duplex SS 25% Cr</td>
<td>A351-CD4MCu</td>
<td>A182-F61</td>
<td>Class 4500</td>
<td>−20 (−28) to 600 (316)</td>
<td>Corrosive, brine, salt water, polluted water, acid-chlorides, better against pitting and crevice attack</td>
</tr>
<tr>
<td>Hastelloy B/B2</td>
<td>A494-N-7M</td>
<td>B335-N10001/ N10665</td>
<td>Class 4500</td>
<td>−325 (−198) to 800 (427)</td>
<td>Superior in hydrochloric acid up to boiling, hydrofluoric acid, strong reducing chemicals</td>
</tr>
<tr>
<td>Hastelloy C/C-276</td>
<td>A494-CW-6M</td>
<td>B564-N10276</td>
<td>Class 4500</td>
<td>−325 (−198) to 1250 (677)</td>
<td>Oxidizing and reducing acids, hypochlorite, chlorine, seawater, acid-chlorides, brines, excellent against pitting and crevice attack</td>
</tr>
</tbody>
</table>

(continued)
### Table 6.19ww (Continued)

<table>
<thead>
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<tbody>
<tr>
<td>Inconel 600</td>
<td>A494-CY-40 Class 2</td>
<td>B564-N06600</td>
<td>Class 4500</td>
<td>−325 (−198) to 1200 (649)</td>
<td>Caustics with chlorides or sulfides, mild oxidizers, excellent resistance to chloride SCC</td>
</tr>
<tr>
<td>Low Temp CS</td>
<td>A352-LCB</td>
<td>A350-LF3</td>
<td>Class 4500</td>
<td>LCB: −50 (−46) to 650 (343)</td>
<td>Neutral and alkaline waters, steam, dilute caustic, hydrocarbons, low-temperature impact strength</td>
</tr>
<tr>
<td>Low Temp CS</td>
<td>A352-LCC</td>
<td>A350-LF3</td>
<td>Class 4500</td>
<td>LCC: −50 (−46) to 650 (343)</td>
<td>Neutral and alkaline waters, steam, dilute caustic, hydrocarbons, low-temperature impact strength</td>
</tr>
<tr>
<td>Monel</td>
<td>A494-M35-1</td>
<td>B564-N04400</td>
<td>Class 4500</td>
<td>−325 to 900 (482)</td>
<td>Hydrofluoric acid, caustic, seawater, brine; not for oxidizing service</td>
</tr>
<tr>
<td>Nickel</td>
<td>A494-CZ-100</td>
<td>B160/B564-N02200</td>
<td>Class 4500</td>
<td>−325 to 600 (316)</td>
<td>Hot concentrated caustics, SCC resistant in chlorinated organics; not for oxidizing service</td>
</tr>
<tr>
<td>Titanium</td>
<td>B367-C-3</td>
<td>B381-F-3</td>
<td>Class 2500</td>
<td>−75 to 600 (316)</td>
<td>Better than Hastelloys for pitting and crevice attack, wet chlorine, dilute HCl, bleaches, brines; not for dry chlorine or fluorides</td>
</tr>
<tr>
<td>Zirconium 705</td>
<td>B752-705C/Flowtherm HT</td>
<td>B550-R60705</td>
<td>Class 2500</td>
<td>−75 to 700 (371)</td>
<td>Dry chlorine, hot hydrochloric, - sulfuric, nitric, and acetic acids; not for fluorides or wet chlorine</td>
</tr>
</tbody>
</table>

*Temperature limits based on ASME B16.34 and ASME B31.3. Courtesy of Flowserve Corporation

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### Reference


### Bibliography