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### Revision Memo

**12/99** Added pages 7-12 containing specific application guidelines for troublesome control valve applications.



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## SCOPE

This section covers those aspects of control valves that are considered and decided during process design. This includes valve type, when it is important from a process design aspect, assigning of pressure drop to the valve, and the application of control valves to some common and troublesome services. Comprehensive information on control valve sizing is also given.

Descriptive and explanatory material is included for the benefit of those not completely familiar with control valves.

## REFERENCES

### DESIGN PRACTICES

Other Sections of [Section XII](#)

[Section X](#), Pumps

[Section XIV](#), Fluid Flow

### INTERNATIONAL PRACTICES

[IP 1-1-1](#) Symbols and Abbreviations for Drawings

[IP 3-6-2](#) Piping at Control Valve Stations

[IP 10-1-1](#) Heavy Duty Centrifugal Pumps

[IP 10-1-2](#) Medium Duty Centrifugal Pumps

[IP 15-9-1](#) Control Valves

### OTHER LITERATURE

ANSI/FCI 70-2 1991, Control Valve Seat Leakage

ANSI/ISA S75.01 1985, Flow Equations for Sizing Control Valves

## BACKGROUND AND DEFINITIONS

### HYDRAULIC CIRCUIT

A hydraulic circuit is an assembly of process equipment, piping and valves that interconnect inlet and outlet reference pressure points. In most cases the inlet and outlet points are storage tanks, process vessels or process pumps.

### CONTROL VALVE

A control valve is an engineered variable flow restriction. The input signal to the control valve is the output signal from a controller. The control valve is constructed such that the stem lift (plug position) is proportional to the input signal. The relationship between stem lift (plug position) and area open for flow is called the valve characteristic (discussed below). This relationship is important in determining the suitability of a given valve for a given service, and therefore receives much attention from control engineers and valve manufacturers.

**Figure 1** (see next page) shows the basic construction of the main types of valves which are used, with a synopsis of their uses. These valves are more completely described and discussed under **CONTROL VALVE TYPES AND THEIR APPLICATIONS**. **Figure 10** shows the names of the various parts of a typical control valve.

### VALVE OPERATOR

The valve operator is the device used to move the stem. The most common operator is a spring-loaded diaphragm. It is actuated with compressed air, whether the controller itself is pneumatic or electronic (see **Figure 10**). Other operators are pistons (air or hydraulic), electric motor and air motor.

### VALVE CHARACTERISTICS

The relationship between the position of a valve plug (or stem lift) and the *area open for flow* is the valve characteristic. With a constant  $\Delta P$  across the valve this relationship would also hold for flow rate.

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## BACKGROUND AND DEFINITIONS (Cont)

In process services, however, the valve  $\Delta P$  is seldom a constant. It varies with flow rate due to the influence of flow rate on such items as pipe friction and pump head. It varies with time due to such items as exchanger fouling. Thus, the flow-lift relationship in actual service (also called the *effective valve characteristic*) is a function of the entire system of which the valve is a part. **Figure 2**, below, illustrates how control valve  $\Delta P$  of a typical system varies with system flow rate. In this example, the static head in the system has been arbitrarily chosen at 30% of the pump head at design flow rate.

The valve characteristics of the two most commonly discussed types of valves, known as linear and equal percentage, are shown in **Figure 3**. This figure also illustrates the "deterioration" of the flow-lift relationship as the assigned  $\Delta P$  across the valve (as a % of total system friction at design flow rate) is reduced from 100% to 5%.

Note that a theoretical equal percentage curve does not pass through zero flow at zero lift. Actual valves, however, are made tight seating. Thus, the lower end of the theoretical curve is adjusted to pass through zero flow at zero lift.

Because of this, the *International Practices* (formally *Basic Practices*) call for the equal percentage characteristic to be supplied. A major exception, for 3-way valves, is discussed under 3-way valve applications.

## RANGEABILITY

Each control valve type (and size) has a minimum area open to flow, below which operation is not sufficiently consistent or precise for satisfactory control. The rangeability of the valve is defined as this minimum divided into the area open to flow at full stem lift.

However, actual control valve rangeability is limited by the following factors:

- Control valves are specified with 80% open at maximum flow, to insure it is in a controlling position.
- The specified valve capacity will rarely match a commercially available size, since the next larger valve is frequently supplied.
- Erosion and corrosion in service will cause a deterioration of the valve's rangeability.

See **Table 6**, Control Valve Rangeability, for a listing of typical values.

If a process rangeability greater than 10 is required, it may be necessary to go into more detail on the actual valve type, size and service to be sure that the process rangeability can be covered by one valve. Another approach, especially if the process rangeability is well above 10, is to use two valves in parallel; the smaller one for small flow rates. The selection of which valve to use should be by manual operation of block valves as it would be expected that the large valve would leak a large percentage of the small valve's capacity.

## CONTROL VALVE TYPES AND APPLICATIONS

In this section the more common types of control valves are described, their limitations and capabilities are discussed and their more normal applications are covered. Valve positioners and their uses are described.

### CONVENTIONAL DOUBLE-SEATED AND SINGLE-SEATED VALVES

The most common control valve is the conventional double-seated valve, the basic structure of which is shown under Background and Definitions. The purpose of using the somewhat complicated double seat construction is to achieve and approximately "balanced" design. The term "balanced" comes from the feature that the forces at one seat caused by the  $\Delta P$  and the stream velocity are approximately balanced by similar and opposite forces at the other seat.

For sizes under one inch, normal machining tolerances are too large to give suitable rangeability, characteristic and leakage for the double-seat design. The single-seat design is then used. Because of the small size, the forces at the one seat (unbalanced because of the absence of the second seat) are sufficiently reduced so that they are no longer of great importance. In these small sizes, the usual construction is to machine flutes or variable depth V-grooves in a solid plug. In the smaller sizes (below a nominal 1/4 in.), with flow coefficients ( $C_v$  below 1), the area open to flow is so small that normal dirt and scale can cause troublesome plugging. In these sizes, consideration should be given to the use of a strainer ahead of the valve.

A double-seated valve, with the seats freshly ground-in, and tested at the factory on water at room temperature, will commonly meet a leakage specification of 1/2% of full open flow. In refinery service at higher (or lower) temperatures (giving differential expansion), connected to lines that can transmit forces to the body (causing distortion), and possibly handling corrosive and erosive fluids, the leakage is not predictable but can be expected to be several times greater than the 1/2%. Thus, when tight shut-off is important, such as on a furnace fuel cut-off valve, the single-seat design is the more logical choice.

The unbalanced forces in the single seat design, especially in the larger sizes, may require a piston type actuator. This will be established during the procurement phase of a project, and is therefore not a primary responsibility of the process designer.

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## BACKGROUND AND DEFINITIONS (Cont)

However, he should be aware that the piston actuator causes some complication and added cost in achieving the fail-safe action (see comments under Fail-Safe Position) that is so simple with the standard spring-loaded diaphragm. He should therefore keep the use of single-seated valves in the larger sizes to a minimum.

### CAGE VALVES

The cage valve has large guiding surfaces and close tolerances, which eliminate the need for some of the special materials used in the conventional double and single-seated designs. The unbalance problem of the cage valve, inherent in its single-seat construction, is overcome by bringing the downstream pressure above the piston. Leakage, rangeability and characteristics are comparable to those of conventional double-seated valves.

### BUTTERFLY VALVES

The original automatic control applications of butterfly valves emphasized their similarity to dampers. Therefore, they were used in large air or gas lines with a low  $\Delta P$ , where limited rangeability was needed and where tight shutoff was not needed. Subsequent developments in their mechanical design, triggered somewhat by process requirements for higher capacities than could be obtained with the largest practicable double-seated conventional valves (about 12 in. size), have made them usable for a wider range of service conditions.

Their flow-lift (rotation) characteristic is between those of linear and equal percentage valves. Their leakage (not well established) should be considered as somewhat greater than that of a double-seated valve, and their torque requirements limit the services for which the conventional spring-loaded diaphragm actuator can be used. Thus, they are seldom used where a conventional double-seated valve is practicable. An 8-in. butterfly valve, 60 degrees open, has about the capacity of a 10-in. conventional double-seated valve; and it is at about this size that the butterfly valve begins to be the first choice. The butterfly valve must now also compete with the ball valve.

Services that frequently use butterfly valves include:

- Suction lines to centrifugal gas compressors and air blowers.
- Outlet lines from water disengaging drums.
- As a substitute for a large (or unavailable) 3-way (two butterfly valves are needed) in gas lines through and by-passing heat exchangers. Special needs of this service are covered under 3-way valves.

When used in a service characterized by (1) large lines, (2) low velocities and (3) a need for minimum  $\Delta P$  for the wide open case (maximum throughput and *no control* except in the down direction), the manifolding and relative sizes of valve and line are important, inasmuch as the pressure loss through two reducers will commonly exceed the  $\Delta P$  of the valve. Note the discussion of this point under Block and Bypass Valves.

### BALL VALVES

The ball valve was originally offered as a competitor for the gate valve; i.e., primarily for services where it would be either open or shut, rather than throttling. Subsequently, control valve manufacturers developed it further for throttling service, to make it suitable for use as a control valve, while retaining the characteristics of good shut-off and high capacity. Several variations of the eccentric rotary valve design are available, the Masoneilan Camflex being a good example. The flow-lift (rotation) characteristic of the shaped ball valve approximates that of the equal percentage valve.

The trend in control valve services involving high flow rates and large line sizes is to use ball valves in place of butterfly valves, because ball valves have less leakage in the closed position and less unbalanced internal forces, while still offering similar high capacity. For high pressure drop services, the ball valve is superior to the butterfly valve. The ball valve is also finding use in place of conventional valves, especially in high flow rate applications, where its smaller size for a given service makes it economical.

The ball valve design is widely used in industries where flow of slurries must be controlled. In high  $\Delta P$  gas services, the ball valve loses some of its capacity advantage, relative to that of other valves. The comments under Butterfly Valves concerning manifolding and relative line and valve sizes apply also to ball valves.

### THREE-WAY VALVES

There are two types of 3-way valves, "double-seated" and "single-seated." The basic structures of these valves are shown in **Figure 1**. The terms "double-seated" and "single-seated," as applied to the two types of 3-way valves, are somewhat confusing, since each type of valve has two seats. However, the body of the 3-way valve labeled "Double Seat-Diverting" (see **Figure 1**) is adapted from the body of a conventional double-seated valve (called a 2-way valve when the discussion covers both conventional and 3-way valves). Similarly, the body of the 3-way valve labeled "Single Seat-Mixing" is adapted from the body of a conventional single-seated valve (also called a 2-way valve to distinguish it from a 3-way valve in discussions covering both).

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## BACKGROUND AND DEFINITIONS (Cont)

The main application of 3-way valves in refineries and chemical plants is for control of heat transfer, as illustrated in **Figure 4**.

Note that in **Figure 4** each valve is shown in its preferred location, with the flow through each port tending to open that port. If the valve were installed in such a location that the flow would tend to close the port, there would be a danger of the valve slamming onto its seat, with resulting line vibration, especially in the larger sizes so often used in our designs.

This action is caused by the following phenomenon: as a valve moves toward its seat, the reduction in flow rate caused by this movement lowers the downstream pressure, thereby increasing the  $\Delta P$  across the valve. This increased  $\Delta P$  results in an increased force acting to move the valve toward the seat. In addition, with the compressibility of air in the diaphragm chamber in the valve actuator, the added forces causes an additional valve movement toward the seat. With all of these forces tending to close the valve, the valve closes too far (or all the way), and the controller is then forced to open the valve again. This action - reaction process continues as the valve slams onto the seat, then opens too far, and repeats the operation. This phenomenon is sometimes called the "bath tub stopper effect," as a hand-held stopper will clearly illustrate.

It is possible to prevent such valve action by use of a sufficiently large operator or by eliminating the air diaphragm. However, unless the valve and actuator forces are reviewed in detail for a specific application, the valve type for its location should be specified per **Figure 4**.

Of the two types of 3-way valves shown in **Figure 1**, the single seat-mixing type is most widely available world-wide and is therefore usually preferred over the double seated-diverting type valve for reasons of procurement.

As an exception to the above rule, the double-seated type in diverting service is usually called for when a large density change takes place in the exchanger, which would cause problems in  $\Delta P$  and rangeability in a 3-way valve in mixing service. The magnitude of this change in density at which the double-seated valve in diverting service should be specified, rather than the single-seat mixing type, is not well established. Partial vaporization of a liquid stream is considered sufficient reason for specifying the double-seated diverting type. On the other hand, partial condensation of a gas stream does not have as pronounced an effect on density, and partial condensation of as much as 1/3 of the process fluid is considered acceptable for the single-seated mixing type valve.

In this 3-way valve service, a linear flow-stem lift characteristic is required to insure a constant total area open for flow in the circuit for all valve stem positions. This linear characteristic is required by the International Practices.

Where the valve size required is greater than 10 inches, which is commonly the case in Powerformer effluent (hot gas) circuits, it is necessary to use two 2-way valves instead of one 3-way valve. These 2-way valves are usually butterfly valves, with one valve opening as the other valve closes, giving the same control result as one 3-way valve. See **Figure 5**.

From the safety aspect, it should be noted that in a 3-way valve the total area open for flow is equivalent to having one port always open. The arrangement with two 2-way valves, on the other hand, can conceivably have both valves shut at the same time. This may result in the need for additional safety valves.

Special requirements of butterfly valves, which are the most common valves in this service, are:

- The characteristic, not being linear, must be made equivalent to linear. A characterizing cam in the valve positioner is a common method of accomplishing this. This is called for in the International Practices.
- The two valves should be the same size. This gives the same result as a 3-way valve, in which the two ports are always of equal size. Experience shows that it is a mistake to use a much smaller valve in the bypass line of the basis that a small percentage of the total stream is expected to be bypassed; clean tubes and slight shifts in temperatures and heat duties have resulted in such designs being inoperable. Despite this, since the bypass valve  $\Delta P$  is 3 times as great as that of the exchanger valve,\* and since large valves are involved, it is acceptable, as an exception to the general rule, to use a bypass valve one size smaller than the exchanger valve.

\*See SELECTION OF CONTROL VALVE DIFFERENTIAL PRESSURE where for 3-way valves an exchanger port  $\Delta P$  of 50% of the exchanger pressure drop is called for, thus giving the bypass port a  $\Delta P$  of 150% of the exchanger  $\Delta P$ .

## OTHER TYPES OF CONTROL VALVES

**Angle valves** (see **Figure 6**), sometimes called angle-venturi valves, are used for service conditions where the direct jetting of the stream from the plug-seat opening into the exit pipe is advantageous. Such services include:

- Streams containing solids which would erode conventional valves, if the jet were to impinge on valve surfaces. Cat plant slurries and fluids having coking tendencies are examples.

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## BACKGROUND AND DEFINITIONS (Cont)

Note that the stream flowing past the plug and jetting into the outlet line gives the "bathtub stopper effect" mentioned above under THREE-WAY VALVES. This situation is called "flow tends to close valve." To prevent this situation from causing valve chatter, line vibration and unsatisfactory control, one can specify a stronger-than-normal operator or the internal design of the valve can be changed to provide some balancing force. This would be done during procurement. Where angle valves are discussed in this subsection, the expression "flow tends to close valve" is included, so that this point should not be overlooked. Angle valves can be used with flow in the reverse direction, so that flow tends to open the valve; however, this is done only in unusual services.

**Saunders Valves**, sometimes called diaphragm valves, are well known but infrequently used. Their main usefulness is for handling some slurries and corrosive fluids. Their services conditions are rather limited, because the diaphragm will withstand temperatures only up to the low 200's (°F), pressures up to about 50 psig and only moderate pressure drops. The allowable conditions should be confirmed from available suppliers, before this type of valve is included in a design.

## VALVE POSITIONERS

In the discussion up to this point, it has been implied that a control valve always responds to a control signal and takes a position proportional to it. Several phenomena prevent the valve from behaving exactly in this manner. Ordinary friction on the valve stem in the stuffing box results in a hysteresis effect (between opposite directions of movement of the valve stem) equivalent to about 1/8 to 1/2 psi on the diaphragm. This corresponds to about 1 to 4% of the 3 to 15 psig operating pressure range of a standard diaphragm - spring assembly. Internal velocity forces commonly amount to another several percent of the force available for the diaphragm - spring assembly, and these forces change with flow rate. Some valves are particularly bad in this respect; butterfly valves and single-seated valves are examples.

Because of these inconsistencies and hysteresis, and because such valve action would result in unsatisfactory control in many applications, valve positioners were developed. The function of a valve positioner is to force the control valve to take a position proportional to the control signal. In principle, it is a position controller with the control signal being its set point. The International Practices require valve positioners to be supplied for all control valves except those with a simple on-off operation.

**Applications of Valve Positioners** - Valve positioners are also useful for such requirements as "split-ranging" and "linearizing." Proper linkage adjustments for this purpose are usually available in normal models. In split-ranging, the valve takes full stroke for half the range of the control signal. Thus, one valve operates between 3 and 9 psig of the control signal, and a second valve operates between 9 and 15 psig. The valves themselves are standard control valves with a diaphragm pressure operating range of 3 to 15 psig.

An example of a split range valve application is suction pressure control for a compressor, where the 3 to 9 psig portion of the control signal range causes the compressor to be progressively loaded (suction valve or speed governor setting), while the 9 to 15 psig portion of the control signal range causes a flare release valve to open progressively.

An example of linearizing is the use of valve positioners with two butterfly valves through and around a heat exchanger, as described under 3-way valves. In this case, the motion balance is made non-linear, usually with a cam in order to compensate for the inherently non-linear characteristic of the valve, to result in overall linear/relationship between control signal and valve opening.

## SPECIFIC CONTROL VALVE APPLICATIONS

This section is intended to provide suggestions on appropriate choices of the style, type and specific items to be included for process services that have proven over time to be particularly troublesome in service. The cases outlined below should be used as guidelines since no new application reflects exactly the same characteristics as the ones identified in this listing. Engineering judgment should be applied as appropriate when making final selections for this equipment. The best guideline is that proven and well documented experience should be used.

## DEFINITIONS

**Low Recovery Valve** is one that does not recover very much pressure at the outlet compared to the differential pressure across the valve itself. Examples are cage valves and globe valves with flow upwards against the seat.

**High Recovery Valve** is one that does recover a significant amount of pressure at the outlet compared to the differential pressure across the valve itself. An example is a streamlined angle valve with flow in the side and out the bottom.

**Erosion/Corrosion** damage is the damage to valve bodies and internal trim due to combined effects of straight erosive material removal and corrosion of internal surfaces. This effect can increase loss of material in the range of orders of magnitude when compared to corrosion or erosion alone.

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## SPECIFIC CONTROL VALVE APPLICATIONS (Cont)

### APPLICATION LISTING

#### 1. Boiler Feed-water or Waste Heat Boiler Supply

**Fluid:** Water

##### Typical Operating Conditions

Valve Inlet Pressure: 300 - 2500 psig (2068 - 17237 kPa gauge) based on feedwater supply pump discharge pressure

Valve Outlet Pressure: atmospheric up to header or drum pressure plus ten percent more

Temperature: 100 - 200°F (37 - 93 °C)

##### Most Likely Problem with Application

Valves tend to be destroyed on startup if they are selected to handle relatively low differential pressure at drum operating pressures but used to handle full pump pressure when initially filling the steam drum and encountering high differential pressure.

##### Problem Solving Approaches in Control Valve Selection

Utilize two separate valves, one for initial filling and one for running. Alternatively use a single high pressure globe style angle valves with flow direction under the seat to out the side outlet. An example of this type of valve is the Fisher DBAQ.

##### Sizing

Liquid sizing methods should be used for normal operation (Method 1). Single compound (water) Flashing methods should be used for steam drum filling (Method 7).

#### 2. Sulfur Vapor to Eductor (Sulfur Pit Application)

**Fluid:** Sweep Air from Sulfur Pit

##### Typical Operating Conditions

Valve Inlet Pressure: 3 in. (76 mm) of water vacuum

Valve Outlet Pressure: 14 in. (355 mm) of water vacuum

Temperature: 300°F (149°C)

##### Most Likely Problem with Application

Plugging of the valve with condensed sulfur vapor forming solid sulfur deposits is the main problem.

##### Problem Solving Approaches in Control Valve Selection

Line size rotary valves should be used. Either body jacketing or well installed (heavy) steam tracing should be used. Butterfly, eccentric or in some cases segmented ball valves should be used.

##### Sizing

Method 2 should be used

#### 3. Liquid Sulfur to Storage

**Fluid:** Liquid Sulfur

##### Typical Operating Conditions

Valve Inlet Pressure: 30 psig (206 kPa gauge)

Valve Outlet Pressure: 20 psig (138 kPa gauge)

Temperature: 300°F (149°C)

##### Most Likely Problem with Application

Plugging of the valve with solid sulfur is the main problem.

##### Problem Solving Approaches in Control Valve Selection

Line size rotary valves should be used. Full body jacketing must be used. Butterfly, eccentric or in some cases segmented ball valves should be used.

##### Sizing

Liquid sizing methods should be used (Method 1).

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|                                                                                  | <b>PROPRIETARY INFORMATION</b> - For Authorized Company Use Only |  | <b>Section</b><br>XII-F       | <b>Page</b><br>9 of 29 |
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### SPECIFIC CONTROL VALVE APPLICATIONS (Cont)

#### 4. Hydrofluoric Acid Service

**Fluid:** Various dilutions of HF

##### Typical Operating Conditions

Wide ranging and not clearly definable

##### Most Likely Problem with Application

Loss of containment in valve body due to incorrect body material, selection or process condition change and foreign material present due to body testing at delivery.

##### Problem Solving Approaches in Control Valve Selection

Carbon steel body should be used for service to about 300°F (149°C). Initial corrosion of the surface creates a protective barrier to limit further corrosion. Abrasion or water can remove this barrier. Monel body should be used services above 300°F (149°C). Since the consequences of process fluid leakage are highly significant detailed attention must be given to adequate body inspection including materials verification. Valve acceptance testing should not employ water as a test fluid due to the negative effects of having water inadvertently introduced into the valve as a leftover from tests at the factory. Voids of all types must be avoided in either body or internal trim parts.

##### Sizing

Method 1 is used in most cases.

#### 5. Slurry Service - FCCU Bottoms, FCCU Pump Around

**Fluid:** Heavy hydrocarbon mixtures with solids present (1% to 15% wt range variable particle size 10 to 200 micron)

##### Typical Operating Conditions

Valve Inlet Pressure: 80 psig (550 kPa gauge)

Valve Outlet Pressure: 20 psig (138 kPa gauge)

Temperature: 500 - 600°F (260 - 315°C)

##### Most Likely Problem with Application

Erosion of valve body, internals and downstream piping are the main to be dealt with in this application.

##### Problem Solving Approaches in Control Valve Selection

Stream lined angle valves with flow entering the side and exit the bottom are the best choice for this service. Hard materials for trim application are also a plus. Downstream piping must straight. Free of elbows and obstructions for a length of 20 inside pipe diameters.

Where hydrostatic pressure is not sufficient to employ streamlined angle valves, full ball rotary valves can be used. Materials used for the ball must be hard. The same suggestions for downstream piping as outlined above should be used.

##### Sizing

Method 1 is used in most cases.

#### 6. Reactor Hot Separator Level Control Letdown Valve

**Fluid:** High temperature hydrocarbon mixture from Reactor effluent usually the result of hydrogen and hydrocarbon materials reacted in the presence of catalyst to form lighter materials.

##### Typical Operating Conditions

Inlet Pressure: typical 1000 - 2500 psig (6895 - 17237 kPa gauge)

Outlet Pressure: typical 200 psig (1379 kPa gauge)

Temperature: 850°F (455°C)

##### Most Likely Problem with Application

Erosion damage to the valve, flashing/cavitation conditions leading to incorrect valve sizing are the primary problems.

##### Problem Solving Approaches in Control Valve Selection

There are two approaches in handling this problem. The first is to use a streamlined angle valve where particulate is thought to be significant (above 1% by wt). Additional purging of the control valve bonnet with gas oil (high boiling range) should be considered to maintain plug to guide bushing freedom from coke build-up.

An alternate, where particulate levels are low, is to use a low pressure recovery cage valve. Straight bore cage types with holes that are not counter bored should be used. Downstream piping should be straight from the outlet of the valve for a distance of 20 diameters.