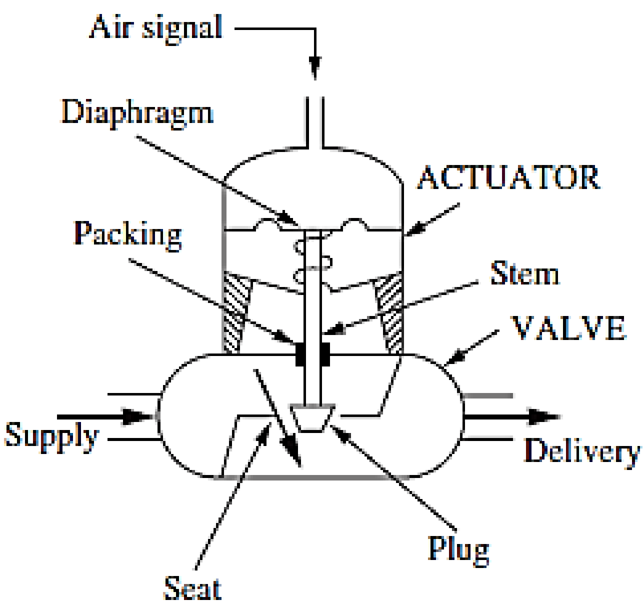
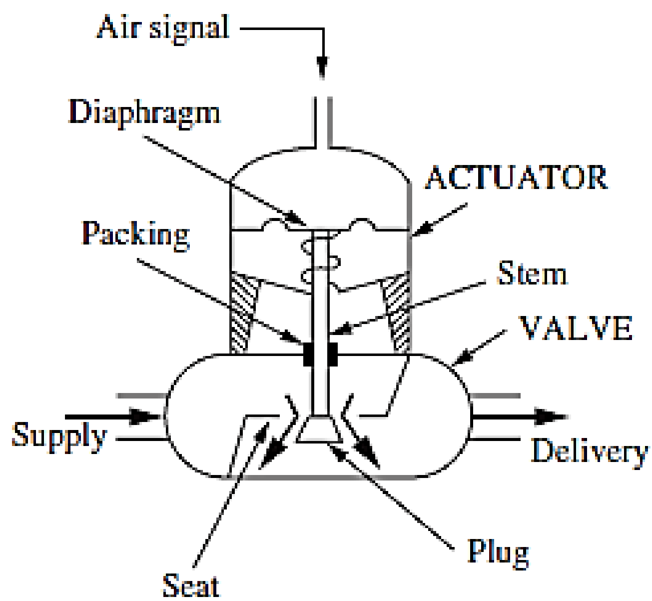
CONTROL VALVES

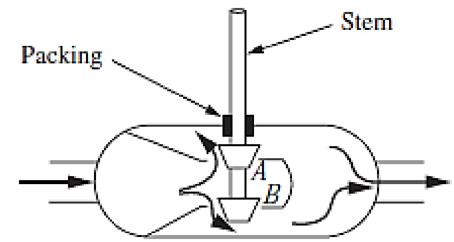
Chapter 19



Air-to-Close Valve



Air-to-Open Valve



The valve shown in Fig. is single-seated, meaning the valve contains one plug with one seating surface. For a single-seated valve, the plug must open against the full pressure drop across the valve.

If the pressure drop is large, this means that a larger, more expensive actuator will be needed.

To overcome this problem, valves are also constructed with double seating as shown in Fig.

In this type valve, two plugs are attached to the valve stem, and each one has a seat.

CONTROL VALVE CONSTRUCTION

- For the control valve shown in Fig. , an increase in signal pressure above the diaphragm exerts a force on the diaphragm and back plate, which causes the stem to move down;
- this causes the cross-sectional area for flow between the plug and the seat to decrease, thereby reducing or throttling the flow.
- Such valve action as shown in Fig. is called air-to-close (AC) action.
- The reverse action, air-to-open (AO), can be accomplished by designing the actuator so that pressure is applied to the underside of the diaphragm, for which case an increase in pressure to the valve raises the stem.
- An alternate method to reverse the valve action is to leave the actuator as shown in Fig. and to invert the plug on the stem and place it under the valve seat.
- In general, selection of the type of valve (AO or AC) is made based on safety considerations.
- We would like the valve to fail in a safe position for the process in the event of a loss of air pressure.

- The flow pattern through the valve is designed so that the pressure drop across the seat at *A* tends to open the plug and the pressure drop across the seat at *B* tends to close the plug.
- This counterbalancing of forces on the plugs reduces the effort needed to open the valve with the result that a smaller, less expensive actuator is needed.
- In a double-seated valve, it is difficult to have tight shutoff.
- If one plug has tight closure, there is usually a small gap between the other plug and its seat.
- For this reason, single-seated valves are recommended if the valve is required to be shut tight.
- In many processes, the valve is used for throttling flow and is never expected to operate near its shutoff position.
- For these conditions, the fact that the valve has a small leakage at shutoff position does not create a problem.

VALVE SIZING

- To specify the size of a valve in terms of its capacity, the following equation is used:

$$q = C_v f(x) \sqrt{\frac{\Delta p_{\text{valve}}}{\text{sg}}}$$

where
q = flow rate, gal/min
$f(x)$ = fraction of maximum flow (= 1 for fully open)
x = fractional stem position (i.e., fraction open)
Δp_{valve} = pressure drop across the valve, psi
sg = specific gravity of fluid at stream temperature relative to water; for water sg = 1
C_v = factor associated with capacity of valve

Equation applies to the flow of an incompressible, non-flashing fluid through the valve.
Manufacturers rate the size of a valve in terms of the factor C_v .
Sometimes C_v is defined as the flow (gal/min) of a fluid of unit specific gravity (water) through a fully open valve, across which a pressure drop of 1.0 psi exists.
This verbal definition is, of course, obtained directly from Eq. by letting
$f(x) = 1$, $\Delta p_{\text{valve}} = 1$, and $s_g = 1$.
Equation is based on the well-known Bernoulli equation for determining the pressure drop across valves and resistances.

- It is important to emphasize that *Cv* must be
- Since so many valves in use are rated in terms of C_v ,Eq practical importance; however, some industries now are defining a valve coefficient *Kv* defined by the equation

$$q = K_v \sqrt{\frac{\Delta p_{\text{valve}}}{\text{sg}}}$$

where q = flow rate, m^3/h

Δp_{valve} = pressure drop across valve, kg_f/cm^2

sg = specific gravity of fluid relative to water

The relation between K_v and C_v is

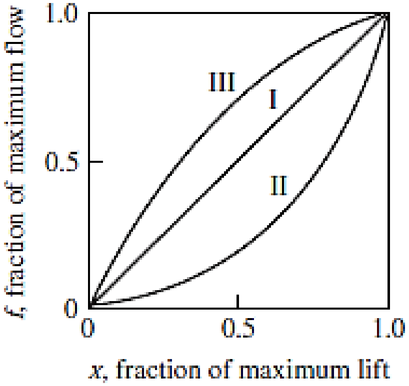
$$K_v = 0.856 C_v$$

Manufacturers of valves provide brochures, nomographs, and computer programs for sizing valves for use with gases and steam.

- For a sliding stem and plug type of control valve, the value of *Cv* is roughly equal to the square of the pipe size multiplied by 10.
- Using this rule, a 3-in control valve should have a *C v* of about 90, with units corresponding to those of Eq. This implies the capacity of the fully open valve is 90 gal/min with a pressure drop of 1 psi.

VALVE CHARACTERISTICS

- The function of a control valve is to vary the flow of fluid through the valve by means of a change of pressure to the valve top.
- The relation between the flow through the valve and the valve stem position (or *lift*) is called the ***valve characteristic,*** which can be conveniently described by means of a graph as shown in Fig.
- Three types of characteristics are illustrated.



Inherent valve characteristics (pressure drop across valve is constant).
I: Linear,
II: increasing sensitivity (e.g., equal-percentage valve),
III: decreasing sensitivity (e.g., square root valve).

- In general, the flow through a control valve for a specific fluid at a given temperature can be expressed as

$$q = f_1(L, p_0, p_1)$$

where q = volumetric flow rate
L = valve stem position (or lift)
p_0 = upstream pressure
p_1 = downstream pressure

The inherent valve characteristic is determined for fixed values of p_0 and p_1, for which

$$q = f_2(L)$$

or, in other words, the flow is a function of the valve stem position.
For convenience, let

$$f = \frac{q}{q_{max}} \qquad \text{and} \qquad x = \frac{L}{L_{max}}$$

where q_{max} = maximum flow when valve is fully open (stem is at its maximum lift L_{max})
x = fraction of maximum lift
f = fraction of maximum flow

In general, *f* will be a function of *x*, which we will denote as $f(x)$.
Equation may be written as

$$f\left(\frac{L}{L_{max}}\right) = f(x) = \frac{q}{q_{max}}$$

- Mathematically, sensitivity may be written

$$\text{Sensitivity} = \frac{df}{dx}$$

In terms of valve characteristics, valves can be divided into three types:

- **Decreasing sensitivity** (square root or quick-opening),
  For the decreasing sensitivity type, the sensitivity (or slope) decreases with increasing flow.
- **Linear**, increasing sensitivity (equal-percentage).
  For the linear type, the sensitivity is constant and the characteristic curve is a straight line.
- **Increasing sensitivity**, the sensitivity increases with flow.

Valve characteristic curves, can be obtained experimentally for any valve by measuring the flow through the valve as a function of lift (or valve-top pressure) under conditions of constant upstream and downstream pressures.

Two types of valves that are widely used are the linear valve and the equal percentage valve.

Linear Valves

- The linear valve is one for which the sensitivity is constant and the relation between flow and lift is linear.
- For the linear valve, the mathematical relationship is

$$\frac{df}{dx} = \alpha \qquad\qquad \int_0^1 df = \int_0^1 \alpha\, dx$$

Integrating this equation and inserting limits give

$$\alpha = 1$$

$$\boxed{f(x) = x \qquad \text{linear valve}}$$

Equal-Percentage Valves

For the equal-percentage valve, the defining equation is

$$\frac{df}{dx} = \beta f$$

where *b* is constant. Integration of this equation gives

$$\int_{f_0}^{f} \frac{df}{f} = \int_0^x \beta\, dx \qquad\qquad \ln\frac{f}{f_0} = \beta x$$

- where f_0 is the flow at $x = 0$. Rearranging gives

$$f = f_0 e^{\beta x}$$

The term β can be expressed in terms of f_0 by inserting $f = 1$ at $x = 1$ into
The result is

$$\beta = \ln \frac{1}{f_0}$$

$$f = f_0 e^{x \ln(1/f_0)} = f_0 e^{\ln(1/f_0)^x} = f_0 e^{\ln(f_0)^{-x}} = f_0 f_0^{-x} = f_0^{1-x}$$

$$f = \alpha^{x-1} \qquad \text{equal-percentage valve}$$

where $\alpha = 1/f_0$ is a constant.

- Shows that a plot of f versus x on semi log coordinates gives a straight line.
- A convenient way to determine if a valve is of the equal-percentage type is to plot the flow versus lift on semi log coordinates.
- The basis for calling the valve characteristic equal percentage can be seen by rearranging into the form

$$\frac{df}{f} = \beta\, dx \qquad \text{or} \qquad \frac{\Delta f}{f} = \beta\, \Delta x$$

- In this form it can be seen that an equal fractional (or percentage) change in flow $\Delta f / f$ occurs for a specified increment of change in stem position *x,* regardless of where the change in stem position occurs along the characteristic curve.
- In integrating the flow was assumed to be f_0 at $x = 0$.
- Mathematically this is necessary, because f_0 cannot be taken as zero at $x = 0$ because the term on the left side of Eq. becomes infinite.

  In practice, there may be some leakage (hence $f_0 \neq 0$) when the stem is at its lowest position for a double-seated valve or for a valve in which the plug and seat have become worn.
- To express the range over which an equal-percentage valve will follow the equal percentage characteristic, the term *rangeability* is used.
- Rangeability is defined as the ratio of maximum flow to minimum controllable flow over which the valve characteristic is followed.

$$\text{Rangeability} = \frac{f(x)_{\text{max}}}{f(x)_{\text{min,controllable}}}$$

- For example, if f_0 is 0.02, the rangeability is 50.
- It is not uncommon for a control valve to have a rangeability as high as 50.

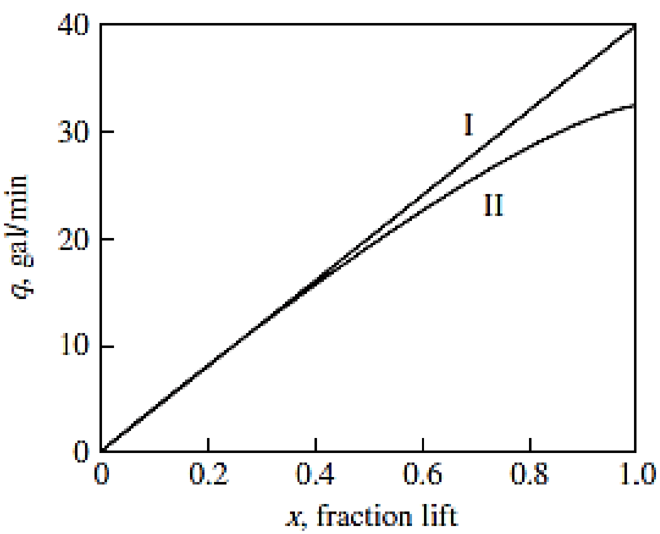
In practice, the ideal characteristics for linear and equal-percentage valves are only approximated by commercially available valves.
These discrepancies cause no difficulty because the inherent characteristics are changed considerably when the valve is installed in a line having resistance to flow, a situation that usually prevails in practice.
The inherent valve characteristics are shown in Table.
In the next section, the effect of line loss on the effective valve characteristic will be discussed.

Inherent valve characteristics

Valve type	Sensitivity $\frac{df}{dx}$	Relationship
Linear	Constant	$f(x) = x$
Equal-percentage	Increasing	$f(x) = \alpha^{x-1}$
Square root or quick-opening	Decreasing	$f(x) = \sqrt{x}$

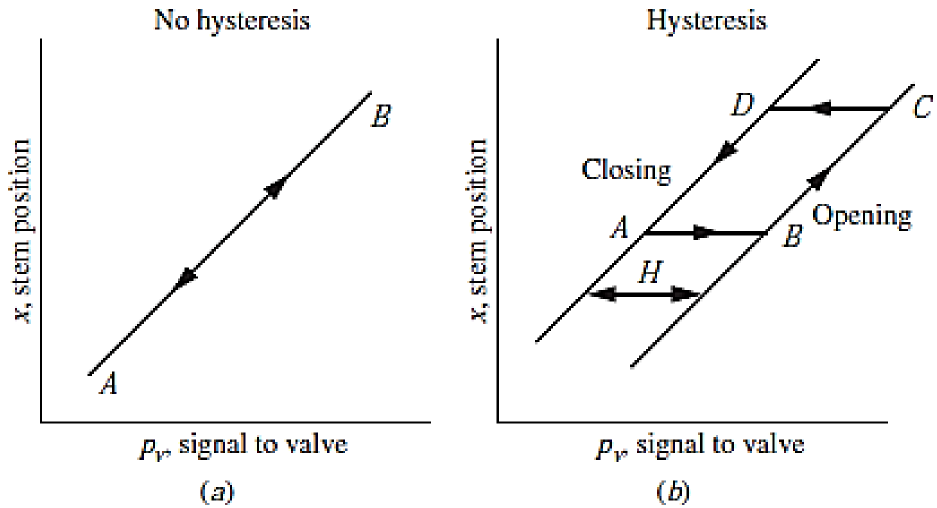
Effective Valve Characteristic

- When a valve is placed in a line that offers resistance to flow, the inherent characteristic of the valve will be altered.
- The relation between flow and stem position (or valve-top pressure) for a valve installed in a process line is called the *effective valve characteristic.*
- A rule often followed in industrial application of control valves is that the pressure drop across the wide-open valve should be greater than 25 percent of the pressure drop across the closed valve.
- A valve not selected according to this rule will lose its effectiveness to control at high flow rates.



Effect of line loss on control valve
I: No pressure drop in supply line to valve,
II: pressure drop present in supply line to valve.

Control valve Hysteresis



The operation of an ideal air-to-open control valve is shown in Fig. *a.*

Any given air pressure signal to the valve results in a unique stem position *x.*

The friction in the packing and guiding surfaces of a control valve often causes a control valve to exhibit hysteresis, as shown in Fig. *b.*

When the air pressure increases to the valve top, the stem position increases along the lower curve.

When the air pressure decreases, the stem position decreases along the upper curve.

At the moment the air pressure signal reverses, the stem position stays in the last position until the dead band *H* is exceeded, after which the pressure begins to decrease or increase along the paths shown by the arrows.

If the valve is subjected to a slow periodic variation in pressure, a typical path taken by the stem position is shown by the closed curve *ABCDA* in Fig. *b.*