

Both of these valve characteristics are described by the equations shown on Figure 19.2(b). Note that these equations only strictly apply for a constant pressure drop across the regulating valve.

Example 19.1

A valve on a coolant stream to a heat exchanger is operating with the valve stem position at 50% of full scale. You are asked to find what the maximum flowrate would be if the valve were opened all of the way (at the same pressure drop). What is an appropriate response given the information in Figure 19.2(b)?

The flow would increase by 100% or more. The exact increase depends upon the design of the valve.

From Figure 19.2(b) we see that a linear valve (Curve 3 on Figure 19.2(b)) has the smallest increase, from $v/v_{max} = 0.5$ to $v/v_{max} = 1$ (100% increase). For constant percent valve 1 (Curve 1), the increase is from $v/v_{max} = 0.3$ to $v/v_{max} = 1.0$ (233%), and for constant percent valve 2 (Curve 2), the increase is from $v/v_{max} = 0.17$ to $v/v_{max} = 1.0$ (488%). The flow increases in the range of 100 to 488%. The problem of predicting the flow from the valve position is even more complex because there usually exists some form of hysteresis. Thus, the pressure drop over the valve changes not only with flowrate of fluid through the valve but also with the direction of change, that is, whether the flow was last increased or decreased.

Most valves installed are constant percentage valves, and there is no generally accepted standard design. Such valves offer fast response at high flowrates and fine control at low flowrates. The prediction of the disk position needed to give the required flowrate would be difficult using the performance diagram in Figure 19.2. In practice, the flowrate is controlled by observing a measured flowrate while changing the valve stem position. The valve position continues to be adjusted until the desired flowrate is achieved. This approach forms the basis of the "feedback control system" used for many automatic flow control schemes and discussed further in Section 19.5.

In practice, automatic control systems change valve positions to obtain a desired flowrate. The valve position is modified by installing a servomotor in place of the valve handle or by installing a pneumatic diaphragm on the valve stem.

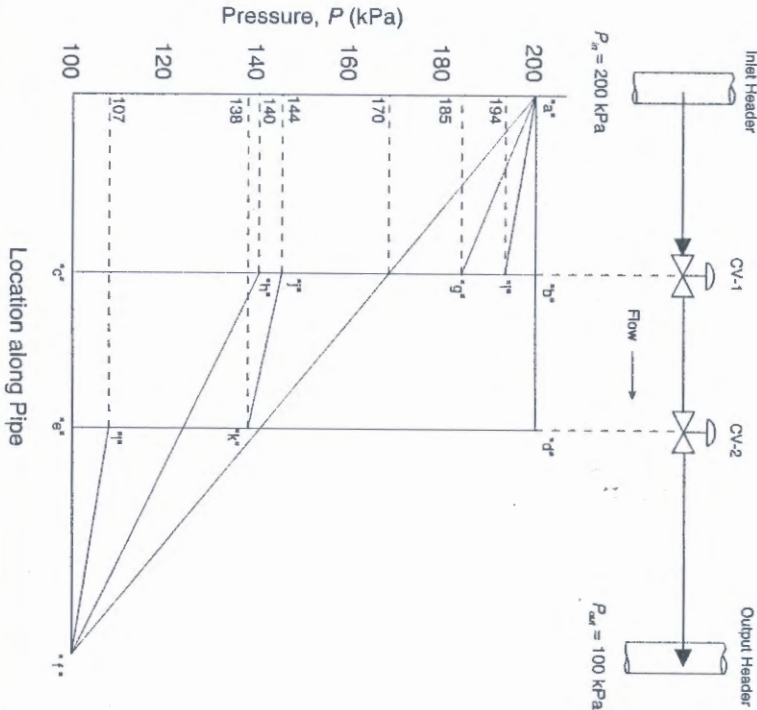
9.3 REGULATING FLOWRATES AND PRESSURES

The rate equation describing the flowrate of a stream is given by

Flowrate = Driving force for flow / Resistance to flow (19.1)

The driving force for flow is proportional to ΔP (pressure head), and the resistance to flow is proportional to friction. The resistance to flow can be varied by opening or closing valves placed in the flow path.

Figure 19.4 shows a pipe installed between a high pressure header, containing a liquid, and a low pressure header. The pressure difference, ΔP, between these two headers is the driving force for flow. Two valves are shown in the line, and when these valves are fully open they offer little resistance to flow. The resistance in the transport line is due to frictional losses in the pipe. The flowrate is at



Profile	CV-1	CV-2	Flow (kmol/h)	ΔP (friction) (kPa)	P (before CV-1) (kPa)	ΔP over CV-1 (kPa)	ΔP over CV-2 (kPa)
1: a-f	open	open	100	100	170	0	0
2: a-b-c-f	closed	open	0	0	200	100	0
3: a-d-e-f	open	closed	0	55	185	0	100
4: a-g-h-f	partially open	partially open	74	74	185	45	0
5: a-i-j-k-l-f	partially open	partially open	44	19	194	50	31

Figure 19.4 Pressure Profiles in a Pipe Containing Two Valves

a maximum value when the valves are fully open. When either valve in the line is fully closed, the resistance to flow is infinite, and the flowrate is zero. The valves may be adjusted to provide flows between these limits.

Plotted below the diagram in Figure 19.4 are pressure profiles for various valve settings. The pressure (in kPa) is plotted on the y -axis, and we note that for the example shown $P_{in} = 200$ kPa and $P_{out} = 100$ kPa. The x -axis indicates the relative location of the valves in the process. In addition, Figure 19.4 includes a table that provides information on the flowrate, pressure drop due to pipe friction, and the pressure before valve CV-1. The resistance in the pipe is proportional to the square of the flowrate, which is the case for fully developed turbulent flow (see Chapter 15).

Profile 1 (a–f) shows the pressure profile with both valves fully open. It gives the maximum flowrate, 100 kmol/h, possible for this system. Profile 2 (a–b–c–f) is for the case when CV-1 is fully closed and CV-2 is fully open. For this case, the flow is zero, and all the pressure drop occurs over CV-1. The pressure upstream of CV-1 is P_{in} (200 kPa), and the downstream pressure is P_{out} (100 kPa). Profile 3 (a–d–e–f) is the case for when CV-2 is fully closed and CV-1 is fully open. The pressure upstream of CV-2 is P_{in} (200 kPa), the downstream pressure is also equal to P_{out} (100 kPa), and the flowrate is zero.

For Profile 4 (a–g–h–f), valve CV-1 is partially open, providing a pressure drop of 45 kPa, and valve CV-2 is fully open. The pressure drop across CV-1 ($\Delta P_{s,4}$) can be varied by changing the valve position of CV-1. The greater the pressure drop across CV-1, the lower the pressure drop available to overcome friction and the lower the flowrate. In Profile 4, the flow is reduced to 74% of the maximum flow. For every setting of CV-1 (with CV-2 fully open), a unique value for pressure and flowrate is obtained.

Either pressure or flowrate, but not both simultaneously, can be regulated by altering the setting of a single valve.

Two valves are required to regulate simultaneously both the pressure and flowrate of a stream. The total system resistance (pipe and valves) determines the flowrate. The ratio of valve resistances establishes the pressure profile through the process. This is shown in Profile 5 (a–i–j–k–l–f), where 50% of the available pressure drop is taken over CV-1 and 31% is taken over CV-2. The resistance ratio, for the two valves, is $31/50 = 1.61$, the flow is 44% of the maximum flow, and the pressure upstream of CV-1 is 194 kPa. To illustrate this concept further, we consider the following example:

Example 19.2

Consider the flow diagram in Figure 19.4. At design conditions, we have 70% of the total available pressure drop across the two control valves, and the flowrate of fluid at these

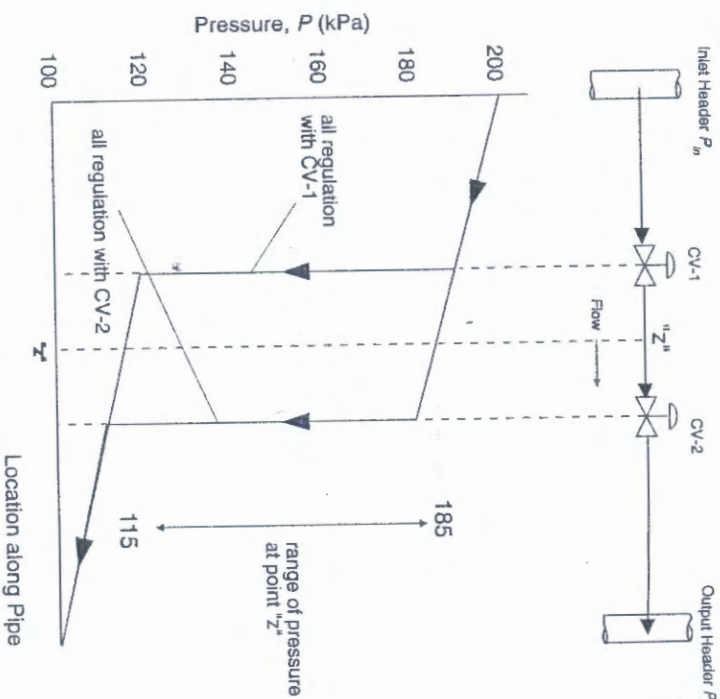


Figure E19.2 Range of Pressure at Point “z” for Design Flow

conditions is given as $100 \text{ } [30/100]^{1/3} = 54.8 \text{ kmol/h}$. If we consider a point, “z,” midway between the two valves, over what range can the pressure at point “z” be varied at the design flowrate?

To solve this problem we consider the two extreme cases: (1) CV-1 regulates the flow and CV-2 is fully open, and (2) CV-2 regulates the flow and CV-1 is fully open. Both these situations are illustrated in Figure E19.2. From the diagram, we can see that the pressure at point “z” may vary between 185 kPa (CV-1 fully open) and 115 kPa (CV-2 fully open). Note that all possible combinations of partially open valves give pressures at point “z” between these two limits.

19.4 THE MEASUREMENT OF PROCESS VARIABLES

The process variables that are most commonly measured and used to regulate process performance are:

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