

# ON SELECTING APPROPRIATE CONTROL VALVES FOR PIPEWORK SYSTEMS

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While the subject of selecting appropriate centrifugal pumps for a given pipework system is treated reasonably well in many textbooks,<sup>[1,2]</sup> there is usually little or no discussion of selection parameters for control valves. Even specialized books on control<sup>[3,4]</sup> tend to concentrate on control theory rather than on what some would regard as a more mundane, but nevertheless necessary, practical understanding of the interaction between control valve characteristics and the dynamics of the system into which it is installed. Although Seborg, *et al.*,<sup>[4]</sup> covers much of this material, it is largely embedded within an example in a short section on final control elements.

At Edinburgh University, in the second year of our four-year undergraduate course, selection procedures for both centrifugal pumps and control valves are taught within the same "Plant Engineering" course. Two aims of the course are to introduce practical aspects of chemical plant control and to give the students a practical understanding of the interactions between pumps, control valves, and the pipework systems in which they are installed.

## SELECTING CENTRIFUGAL PUMPS

For pipework systems (excluding control valves) a pump with a suitable characteristic can be chosen by reference to the system curve (plot of pressure drop through system,

expressed in terms of fluid head,  $h$ , versus flowrate,  $Q$ ), as shown in Figure 1. The pump should be chosen so that 1) the operating point is close to the most efficient operation of the pump, and 2) the net positive suction head (NPSH) required by the pump is less than the calculated available net positive suction head.

The students are also taught about other design criteria for the pump, such as materials of construction, types of impeller, or the possibility of increasing throughput by mounting a larger impeller in the pump (provided that the pump casing is large enough). To ensure that the students have an understanding of the significance of the operating point on the graph, they are asked to consider what will happen to the operating point upon changing 1) the static delivery head, 2) the resistance to flow in the system (obtained, for example, by partially closing a valve), and 3) the pump characteristic.

## SELECTING CONTROL VALVE SIZE AND TRIM

In the following discussion, numerical values quoted are based on the assumption that a wide range of controllable flowrates is required, with significant turndown ratios (rangeability).

When designing a pipework system including a control valve, the same graphical technique can be used as shown in Figure 1. The pump should usually be chosen, however, so that 1) the operating point without a control valve in place corresponds to a flowrate about 40-50% greater than the normal operating flowrate, and 2) there is a reasonable head difference between the characteristic curve and the system curve at the normal operating flowrate (usually about 5m or more). This will allow both for efficient control around the normal operating point and for moderate controlled increase in the flow.

From the plot of system curve and the chosen pump char-



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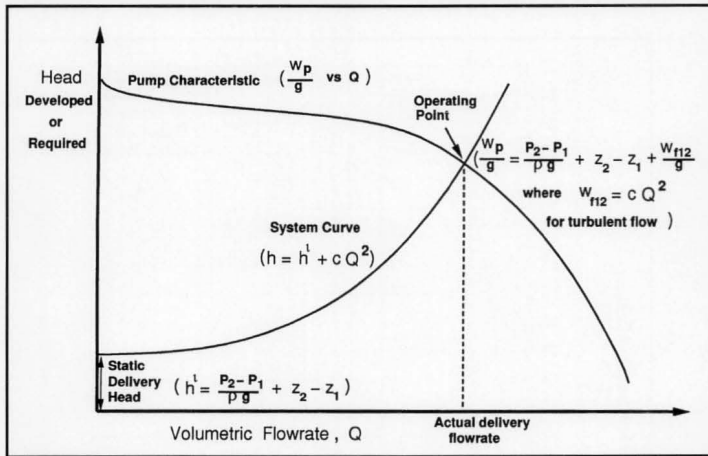


Figure 1. Calculation of operating flowrate in a pumped system.

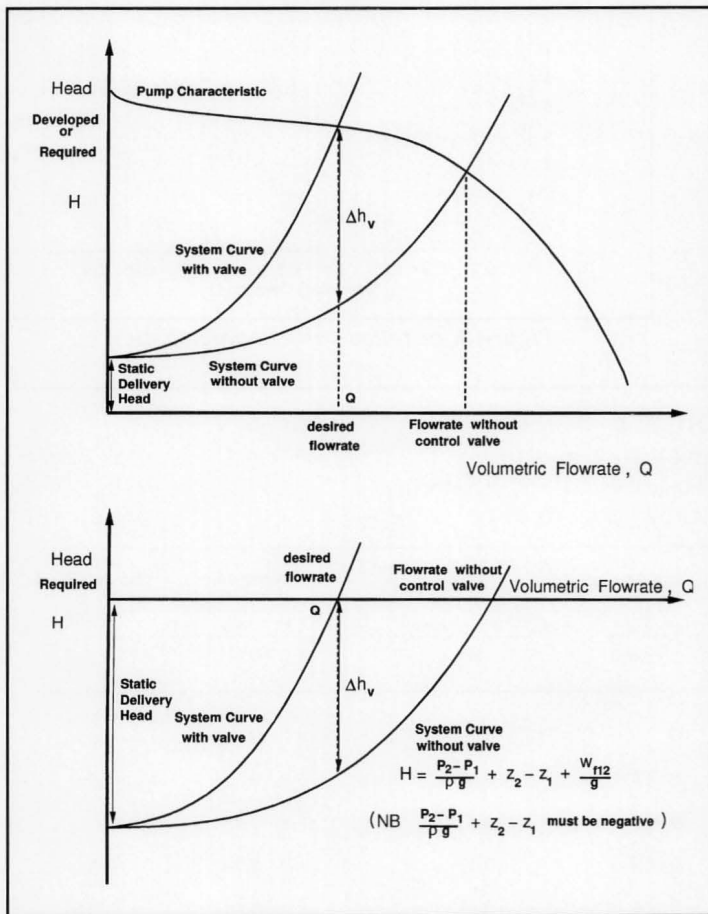


Figure 2. Calculation of  $\Delta h_v$  for pumped and gravity-fed systems.

acteristic, it is then possible to determine the head loss across the control valve,  $\Delta h_v$ , at a full range of flowrates. The same procedure can be used even if the flow is gravity driven rather than being pumped (as shown in Figure 2).

For control valves, we must first specify the maximum volumetric discharge coefficient or valve constant,  $C_{v,max}$ . The operating volumetric discharge coefficient,  $C_v$ , is a function of the fractional stem position,  $x$ , such that

$$C_v = f(x)C_{v,max}$$

The value of  $x$  lies between 0 (fully closed) where  $f(x) = 0$  and 1 (fully open) where  $f(x) = 1$ . It should be noted that the mathematical functions describing valve characteristics do not always fit these limits. Since

$$C_v = \frac{Q}{\sqrt{\rho_w g \Delta h_v}}$$

if  $\Delta h_v$  is independent of flowrate, then a plot of  $Q$  vs.  $x$  is identical in form to  $f(x)$  vs.  $x$ —the inherent valve characteristic.

By plotting head loss,  $\Delta h_v$ , versus flowrate, an initial choice of valve trim can be made; if  $\Delta h_v$  remains almost constant over the desired controllable range, a linear trim should be chosen, whereas if  $\Delta h_v$  drops as the flowrate increases, a valve trim giving increasing sensitivity (such as a hyperbolic or equal percentage trim) may be more suitable. Decreasing sensitivity trims, such as the square root trim, are usually reserved for situations where rapid opening is required.

Several criteria can be used to estimate an appropriate maximum volumetric discharge coefficient  $C_{v,max}$ . If  $\Delta h_v$  is independent of flowrate, then the variation of  $Q$  with  $x$  will be linear and a linear trim, such that  $f(x) = x$ , should be chosen, with  $C_{v,max}$  set so that the normal operating,  $C_v$ , is around 60-70% of  $C_{v,max}$ . For most systems, however,  $\Delta h_v$  varies with  $Q$ —in which case it is better to select an upper limit for the flowrate. This, for example, could be approximately 40% greater than the normal flowrate, providing that there is still sufficient head available to accommodate the pressure drop across the valve. We can then evaluate  $C_{v,max}$  directly as

$$\frac{Q_{\max}}{\sqrt{\rho_w g \Delta h_v}}$$

where  $\Delta h_v$  is determined at  $Q_{\max}$ . These values of  $C_{v,\max}$  are best chosen using typical manufacturers' data and should in any case be assessed to ensure that they correspond to a valve with a diameter less than that of the pipework.

Values of  $C_v$  can be evaluated at a range of flowrates between zero and  $Q_{\max}$ . Using the chosen value of  $C_{v,\max}$ , values of  $f(x)$  ( $=C_v/C_{v,\max}$ ) can then be tabulated against  $Q$ . By rearranging the expression for  $f(x)$  for each type of valve to give  $x$  in terms of  $f(x)$ , the values of  $x$  for each trim can be tabulated against  $Q$ . An example using four types of trim is given in Table 1. (Note that where the mathematical function,  $f(x)$ , leads to values of  $x$  outside the range of 0 to 1, the appropriate limit of  $x$  has been entered in the table.)

By plotting  $Q$  vs.  $x$  for each type of trim (see Figure 3), the valve trim giving the most linear response over the required controllable range can be chosen. For the example given, the hyperbolic trim gives the greatest sensitivity with an almost linear response over the widest range of flowrates (5-25  $\text{m}^3/\text{h}$ ). At this stage, the chosen value of  $C_{v,\max}$  may be altered with the last stage in the procedure being repeated, if necessary, until a good linear response is obtained. In the example above (Table 1), it is clear that the maximum controllable flowrate and hence  $C_{v,\max}$  chosen is too close to the operating capability of the pump with no valve present. It would be better here to reduce the maximum controllable flowrate to, say, 20  $\text{m}^3/\text{h}$  or to use a larger pump, which would allow a valve with a considerably lower  $C_{v,\max}$  (say, 22  $\text{m}^3/\text{h} \cdot \text{bar}^{-1/2}$ ) and perhaps a linear trim to be used.

For a rapid choice of valve trim, inspection of the graphs showing both the pump characteristic and the system curve excluding the control valve will yield useful information.

Figure 4 shows the regions of flowrate for which linear and equal percentage trims would be applicable in four systems with quite different dynamics.

## OTHER SPECIFICATIONS

Apart from the choice of materials for the valve parts, including the gland and the valve seat, the students are

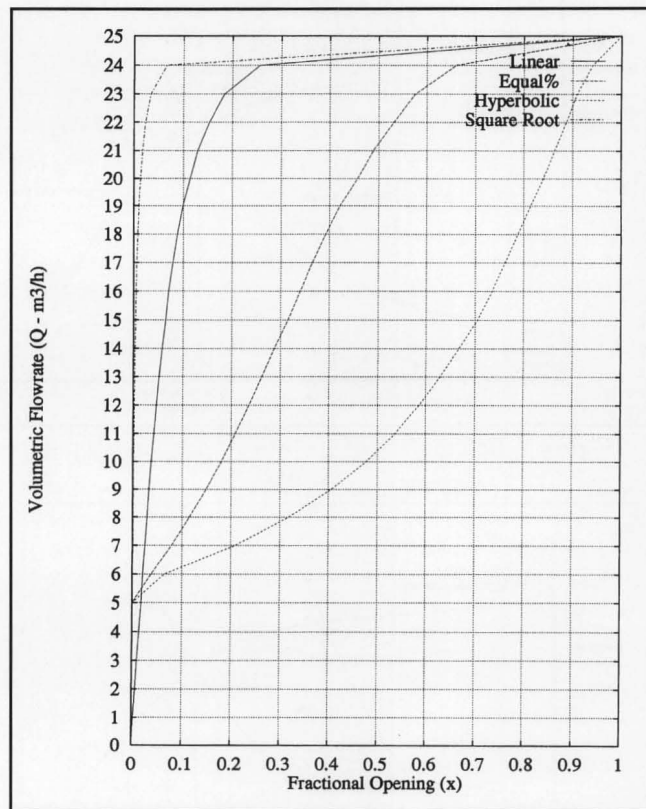


Figure 3. Installed valve characteristics.

TABLE 1

Sample Data for Control Valve Trim Selection

$C_{v,\max} = 113 \text{ m}^3/\text{h} \cdot \text{bar}^{-1/2}$ ;  $a = 4$  (equal%);  $\alpha = 50$  (hyperbolic)

Q	$\Delta h_v$	$C_v$	$f(x)$	Linear	Equal %	Hyperbolic	Square Root
$\text{m}^3/\text{h}$	m	$\text{m}^3/\text{h} \cdot \text{bar}^{-1/2}$		$x = \frac{C_v}{C_{v,\max}}$	$\frac{\ln(C_v/C_{v,\max})}{a} + 1$	$\frac{\alpha - (C_{v,\max}/C_v)}{\alpha - 1}$	$\left(\frac{C_v}{C_{v,\max}}\right)^2$
0	68	0	0	0	0	0	0
5	65	1.98	0.018	0.018	0.00	0	0
10	56.5	4.25	0.037	0.037	0.18	0.48	0
15	43	7.30	0.065	0.065	0.32	0.70	0
20	24.5	12.9	0.114	0.114	0.45	0.84	0.01
25	0.5	113	1.0	1.0	1.0	1.0	1.0

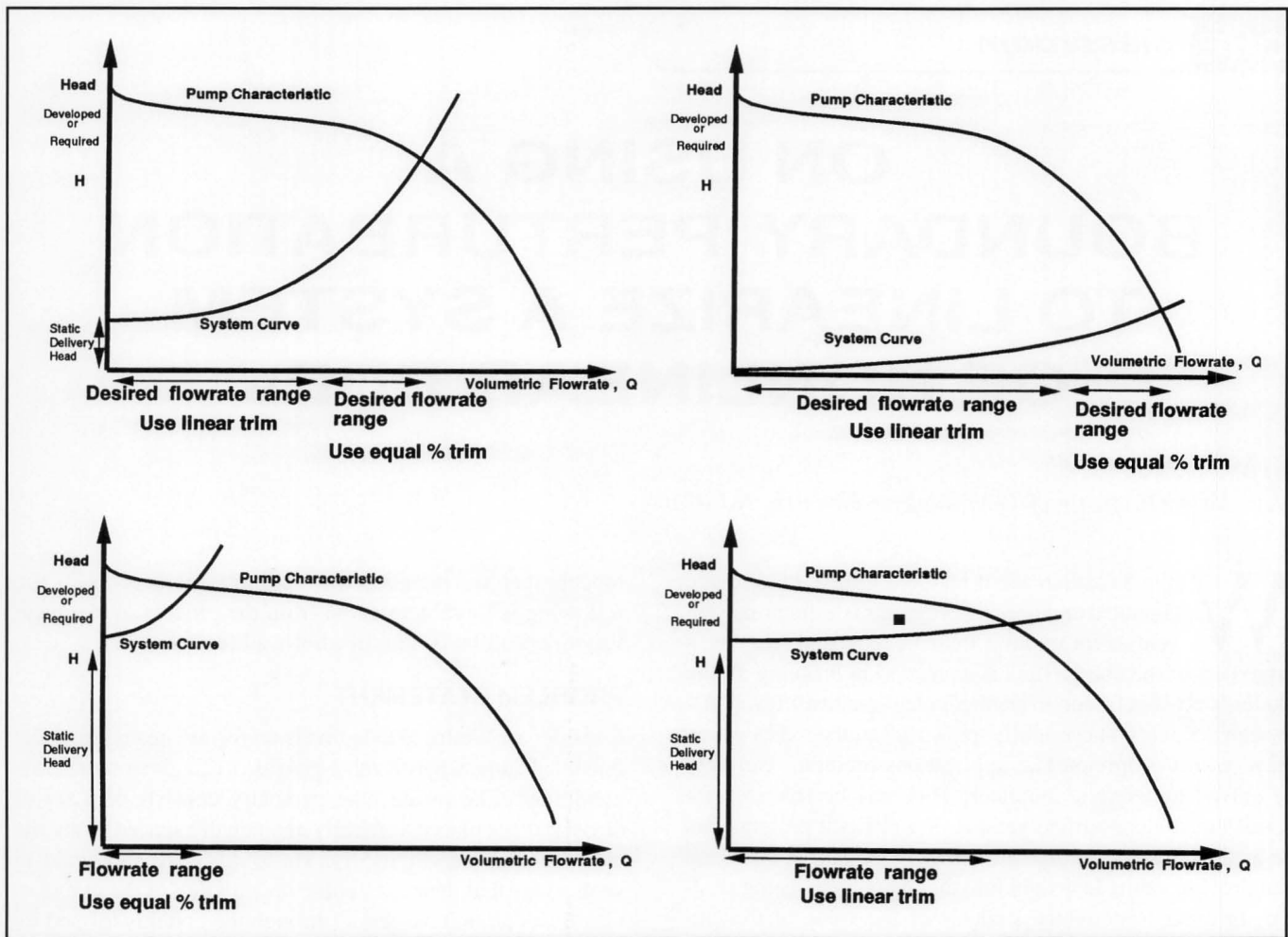


Figure 4. Choice between linear and increasing sensitivity valve trims.

taught why it is important to specify the position of the valve on control failure and to be able to identify which way a valve will fail by inspection. For high pressure drops in the flow, the use of double ported valves or valve positioners is also discussed.

## ASSESSMENT

Due to the practical nature of this topic and the range of design assumptions to be made, examination questions of the length traditionally set in the second year of our course would not adequately test the students' abilities. Instead, the students are given a hand-in exercise to complete that counts towards the degree assessment. This normally involves a given pipework system and the pump characteristic, with the students being asked to evaluate the available net positive suction head and the operating flowrate without a control valve in place. A selection of four or more control valves having different valve constants and trims are then given and the students are asked to select the most appropriate valve for the given duty. Normally, two of the given valves could be chosen, neither being perfect for the duty. The students are thus encouraged to discuss the

reasons for their choice of valve.

## CONCLUSIONS

A procedure has been described for teaching students about the selection criteria for both centrifugal pumps and control valves for a given pipework system, along with comments on the way this is taught and assessed at Edinburgh University. While the typical values given in the text assume a straightforward case in which a wide controllable range is required, the same procedure is suitable for more specialized applications where the choice of  $C_{v,max}$  and trim may be based on alternative criteria.

## REFERENCES

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