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Easy way to estimate realistic control valve pressure drops

Use this method to ensure proper operation and minimize operating costs

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When designing a new plant or revamping an existing one, a key task is to estimate or calculate pressure drop allowed for each control valve. For a control valve that has a pump or compressor upstream, there are three methods to do this. The traditional method is to allow 50% to 25% of the system frictional pressure drop (other than control valve pressure drop) as the control valve pressure drop. The second method is to calculate the allowed control valve pressure per an equation proposed by Connell.[1] The third technique is to assign a minimum pressure drop to the control valve at maximum design flowrate.

This article studies three typical systems that require calculating control valve pressure drop. It also studies the above-mentioned three control valve pressure drop estimation methods for a system with a pump or compressor.

System under study. The three typical piping systems with control valves are shown in Fig. 1. For simplicity, only one control valve in the system is considered. A system with more than one control valve is discussed later.

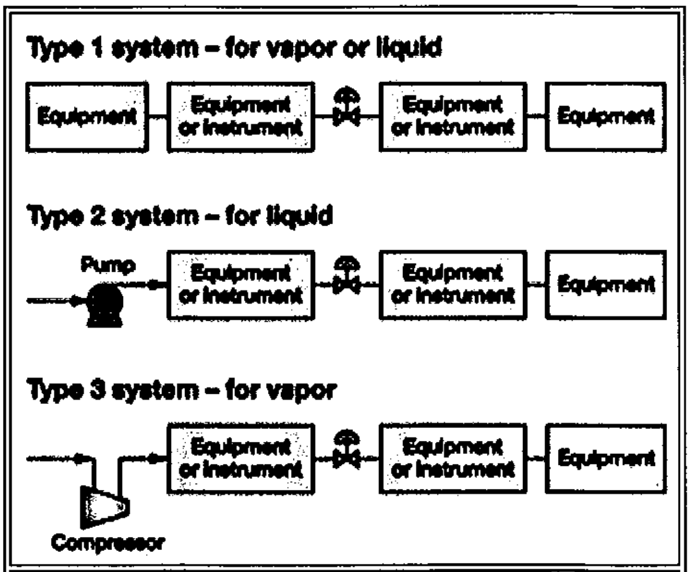

Fig. 1. These three different piping systems with control valves will be analyzed.

The type 1 system starts from equipment such as a vessel, which will not generate differential pressure, and ends at another piece of equipment. Between the equipment are piping, one control valve and additional equipment and/or an instrument upstream or downstream of the control valve. Fluid in the system is either vapor or liquid.

The type 2 system is for liquids. It starts with pressure-generating equipment such as a pump and ends with another piece of equipment. Between the equipment are piping, one control valve and additional equipment and/or an instrument upstream or downstream of the control valve.

The type 3 system is for vapor. It starts with pressure-generating equipment such as a compressor and ends with another piece of equipment. Between the equipment are piping, one control valve and additional equipment and/or an instrument upstream or downstream of the control valve.

Equipment items upstream or downstream of the control valve are usually heat exchangers, filters, etc., and the instruments upstream or downstream of the control valve are usually orifice plates, flow meters, etc.

The control valve can be globe, ball, butterfly or any other type, but not an on-off valve.

Assumption and basis.

Assumptions: Pressure drop through the line, equipment and instrument are proportional to the square of the flowrate.

Basis of good control valve performance: A control valve is able to do its job if its opening is between 20% to 80%. A 20% valve opening is the lower limit and 80% valve opening is the upper limit. (See item 1 under "discussion" for this valve opening range.) Outside this opening range, it is assumed that the control valve has difficulty carrying out its intended function.

Control valve pressure drop estimation. This section studies control valve pressure drop estimation. First, some terminology is explained.

Let *Ps* be the system starting pressure and *Pe* the end pressure. For the type 1 system, *Ps* and *Pe* are fixed. For the type 2 system, *Ps* is the pump discharge pressure and for the type 3 system, *Ps* is the compressor discharge pressure. For type 2 and 3 systems, *Pe* is also fixed, but *Ps* is calculated.

Let *F* be the total frictional pressure drop in the system excluding the control valve pressure drop, *DPcv*, at any flowrate. Therefore, it consists of total pressure drop through the line, *DPl*, and total equipment and/or instrument pressure drop upstream and/or downstream of the control valve, *DPe*. Let F_d be the *F* at maximum design flowrate, and Q_d, and F_n be the *F* at normal flowrate. Therefore:

$$Ps - Pe = F + DPh + DPcv \quad (1)$$

where *F* = *DPe* + *DPl* , and *DPh* is the static head difference between system starting and end points. *DPh* for type 1 and 3 vapor systems is negligible.

Therefore, for a type 1 system, *Ps*, *Pe* and *DPh* are fixed values. *F* varies with flowrate, and *DPcv* is calculated using the following equation at different flowrates.

$$DPcv = (Ps - Pe) - F - DPh \quad (2)$$

For type 2 and 3 systems, *Pe* and *DPh* are fixed values. *F* varies with flowrate, and *DPcv* is calculated by one of the following three methods using Eqs. 4, 5 or 6. Pump or compressor discharge pressure is calculated using the following equation:

$$Ps = Pe + F + DPh + DPcv \quad (3)$$

The relationships between *Ps*, *Pe*, *DPh*, *F* and *DPcv* for the three types of systems are shown in

Figs. 2, 3, 4 and 5.

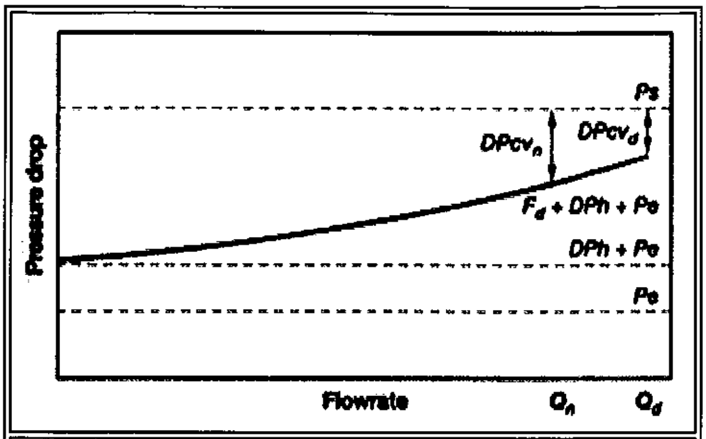

Fig. 2. Type 1 system for liquid.

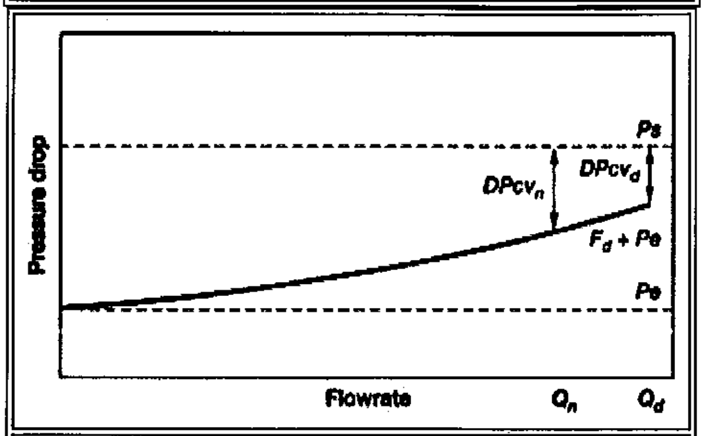

Fig. 3. Type 1 system for vapor.

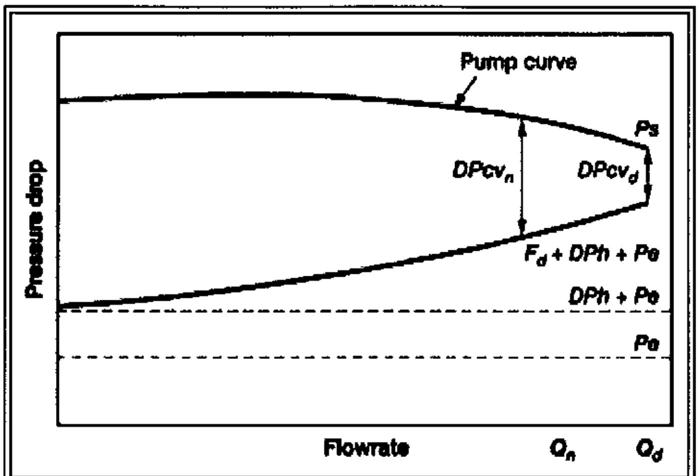

Fig. 4. Type 2 system for liquid.

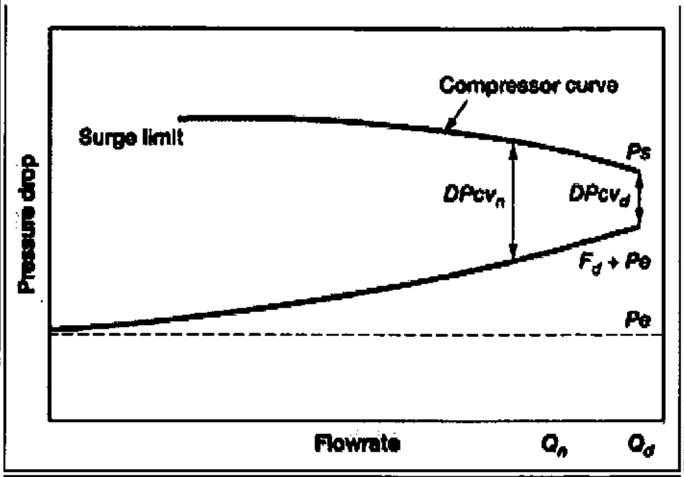

Fig. 5. Type 3 system for vapor.

Let *B* be the pressure drop through the control valve when it is fully open.

For type 2 or 3 systems, there are three methods to estimate control valve pressure drop. Each method is reviewed.

Traditional method. The allowed pressure drop through the control valve equals 50% to 25% of the system frictional pressure drop excluding itself. This relation can be expressed in the following equation:

$$DPcv = C\,(F) \quad (4)$$

$$C = 0.25 \text{ to } 0.5$$

The basis for selecting *C* is not very clear and it doesn't mention if the system frictional pressure drop, *F*, is based on normal or design flow.

Connell method. Connell's method is based on normal flowrate. Connell proposed the following equation to calculate allowed control valve pressure drop:

$$DPcv = 0.05\,Ps + 1.1[\,(Q_d\,/\,Q_n)^2 - 1]\,F_n + B \quad (5)$$

Eq. 5 was derived by considering: 1) starting and ending system pressure fluctuations, 2) increased frictional pressure drop due to design flowrate and 3) control valve pressure drop when it is full open. F_n is the system frictional pressure drop at normal flowrate.

Minimum control valve pressure drop method. In this method, minimum control valve pressure drop is assigned to the control valve for the system at its maximum expected design flowrate, Q_d. The control valve is sized at the upper opening limit of 80% and design flowrate.

DPcv = minimum pressure drop (at design flow and max. 80% control valve opening) (6)

The selected minimum pressure drop for a control valve is usually 10 or 15 psi, which is larger than a control valve's full open pressure drop.

Discussion.

1. The upper and lower opening limits of a control valve during operation vary among manufacturers and instrument engineers. The lower opening limit varies from 0% to 40% and the upper varies from 80% to 90%. Most instrument engineers like to select a control valve operating at 60% to 70% opening.
2. For a new design or revamp project, usually normal and maximum design flowrates are

defined. Equipment design, instrument selection and hydraulic calculation are all based on maximum design flowrate, not normal flowrate. Therefore, in most cases F_d is calculated first.

3. For a type 1 system, allowable control valve pressure drop should be calculated using Eq. 2. F should be calculated at maximum design flowrate. The control valve should be sized at the upper opening limit. This way, available pressure drop is fully utilized, and a smaller control valve will be selected. The user should also check the control valve opening at normal flow to make sure that it is not below the lower opening limit. This way, the control valve will be operated within the upper and lower opening limits at design and normal flows.

   For type 2 and 3 systems, the minimum pressure drop (Eq. 6) should be assigned for the control valve at the maximum design flowrate. The control valve should be sized for the upper opening limit. The user should also check the control valve opening at normal flow to make sure that it is not below the lower opening limit. This way, the control valve will be operated within the upper and lower opening limits at design and normal flows. Usually a larger control valve will be selected, but the system operating cost will be reduced.

4. For any system, when F_d is estimated, it is usually on the high side. For example, the equipment data sheet for a heat exchanger allows 10 psi for tube-side flow. A good heat exchanger designer will try to use up the 10 psi allowed pressure drop to minimize cost of the unit. However, after the heat exchanger is designed, often actual pressure drop is less than 10 psi.

   During hydraulic calculation, a certain amount of contingency will be added to the calculated system pressure drop to account for uncertainties. This also will cause F_d to be estimated on the high side.

   Therefore, when actual F_d is less than estimated, more pressure drop will be available to the control valve and its opening will be smaller than the selected upper opening limit.

   Of course, there is a possibility that F_d is underestimated due to a mistake in hydraulic calculation such as the design engineer forgot to account for certain pressure drops in the system. If this happens, less pressure drop is available to the control valve. If the system is operated at design flow, the control valve will be opened wider than the upper opening limit, and the control valve will have difficulty controlling the flowrate.

5. Pressure fluctuations at either end of the system should be handled by the control valve as long as valve opening does not exceed upper or lower opening limits.
6. Connell's method calculates allowable pressure drop at normal flow. However, it does not mention what valve opening should be used to size the valve, and at maximum design flow, it will not ensure that the control valve is still under the upper opening limit, unless a valve opening calculation is made. In general, Connell's method allows more pressure drop for a control valve, and a smaller control valve will be selected for the system at the expense of operating cost.
7. For a system that has more than one control valve, the following treatment is suggested. For a type 1 system, calculated allowable control valve pressure has to be divided among the control valves in the system. For type 2 or 3 systems, minimum pressure drop should be assigned to each control valve at design flow and they should be sized at their upper opening limit.

Examples. Two examples from Connell's article[1] are recalculated using the methods outlined in this article. One of the examples is a type 2 system and the other is a type 1 vapor system.

Example 1: A charge pump pumps feed to a fractionator through three preheaters and a fired heater. Feed is on flow control at the pump discharge. At design flow, total equipment and flow orifice pressure drop is 114 psi and line loss is 36 psi. The ratio of design flow to normal flow is 1.2. Static head from pump to fractionator is 15 psi. Fractionator top operating pressure is 20 psig.

$F_d = 114 + 36 = 150$ psi

$F_n = F_d / (1.2)^2 = 104$ psi

$DPh = 15$ psi

This is a type 2 system. Using minimum pressure drop for the control valve, let $DPcv_d = 10$ psi at design flow. The control valve is sized at the upper opening limit. Pump discharge pressure, *Ps*, will be calculated as follows, per Eq. 3:

$$Ps_d = 20 + 150 + 15 + 10 = 195 \text{ psig}$$

Let us check the *DPcv* at normal flow. At normal flow, pump head can be read from the pump curve. Pump discharge pressure equals the suction pressure plus this head. Usually, pump head is larger at smaller flow. Therefore, discharge pressure at normal flow will be larger than 195 psig. Let us assume that the pump curve is flat and pump discharge pressure remains at 195 psig. Eq. 3 can be written as:

$$Ps_n = 195 = 20 + 104 + 15 + DPcv$$

Therefore, at normal flowrate,

$$DPcv_n = 56 \text{ psi}$$

Per Connell's method, *DPcv* is 76 psi for normal flowrate. Therefore, a 20 psi saving is realized by using the minimum pressure drop method instead of the Connell method.

To compare the cost difference between both control valve pressure drop methods, capital and operating costs are calculated for design feed flows at 1,000, 500 and 100 gpm. The pumping fluid is a hydrocarbon with specific gravity of 0.8.

Based on the minimum pressure drop method, a 6-in. globe valve ($Cv = 394$) is selected for the 1,000-gpm case at 76% opening, a 4-in. globe valve ($Cv = 224$) is selected for the 500-gpm case at 74% opening and a 2-in. globe valve ($Cv = 60$) is selected for the 100-gpm case at 72% opening. Estimated cost for a carbon steel 6-in. globe valve is $8,600, $6,600 for a 4-in globe valve and $4200 for a 2-in. globe valve.

Based on Connell's method, the corresponding normal flowrates are 694, 347 and 69 gpm for the 1,000-, 500- and 100-gpm design flow cases. Control valve pressure drop per Connell's method is 76 psi. A 4-in. globe valve ($Cv = 224$) is selected for the 1,000-gpm case at 65% opening, a 3-in. globe valve ($Cv = 136$) is selected for the 500-gpm case at 64% opening and a 1.5-in. globe valve ($Cv = 36$) is selected for the 100-gpm case at 58% opening. Estimated cost for a 4-in. carbon steel globe valve is $6,600, $5,200 for a 3-in. globe valve and $3,800 for a 1.5-in. globe valve.

Extra operating cost for each case using Connell's method are calculated by:

$$DHP = Q_n\,(DDP)/1{,}715/E \tag{7}$$

$$DCO = 0.76\,(DHP)\,(0.05)\,(8{,}400)\,(8) \tag{8}$$

DHP, DDP and *DCO* are the extra horsepower, extra control valve pressure drop and extra operating cost per year by using Connell's method. *E* is pump efficiency, 0.76 converts hp to kW, 0.05 is the cost of electricity in $/kW and 8,400 is the annual operating hours.

For our example, *DP* = 20 psi. Assuming pump efficiency is 75%, the extra annual operating cost of Connell's method valve is $4,536 for the 1,000-gpm case, $2,268 for the 500-gpm case and $462 for 100-gpm case.

Therefore, the extra capital cost for using the minimum pressure drop method is $2,000 for the 1,000-gpm case, $1,400 for the 500-gpm case and $400 for the 100-gpm case. However, these extra capital costs can be recovered in 0.44 years for the 1,000-gpm case, 0.62 years for the 500-gpm case and 0.87 years for the 100-gpm case.

Therefore, it is concluded that the minimum pressure drop method for control valve pressure drop estimation is better than Connell's method.

Example 2: Fuel gas is fed to a fired heater burner on temperature control. Fuel gas header pressure is 35 psig. Fired heater pressure is 0 psig. System pressure drop at design flow, F_d, is 25 psi; 20 psi for the burner and 5 psi for the line and flow orifice plate. The ratio of design to normal flowrates is 1.4.

Per Eq. 2:

$$DPcv_d = (35 - 0) - 25 = 10 \text{ psi}$$

Therefore, the control valve should be selected at design flow with 10 psi pressure drop and sized at the upper opening limit.

At normal flow, $F_n = 25 / (1.4)^2 = 13$ psi

Therefore,

$$DPcv_n = (35 - 0) - 13 = 22 \text{ psi}$$

With 22 psi pressure drop, control valve opening (at normal flowrate) will be less than its upper opening limit.

On the contrary, using Connell's method, 20 psi will be allowed for control valve pressure drop at normal flow, assuming sizing at 60% to 70% opening. It is not sure at design flow with 10 psi control valve pressure drop whether the control valve opening is still under the upper opening limit unless a valve opening calculation is made.

The control valve pressure drop proposed in this article ensures that the control valve still works at normal flow and design flow. For type 2 and type 3 systems, it minimizes operating cost at the expense of selecting a larger valve. **HP**

Nomenclature

- *B* = pressure drop through a fully opened control valve, psi
- *C* = a constant used in Eq. 4
- *DCO* = extra operating cost used by Connell's method valve, $/yr
- *DDP* = extra control valve pressure drop used by Connell's method valve compared to minimum pressure drop method, psi
- *DHP* = extra horsepower used by Connell's method valve, hp
- *DPcv* = allowed or calculated control valve pressure drop, psi
- *DPe* = total equipment and/or instrument pressure drop upstream and/or downstream of control valve, psi
- *DPh* = static head difference between system starting and ending points, psi
- *DPl* = total line loss, psi
- *F* = system pressure drop excluding control valve pressure drop, psi
- *Ps* = system starting point pressure, psig
- *Pe* = system end point pressure, psig
- *Q* = volumetric flowrate through the system, gpm for liquid or acfm for vapor

Subscript:

- *n* = normal flow condition

d = design flow condition

Literature Cited

Connell, J. R., "Realistic Control Valve Pressure Drops," *Chemical Engineering,* Sept. 28, 1987, p. 123.

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