Lecture Eight

Control Valves

A control valve is the final control element in a process control. Thus the effectiveness of any control scheme depends heavily on the performance of the control valve. The proper design and fabrication of the valve is very important in order to achieve the desired performance level. Moreover control valves are of different size and shapes.

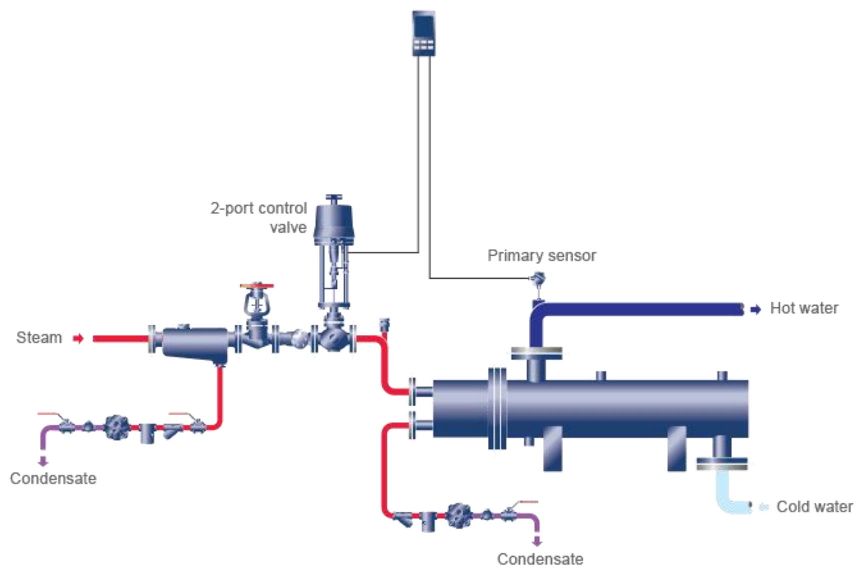
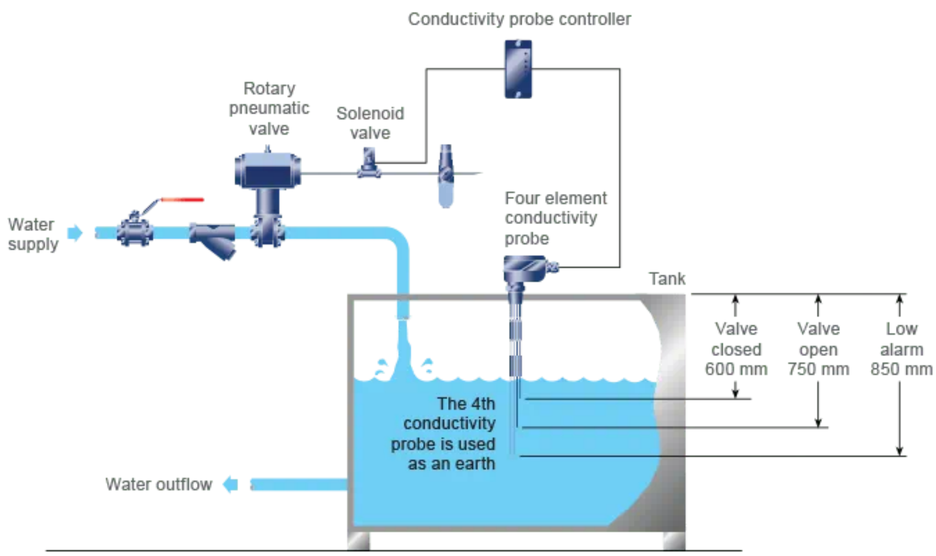


Fig. 5.3.4 Single loop control on a heating calorifier

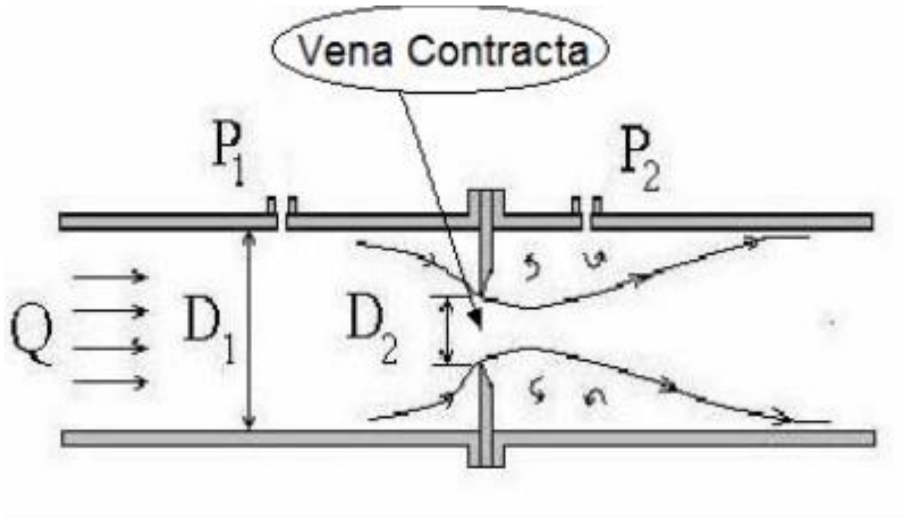
What Is a Control Valve?

A valve that controls the rate of flow in a piping system as commanded by a pneumatic or electronic signal

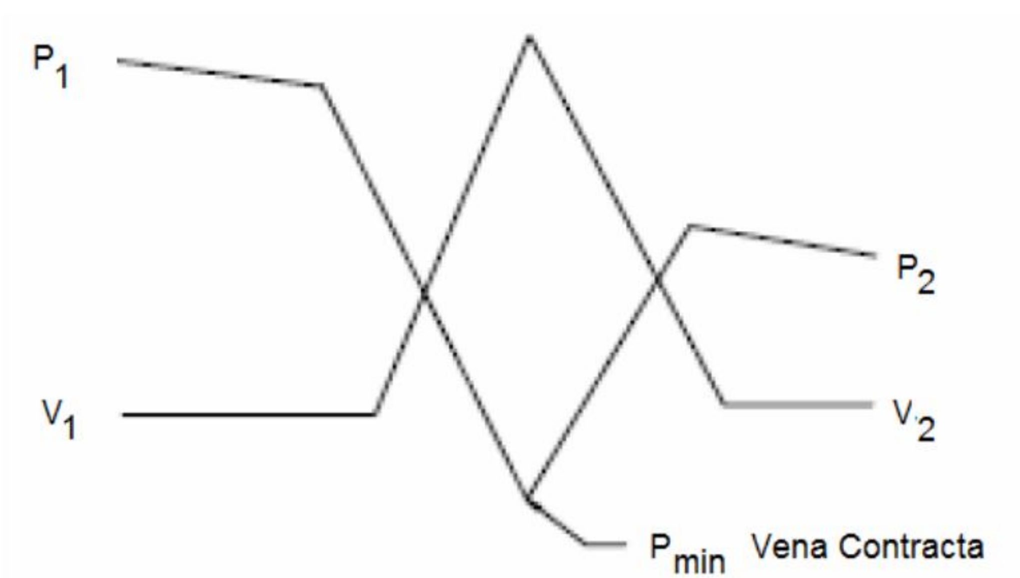
A more technical example would be the case in which a control valve controls the filling of a storage tank with crude oil originating from a pipeline. A level controller is used to sense the tank level and send a signal to the control valve. Here again, the controller will instruct the valve to be fully open until the tank is about 80% full in order to speed up the filling process. Thereafter, the controller instructs the valve to start closing in proportion to the remaining empty tank space. This would mean that for every 2% of tank level, the valve's travel will be reduced by 10%, until the valve is fully closed when the tank is full.



The flow regulation in a valve is accomplished by the varying resistance as the valve is stroked, i.e. its effective cross sectional area is changed. As the fluid moves from the piping into the smaller diameter orifice of the valve, its velocity increases to enable mass flow through the valve. The energy needed to increase the velocity comes at the expense of the pressure, so the point of highest velocity is also the point of lowest pressure (smallest cross section). The point where the pressure is at the lowest is called **"vena contracta"**. To display the general behavior of flow through a control valve, the valve is simplified to an orifice in a pipeline as shown in the figure below:



As the liquid passes the point of greatest restriction (vena contracta); its velocity reaches a maximum and its pressure falls to a minimum. Hence we would expect the highest velocity at the internal to the valve than on upstream and downstream. Beyond the vena contracta, the fluid's velocity will decrease as the diameter of piping increases. This allows for some pressure recovery as the energy that was imparted as velocity is now partially converted back into pressure (refer pressure-velocity profile below).



It is important to understand how the pressure-velocity conditions change as the fluid passes through the restriction. This is best described by the continuity equation:

$$\sum \rho \cdot A \cdot V\ (\text{in}) = \sum \rho \cdot A \cdot V\ (\text{out})$$

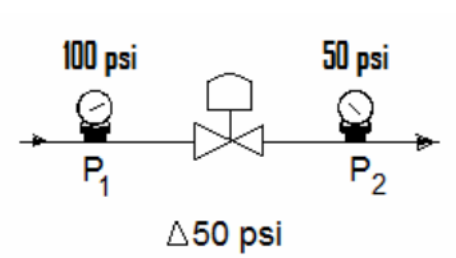
Control Valve Capacity (Cv)

For sizing a control valve we are interested in knowing how much flow we can get through the valve for any given opening of the valve and for any given pressure differential. The relationship between pressure drop and flow rate through a valve is conveniently expressed by a flow coefficient (Cv).

Flow coefficient (Cv) is defined as the number of **gallons per minute (gpm)** at 60°F that will pass through a full open valve with a pressure drop of 1 psi. Simply stated, a control valve which has a Cv of 12 has an effective port area in the full open position such that it passes 12gpm of water with 1 psi pressure drop. The Cv for water is usually determined experimentally by measuring the flow through a valve with 1 psi applied pressure to the valve inlet and have a 0 psi pressure at the outlet. For incompressible fluids like water, a close approximation can be found mathematically by the following equation:

$$Cv = Q\sqrt{(S / \Delta P)}$$

The equation shows that the flow rate varies as the square root of the differential pressure across the control valve. Greater the pressure drop, higher will be the flow rate. Pressure drop across a valve is highly influenced by the area, shape, path and roughness of the valve.



Where:

- Cv = Valve flow coefficient
- Q = Fluid flow, US GPM (also given by Area of pipe x mean velocity(A.V))
- S = Specific gravity of fluid relative to water @ 60ºF
- ΔP = Pressure drop (P1 – P2) across the control valve at maximum flow, psi.

Example 1

Assume there is a 15 psi pressure drop across a control valve when the valve is wide open with a flow rate of 150 gpm of water through the valve. The specific gravity of water is one. Calculate the valve coefficient.

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The valve coefficient can be calculated as:

$Cv = 150 * (1 / 15)^{½} = 38.72$ gpm

Once we know the valve coefficient, we can then calculate the pressure drop across the valve for a given flow rate, OR a flow rate for a given pressure drop. For example, determine the pressure drop across the above valve if the flow rate increases to 200 gpm.

$\Delta P = (Q / Cv)^2 \times S = (200 / 38.72)^2 \times 1 = 26.68$ psi

In practice, once you know the design flow rate and the desired pressure drop, one can calculate the required valve Cv and select a proper valve from the manufacturers' literature.

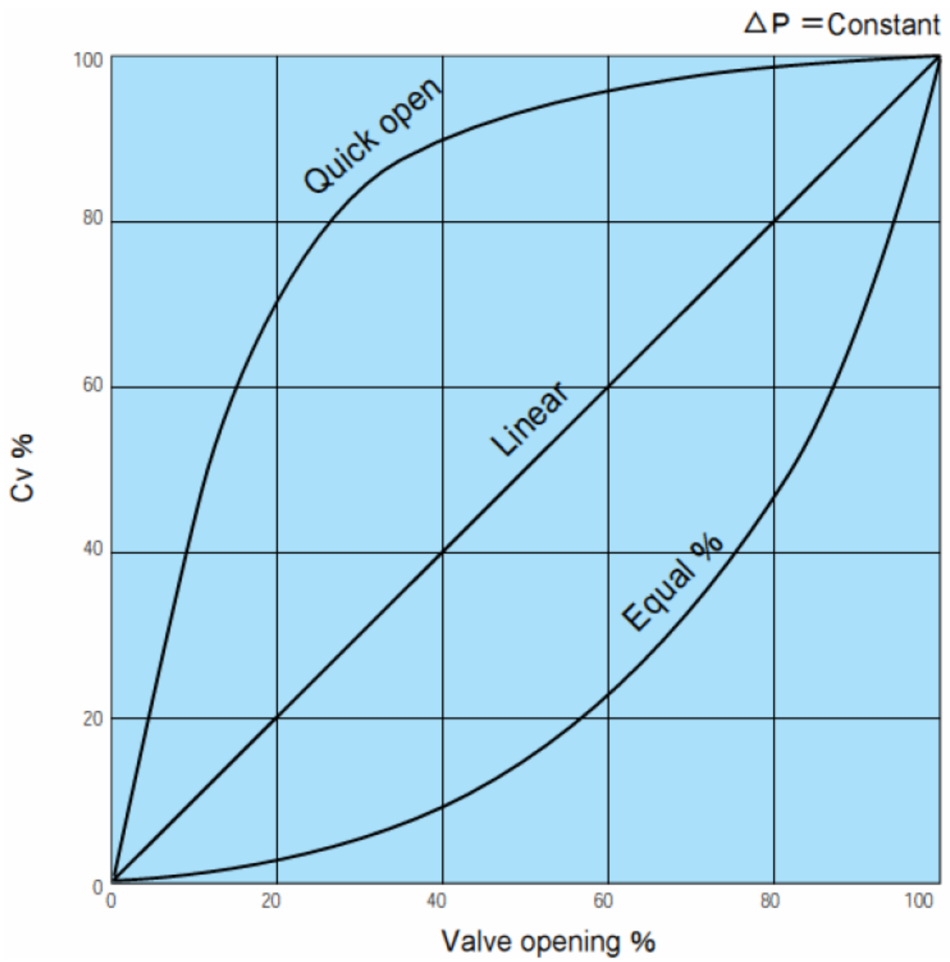
Control Valve Characteristics

Each valve has a flow characteristic, which describes the relationship between the flow rate and valve travel. As a valve opens, the flow characteristic, which is inherent to the design of the selected valve, allows a certain amount of flow through the valve at a particular percentage of the stroke. This enables flow regulation through the valve in a predictable manner. The three most common types of flow characteristics are:

1. Linear

2. Equal percentage

3. Quick opening



Control Valve Sizing Parameters

The valve is very important component of any process system. It is important not to choose a valve that is too small or too large.

1. If the control valve is undersized (Cv - too small), the required flow rate will not be achieved even when the valve is fully opened. If a higher pressure is applied to force a higher flow rate across the undersized valve; not only the pump energy will be excessive but also the valve may cavitate or develop flashing.
2. If a selected control valve is too large (Cv – too large), it will not provide the desired control and may cause the system to hunt or cycle. When a valve is operated at below 10% of its Cv for an extended period of time, the valve seat and the closure member may get damaged.

Control valve sizing and selection is based on a combination of theory and empirical data.

There are distinct guidelines for selecting the valve size and shape depending on load change, pipeline diameter, etc. To properly select a control valve, the following fluid and system properties must be known:

1. **Medium** - What is passing through the valve? – If it is a special liquid, provide specific gravity (at flowing temperate), critical pressure, vapor pressure and viscosity.

2. **Pressures** - What is the maximum pressure that the valve needs to be rated for?

What are the upstream and downstream pressures for each of the maximum, normal and minimum flow rates?

3. **Flow rates** - Maximum, normal and minimum. The maximum is used to select the valve size, the minimum to check the turndown requirement and the normal to see where the valve will control.

4. **Temperature** - Maximum temperature for design plus temperatures at maximum, normal and minimum flow conditions.