CONTROL VALVE – WHAT YOU NEED TO LEARN?

i) The control valve **characteristics** refers to the relationship between the volumetric flowrate **F** (Y-axis) through the valve AND the valve travel or opening position **m** (Xaxis), as the valve is opened from its closed position to various degree of opening. (Note that the symbol **m or Z** is used here to represent the valve travel or opening position, in %).

ii) The control valve Manufacturer can only state the **Inherent** valve characteristics, which refer to the flowrate (F) – valve travel position (m or Z) relationship**, when the pressure drop across the control valve (DPv) is constant**. Note that the pressure drop across the control valve **(DPv)** can be almost constant only if the piping system pressure drop **(DPs)** is concentrated at the control valve and not distributed along the pipeline. This means that the pipeline must be of very short length with minimum pressure-reducing-devices or equipment in series with the control valve. Such a condition rarely exist in actual installation except in the control valve Manufacturer test facilities, where the control valve characteristics are obtained using very short length of piping. Such ideal valve characteristics are the valve **Inherent** characteristics.

iii) Note that in the rectangular plot of flowrate F (Y-axis) against valve travel or position m or Z (X-axis), Cv is often used instead of F. **Cv** is the valve sizing coefficient defined for liquid as follows:

$$\text{Cv} = \text{F, USGPM} \frac{\sqrt{\text{SG}}}{\sqrt{\text{Valve pressure drop (DPv), psi}}} \quad \text{i.e. } \text{F}\frac{\sqrt{\text{SG}}}{\sqrt{\text{DPv}}} \text{ in USGPM/psi units}$$

Furthermore, for comparison between different valves, % F and % Cv are also used for the Y-axis instead of F or Cv. For % F, the maximum flowrate through the particular valve is its denominator. For % Cv, the particular valve maximum Cv is its denominator

F(actual) Cv(actual)

i.e. %F=×100% ; %Cv =

F(max) Cv(max)

When the valve is fully opened (i.e. Z or m = 100%), F becomes F(max) and Cv becomes Cv(max). Unless specifically stated, "Cv" usually means Cv(max), since it determines the valve maximum flow capacity, which is of interest in flow study and valve size selection.

iv) The control valve **Installed** characteristics refer to the relationship between the volumetric flowrate F (Y-axis) through the valve AND the valve travel or opening position m or Z (X-axis), as the valve is opened from its closed position to various degree of opening, **when the pressure drop across the valve (DPv) varies**. Note that the pressure drop across the valve (DPv) varies in most actual installation, influenced also by various pressure-reducing devices in series with the control valve, such as the pipe length, pipe fittings and various types of valves, flowmeter and process equipment. In general, the pressure drop across these devices also vary with the flowrate squared. Thus constant valve pressure drop (DPv) rarely exists except in the ideal conditions of the Manufacturer's test Lab. A control valve displays its **Inherent** characteristics at such ideal conditions. In actual plant installation, it displays the **actual** or **Installed** characteristics.

The Installed valve characteristics can be very different from its Inherent or ideal characteristics.

v) There are three most common control valve characteristics viz Linear, Equal % and Quick-Opening.

a. A control valve is labelled **LINEAR** if its **inherent** flow characteristics can be represented by a straight line on a rectangular plot of flowrate F (or % F, or Cv or % Cv) versus % travel m (or Z for opening position) at the ideal condition of constant valve pressure drop (DPv).

Therefore equal increment of travel or opening m produce equal increment of flow F (or Cv) at constant valve pressure drop (DPv). If m represents travel and F represents flowrate,
then dm = k dF, where k is a proportional constant.

Thus the valve gain or sensitivity, which is change in flow F divided by the change in travel m is constant, whether at low flow or high flow

i.e. valve gain Kv = Df/dm = constant, independent of flowrate and valve opening.

Note also that the valve gain Kv is the slope (tangent) of the rectangular plot of flowrate F (Y-axis) versus valve travel or position m (X-axis). The slope remains constant and independent of flowrate throughout.

b. A control valve is said to be **EQUAL %** if equal increment of valve travel or opening m (or Z) produces equal PERCENT (%) increment in flow F. If this occurs at the ideal condition of constant valve pressure drop (DPv), the valve is said to be **inherently EQUAL %**. Therefore dm = k^1 (dF/F) x 100% where k^1 is a proportional constant. Hence valve gain Kv = (dF/dm) = k_1 F where k_1 is a proportional constant.

Note that the valve gain Kv is not constant but increases as flow increases. Hence at low flow when the control valve is just opening, the valve gain is low and its flow change is insensitive. At high flow at the upper portion of travel, the valve gain is high which means that the flow increases rapidly (sensitively) for the same increment in valve travel. On a rectangular plot of flowrate F (Y-axis) versus valve travel or position m (X-axis), the slope is flattish near the initial travel position m (X-axis), but increases rapidly with flow as the valve opens at the upper portion of travel. This can also be illustrated if $dm = k^1 (dF/F)$ is integrated to solve for m versus F, giving $m = k^1 \log F$ or a straight line plot on a semi-logarithmic paper for log F versus m.

c. The **Quick-Opening** characteristic control valve has a flat disk instead of a contoured valve plug. Its flow (or Cv) increase rapidly to its maximum flow with minimum initial valve opening. At the initial or lower portion of travel position, the valve gain Kv is too high for use in modulating control. Thereafter, the slope is flattish, where the flowrate hardly increases with valve opening m. Therefore, such control valve is limited to ON-OFF service and application or in specific application which requires fast initial release or discharge of flow.

d. Other less common types of characteristics include the “modified parabolic” which is approximately mid-way between the Linear and Equal % characteristics, giving fine throttling action at low valve travel (like Equal %) and approximately linear characteristic for the upper portion of travel. The so-called ‘hyperbolic’ characteristic rectangular plot is “bowed”, below the Linear characteristics. These two characteristics (Quick-Opening, modified parabolic) are mentioned here for interest sake only as the Linear and Equal % characteristics can meet almost all control requirement.

vi) When control valve characteristics is specified to the valve Manufacturer, its inherent characteristics is specified. However, when the control valve is installed at the pipeline, the ideal condition of constant valve pressure drop (DP_V) is unlikely to be true and the ‘operating’ characteristics will no longer be the inherent characteristics. Most likely, it will have deviated or distorted, into what is referred to as the **installed** characteristics. The deviation in the characteristics depends on the pressure drop variation across the control valve, as the control valve operates from minimum flow at its initial travel position to its maximum flow at its fully opened position.

Consider the valve pressure drop ratio DPv/DPs =DpV/(DPv + DPL), where DPv is the pressure drop across the control valve and $DP_S = DP_V + DP_L$.

DPs is the pipeline system dynamic pressure drop made up of the pressure drop across the control valve (DP_V), plus the pressure drop along the whole length of pipeline including those of all the pressure-reducing devices and process equipment in series with the control valve (DP_L), but EXCLUDING any unchanging static or elevation pressure head component.

If this ratio is almost constant and approaches 1.0, then DP_L is almost zero which means that most of the pipeline system pressure drop (DPs) is concentrated at the control valve ie DPv approaches DPs. This satisfy the requirement for the definition of valve inherent characteristics. The installed valve characteristics remains similar to the inherent valve characteristics with minimum distortion if DPv is almost equal to DPs and the pressure drop ratio is almost 1.0.

Deviation or distortion gets worse as the ratio DPv/DPs decreases from 1.0. This is the situation when the pipeline system pressure drop (DPs) is not concentrated at the control valve but well distributed along the pipeline. An inherently Equal % characteristics control valve when installed and operating under such condition of low DPv/DPs ratio will behave like a Linear control valve.

An inherently Linear characteristics control valve when installed and operating under low DPv/DPs ratio condition will behave like a Quick-Opening control valve!

Quick-opening characteristics is not much use for modulating process control except in ON-OFF application! This is the main reason why inherent Equal % control valve (which tends towards linear characteristics when installed) is usually installed. An installed linear valve characteristics may not be the preferred characteristics in certain application (such as Heat Exchanger control which prefers Equal % characteristics) but it is at least modulating.

vii) Sometimes, instead of referring to the pressure drop ratio DPv/DPs, the ratio Max.DPv/Max.DPs is used instead.

-**Max. DPV** is the maximum valve pressure drop which occurs at the minimum flow condition when the valve is almost but not fully shut, and where the valve can still regulate the flowrate. The flow is said to be at its **minimum controllable flow.**

-**Min. DPV** is the minimum valve pressure drop which occurs at maximum flow when the valve is fully opened. This ratio approaches 1 when DPv/DPs approaches 1.0, or DPv approaches DPs, because Min. DPv approaches Max. DPv only when all the system pressure drop (DPs) is concentrated at the control valve, irrespective whether the valve is fully opened (i.e. at maximum flow condition producing minimum DPv) or almost shut (i.e. at minimum flow condition producing maximum DPv). However, deviation or distortion of the inherent valve characteristics get worse when this ratio Max.DPv/Max.DPs increases, or DPv/DPs decreases from 1.0.

viii)Summarising, note that irrespective whether the control valve is fully opened or almost shut,

the MAX DPv is almost equal to MIN DPv and the DPv is almost equal to DPs	} ONLY if almost all the pipeline system pressure drop is concentrated at the control valve at all times.

This is only possible if the system pipeline is very short with minimum pressure-reducing devices along the pipeline. Such condition is used in the valve Manufacturer test lab but is rare in actual plant installation. Thus most installed valve characteristics are distorted and no longer at their inherent characteristics.

Inherent Equal % characteristics tends towards Linear characteristics when installed.
Inherent Linear characteristics tends towards Quick-opening characteristics when installed.

ix) Valve Capacity sizing, Cv The valve size or Cv need to be determined so that it can handle the maximum flowrate when the control valve is almost fully (say 70-85%) opened. If the control valve is undersized (Cv is too small), the required maximum flowrate will not be achieved even if the undersized valve is fully opened. If a higher pressure drop is applied to force a higher flowrate across the undersized valve, the valve pressure drop may be too excessive which may cause Noise, Cavitation or even Flashing to develop, especially if the operating upstream pressure/temperature are high. If the control valve is significantly oversized (Cv is too large), it may only need to open slightly to allow the maximum required flow through, resulting in poor control. When the flow drops, the control valve plug will 'chatter' at the valve seat causing not only poor control but also valve seat damage. Both oversized (Cv too large) or undersized (Cv too small) valves should be avoided.

For liquid under turbulent, non-vaporising flow conditions, the control valve sizing (Cv) equation is expressed as follows:

$$\text{Cv} : \quad \frac{F}{N_1 F_P} \frac{\sqrt{S.G}}{\sqrt{DPv}}$$

where

Cv : Valve sizing coefficient
F : Flowrate
S.G. : Specific Gravity which is 1.0 for water at 60°F
DPv : Pressure drop across the control valve
N_1 : Numerical constant

: 1.0 if F is in USGPM and DPv is in psi
: 0.865 if F is in m3/Hr and DPv is in bar
Fp : Assume Fp = 1 if the valve body or line size is the same size as its adjoining pipelines.

$$Cv = F(USGPM).\frac{\sqrt{S.G}}{\sqrt{DPv, psi}}$$

The above formula should be applied to calculate the **maximum** required Cv, by using the **maximum** required flowrate for F, and the **minimum allowable** valve pressure drop for DPv. Note that the minimum allowable pressure drop across the control valve DPv corresponds to the maximum flow condition when the control valve is fully opened.
The calculation is simple but the minimum allowable pressure drop across the control valve **DPv** can only be determined by carefully evaluating the various pressure drop across all the components in the pipeline system at the maximum flow condition.

Simply assuming DPv = 30% DPs is not likely to give the correct Cv, as DPv/Dps varies case by case depending on the specific piping configuration and application.

x) Valve Rangeability Rangeability of a flowmeter or control valve is a means of expressing its acceptable working range, by using a ratio of its maximum to minimum acceptable (accuracy wise)flowrates. For instance, a flowmeter cannot measure very low flow, say flowrate below 3%, accurately. Hence, its rangeability is then 33.

The installed Rangeability of a control valve is a means to express the best working flow range limits of the control valve, say from 5% to 95%. **Outside this flow range limits, the installed valve characteristics deviates from the desired characteristics by more than some stated tolerance.** It would be mechanically difficult to machine the valve plug and seat to perfection to give the desired characterized flow when the valve plug is just lifting off its seat. True characterised flow can only begin after the plug contour is sufficiently clear off the seat and orifice, by which time the minimum controllable flow may already be 3% to 5% of its maximum flow.(Take note of the **minimum controllable flow** just explained here. At this condition, the valve pressure drop is maximum ie **Max DPv**. Max DPv is not the valve shut-off pressure. See (vii) also).

Thus the installed Rangeability of a control valve may be defined as the ratio of its **maximum controllable flow** to its **minimum controllable flow**.

The inherent Rangeability, a property of the control valve alone, may be defined as the ratio of its **maximum Cv** to its **minimum controllable Cv between which the valve gain (slope of its F versus m characteristic curve) does not deviate from**

a specified gain by more than some stated tolerance.

Note that the valve inherent Rangeability is reduced during actual operation by the varying valve pressure drop (DPv). Thus if the inherent Rangeability is stated as 50, and if the valve pressure drop (DPv) is 30% of the pipeline system pressure drop (DPs), the installed Rangeability can be expected to be only 50 x $\sqrt{0.3}$ or 27. Again, what counts in actual operation is the installed Rangeability but the valve Manufacturer can only state the inherent Rangeability, not knowing what DPv/DPs is going to be in actual installation. If DPv approaches DPs so that DPv/DPs = 1, then the installed Rangebility is similar to the stated inherent Rangeability. As stated earlier in the discussion on inherent and installed Valve Characteristics, such condition rarely occurs in practice.