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Basic Scope of Document

This document defines the basic principles of the design for control valves. It shall be a guide for filling in BC standard specification and help to deal with client specifications. Deviations from this document could be required depending on the respective applications.

1. Background

Control valves are used in pipeline systems to control the flow rate, the pressure, or the direction of a fluid. They can turn on, turn off, regulate, modulate, or isolate the fluid.

Selecting the right control valve to perform the desired task requires understanding of the characteristics of all different types of valves normally used for various applications; knowing the advantages and limitations of the valve types ensures that the right one is chosen for a given application.

Various standards and norms define the design, construction and testing of the valves. A general overview of this information is helpful to deal with the client specifications.

Knowing various materials of construction for valves and their components and their limitations is an important aspect for specifying the valves for procurement.

A control valve may be defined as a valve with a powered actuator that responds to an external signal. The signal usually comes from a controller. The controller and valve together form a basic control loop. Control valves are seldom fully open or closed but in an intermediate position controlling the flow of fluid through the valve. In this dynamic service condition, the valve must withstand the erosive effects of the flowing fluid while maintaining an accurate position to maintain the process variable.

A control valve will perform these tasks satisfactorily if it is sized correctly for the flowing and shut-off conditions. The valve sizing process determines the required flow coefficient Kv/C_V, flow velocities, flow noise and the appropriate actuator size.

1.1 Valve types

- Butterfly valves
  are used for small differential pressures and large nominal diameter. As their flow characteristic is not adaptable, they are largely used for ON/OFF functions only

- Quarter-turn plug valves
  may be used for higher differential pressures, but flow characteristic is also not adaptable. From DN80-100 upward they are commercially attractive in comparison to conventional linear stroke valves (globe valves). There are fewer possibilities for noise attenuation.

- Ball and gate valves
  are used only for ON/OFF control due to their adverse flow characteristics, i.e. large break-away torques, and dead time. Their advantage is the low-pressure loss across the valve. Special types

of internals allow a control function as well and can be evaluated in some cases where for example a very dirty fluid needs to be handled.

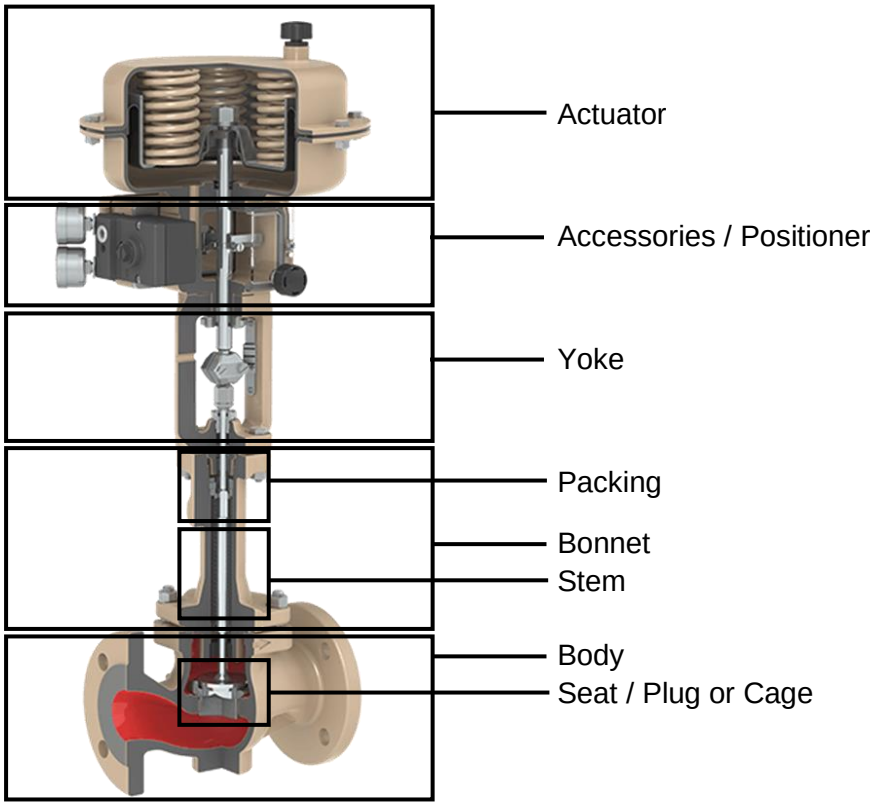
- Globe valves
  are hence the universal type used for regulated control valves. This is due to their adaptable flow characteristic.

- Axial Valves
  a very special type of valve where the cage is mounted in a streamlined case in line with the flow direction. These valves are very efficient, allow a high control range but are also more expensive compared to their counterpart the globe valve.

1.2 Body types

Body type depends on valve type selected. For globe valves, cast bodies with three integral flanges are most common. Four-flange bodies are used only when double-sided guiding of the plug is required in severe conditions. As they are expensive, this design should be avoided.

1.3 Valve nomenclature



1.4 Cv/Kv Value

The flow coefficient Kv or Cv is a standard definition of a valve's flow capacity. It represents the flow of water across a valve at a predefined pressure drop and nominal stroke. The nominal stroke is usually referred to 100%, therefore the notation Kv100 or Cv100 is used as well. Kv and Cv are both flow coefficients and are both defining the rated flow through a valve. The only difference is that the Kv Value (Unit: m3/h) is calculated from metric units, whereas Cv is calculated from customary (US, Unit: USGpm) or imperial (UK) units. This leads to a slight difference of those values for the otherwise exact same valve.

Conversion of Kv into Cv values is possible through a simple factor.

$$Cv = 1.156 * Kv$$

$$Kv = 0.864 * Cv$$

A simple calculation of the Cv Value is described in Chapter 2.2, which is neglecting some details of influences of the valve. However, for the first calculation steps in choosing a control valve, those simple formulas are suitable. The official definition for the precise calculation of Kv/Cv values are defined in the standard IEC 60534-2-1.

1.5 Valve characteristics

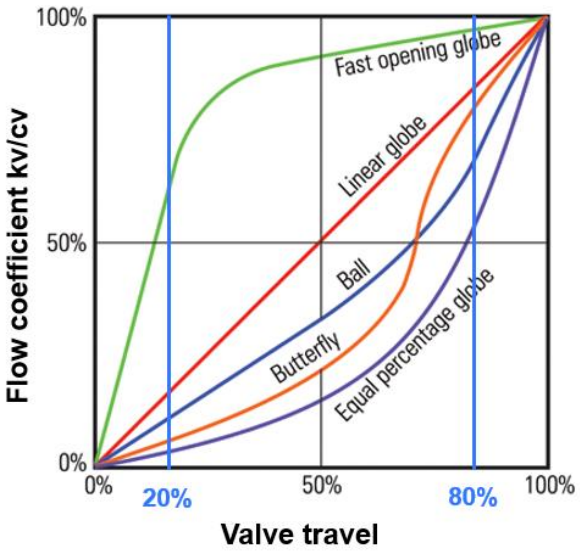
Each type of valve has a unique signature of its flow change when it travels through the stroke. For some valves its predefined by the geometry and physical behaviour of the internal components, while as for other valves the internals can be manipulated in a way, that a specific wanted characteristic is met. In globe valves for example, the shape of the plug or the drillings in a cage which surrounds the plugs can be varied to manipulate the flow behaviour of a valve. The selection of a characteristic is determined by the process and its needs. See the chapter 1.6 as well for details.

The most common characteristics are shown below:

- Linear characteristic
  Found in globe valves or axial valves. A steady change of flow rate throughout the complete range.
- Equal percentage characteristic
  Found in globe valves, axial valves, or special ball valves. A change in travel is not linear but logarithmic.
- Quick opening characteristic
  Slight openings lead to a fast change initially in flow rate. This characteristic is mostly used in on/off applications, where you don't need a flow control or want a quick activation or deactivation of the flow.

- Ball valves
  Most ball valves exhibit a bit of a curved characteristic due to the flow behaviour of the opening itself. However, there are special ball valves internals available from some suppliers to influence this characteristic a little bit.

- Butterfly valves
  Due to the plate in the valve, which is moving, the opening describes a S-shape.



1.6 Installed / Combined characteristics of valve and pipe components

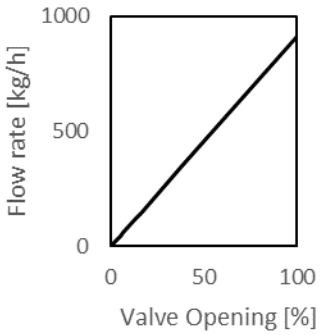
The installed characteristic is simply the behaviour of the complete system where the valve is installed and not only the valve itself. This includes all pipeline components such as orifices, valves, bends, restrictions, and the straight pipes itself. As the flow increases through the valve the upstream and downstream components are experiencing a pressure drop. This changes the inlet and outlet pressures and they will shift the characteristics curve slightly. Also, you may experience other inlet temperatures or similar due to those pressure drops which need to be accounted for as well.

The installed characteristic is seldomly calculated as most of the time with modern control software it is less of an issue. For recycle valves in installations designed as per BC pipeline rules, the installed characteristic is also negligible, as there is no big influence from the piping itself and the pressure drop is always critical (meaning there is no influence at all from the downstream side).

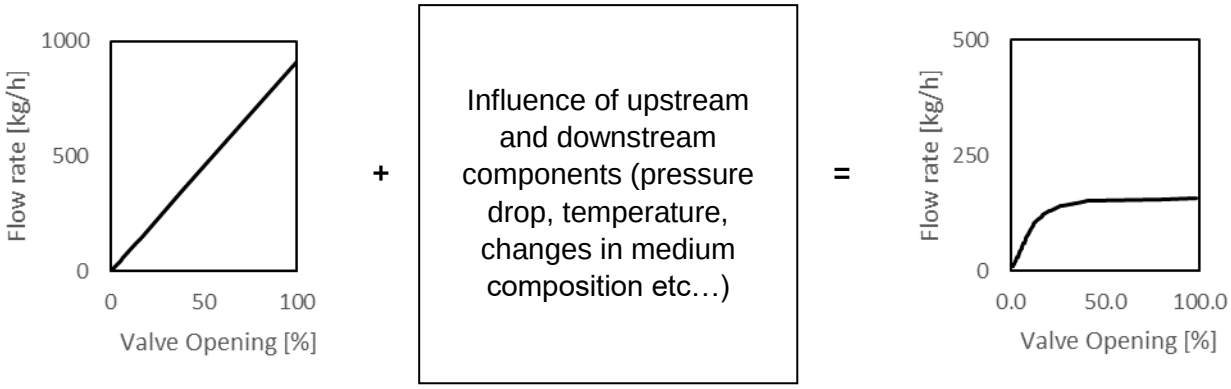
However, in certain moments, especially where high-pressure drops are expected in a pipeline or its components (e.g. installed orifices downstream of the valve), it makes sense to take a closer at it.

For an example see chapter 2.4, where an installed characteristic of a self-controlled valve is calculated.

Example of an inherent Valve characteristic (valve characteristic at constant inlet/outlet conditions):



Example of the same Valve's installed Valve characteristic:



The influence of high pressure drops on the inlet or outlet side is clearly visible. The characteristic tends to flatten off towards higher opening and the related higher flows. A control loop in an automated system is working best if there are linear relationships between travel and flow rate (see also chapter 1.8 for details). Where either high pressure-drops or the physics of the process are leading to such a drop of flow rate towards higher openings, it can be encountered by using a equal percentage characteristic. Equal percentage characteristics are by its shape trending towards a linear installed characteristic in high-pressure drop systems.

Systems with orifices, small pipes, or liquid flows (i.e. pumps) are mostly affected of such an influence. Recycle streams with relatively short pipes designed as per BC line sizing standards are less affected of such a phenomenon. If the process requires a trade-off between characteristic there is the option of a so called "linearization" of the control signal (for example an equal percentage valve must be installed in order to fulfill the accuracy in small flow control but leads to a non-linear behavior in the installed characteristic, therefore contradicting the linear requirement of the control loop). This linearization is giving the control loop the knowledge of the valve flow and the control system can calculate precisely which opening is required to achieve a steady gain of flow at each position of the valve.

1.7 Selection of a specific characteristic

As a general guideline (when no installed characteristic and gain is calculated in detail) the variation of differential pressure across the valve overall operating cases may be used (installed valve pressure drop at min. and max. opening). When the ratio of maximum differential pressure to minimum differential pressure is in the range of 1.2 to 1.5, use linear characteristic, between 1.5 to 2.0 and above that ratio equal percentage is recommended.

When nothing is known it is recommended to select an equal percentage characteristic for discharge pressure control, as the pressure variation of the downstream system depends on the compressor flow in most cases.

For systems controlled by suction pressure, e.g. upstream vessels the tank pressure drop can be assumed to vary linear with the flow consequently linear characteristics shall be chosen.

Plug Types

There are various types of plugs depending on the manufacturer, such as parabolic plugs, throttle plugs, divider plugs etc. in principle, they are designed to gain the desired flow characteristic – see below - and to minimise the noise emission.

Parabolic plugs require flow to open (FTO) direction in order to avoid formation of a Laval-jet and supersonic velocities, whereas throttle plugs require flow to close (FTC) to control the flow characteristic and flow area across the valve stroke.

Balanced plugs shall be used only in clean applications, as they are prone to plugging. Additionally, the requirement for balanced plugs shall be in the responsibility of the supplier/manufacturer. They can calculate and define if it is required to maintain closing/opening speeds and avoid oversizing of the actuator.

Plug Guiding

Guidance of the plug and spindle can be made in various ways: Single or double sided, on the spindle, on an enlarged stem, on the plug or throttle cage etc. Normally, for differential pressures up to 20 bar conventional plugs guided by the spindle only may be used. Parabolic plugs may be used for differential pressures up to 40 bar. However, note that these values largely depend on the nominal diameter of the valve – generally, the larger the size the better guiding of the valve. For even higher differential pressures accessories for multi-stage expansion are required such as throttle cages, throttle plugs, etc.

1.8 Valve gain

Valve gain is an important parameter of a control valve. With gain the change of flowrate throughout the travel is described. Mathematically spoken it is the first derivative of the characteristic's curve.

The gain value gives us a good indication if the flow over a valve is changing fast or slow on one hand. On the other hand, it also indicates us if the change is the same over the complete range of travel or if

we encounter changes in the flow rate change (non-linearities). This is important when you dynamically operate the valve over a big range of flows. Gain shall be checked always at installed conditions and not inherent conditions.

You can calculate the gain with the following formula:

relative valve gain = (Δ relative flow rate) / (Δ opening)

While Δ relative flow rate = (Δ absolute flow rate) / (absolute flow rate at 100% opening)

A linear valve-characteristic for example has a constant gain of 1.0 as the slope of the characteristic is not changing.

For a simple PID controller to work it is recommended to experience the following gain limits in the valve:

Minimum gain = 0.5
Maximum gain = 3.0
Gain (max) / Gain (min) < 2.0
As close to 1.0 as possible
As constant as possible (aim for a linear installed characteristic).

If those values can't be met, a so called linearisation in the control system is necessary. With the linearisation the behaviour of the control valve is known to the control system and it can adapt to its change in behaviour automatically.

2. First valve sizing steps

2.1 Valve sizing and calculation

In this chapter the focus is set onto three types of control valve types often encountered in your daily work. Process control valves for recycling, isolating valves, drain valves and self-regulating valves. The four different types are serving a completely different function and are sized differently as the needs differ.

In case for the recycling valve a user wants to achieve a good and stable control over the complete flow range, while as with an isolation valve a good isolation/shut off capability with a minimal acceptable pressure loss is key. A drain valve handles liquids and encounters in some cases flashing or cavitation during operation. A phenomenon the other valves don't encounter as this is only happening in liquids. A self-regulating valve is as said regulating a pressure or temperature by itself, without the input of a control software.

2.2 Valve sizing for recycling valves

The process described below is broken down into the following steps:

1. Selection of design cases
2. Evaluation of flow values required
3. Selection of a valve characteristic
4. Evaluation of valve body size required
5. Definition of design temperatures and pressures

Selection of Design cases

The selection of suitable design cases is crucial for the use of such valves and sometimes not all information is found in the compressor performance summary. This is especially the cases when a plant is used in different flow configurations and can encounter a high range of different flow and pressure requirements during operation. One example is a boil off gas (LNG Bunker, small vessel with high design pressure, not on shore application) plant where the suction pressure can have large variations and the reciprocating compressor will have from its nature a change in flow-rates due to the change of suction conditions. Another example are plants where consumers with a variable flow demand (such as gas-powered engines) are fed by our compressor unit.

Less complicated are plants where a static service is achieved such as production plants for LDPE or similar, where the process is not undergoing strong fluctuations.

The selection of design cases shall include as minimum the following questions.

1. Start-up Cases
   How is the compressor started?
   Are there temperature differences (e.g. hot pipes after long standstill for cold applications)?
   Can a higher suction pressure occur during such operation?
   What's the start-up medium (Process gas, nitrogen)?

2. Maintenance Cases
   Do you need to consider a nitrogen running case for maintenance or test purposes?
   Do you need to consider a running-in on-site (Laby specific)?

3. Maximum Flow Rates
   Each valve has a limit in flow, either determined by the flow speed or the size of internals itself. Also a control valve loses its ability to precisely control the flow in the range of 90-100% opening and therefore the information of a maximum flow rate to be covered by the valve is crucial.
   Has the valve to be able to cover the complete flow of a stage (100% service) or do you only need to cover a reduced amount (i.e. 50% of the flow over a stage, as valve unloaders are part of the concept), specially check client requirement?
   Are there influences from the process which are influencing the maximum flow rate (e.g. suction pressure changes, discharge pressure changes, suction temperature changes from the process or from the returned process gas)?

4. Minimum Flow Rates
   A valve can't control fluently down to a 0% flow. Especially in case of a recycle valve there is a "jump" in flow rates as soon as you open the valve and the plug starts to move. This leads to a sudden change of flow to the consumers, instead of a smooth transition. Luckily, this phenomenon occurs only at low openings, usually in the range of 0-5% opening. Therefore, a minimum flow rate is given by a valve and if the valve operates in this regime it will start to hunt, as it violently opens and closes in succession.
   Is the process operating with usually low flow values through the valves?
   Are the consumers connected to our plant sensitive to flow or pressure fluctuations?

5. Maximum pressure differences
   A valve is always equipped with an actuator, so that the opening of the valve can be adjusted. The maximum pressure difference is very important to ensure the tight shutoff and the position required can be held and achieved always.

Selection of Valve flow values

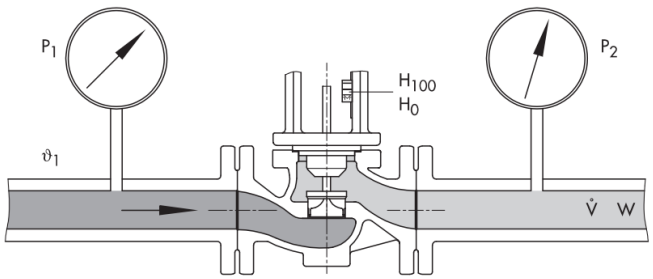
The selection of the valve flow values (cv or Kv) is based on the cases selected. In case of the recycling valve selection the maximum encountered flow value shall be at not more than 90% opening, to ensure a slight tolerance to the rated flow.

At the same time the minimum value of the encountered minimum flows shall be not less than 10% opening. At lower openings a precise regulation is not warranted anymore, although we have

experienced in the field with stable control down to 3-5%. Those two hard limits are ensuring that the valve travel is always in a region where a stable control is possible.

For a first sizing a rough calculation of flow values is sufficient. For this calculation we need for each case:

- The process pressures upstream and downstream the valve
- The process temperature upstream the valve
- The specific density of the medium flowing through the valve. This is the density of the fluid flowing through the valve at 0°C and 1.01325 bara conditions.



p_1 Upstream pressure
p_2 Downstream pressure
H Travel
$\dot{V}$ Volume flow rate in m³/h (gases)
W Mass flow rate in kg/h (liquids, steam)
ρ Density in kg/m³ (general, also in liquids)
ρ_1 Density upstream of the valve in kg/m³ (in gases and vapors)
ϑ_1 Temperature in °C upstream of the valve

Medium / Pressure drop	Liquids m³/h	Liquids kg/h	Gases m³/h	Gases kg/h	Steam kg/h
$p_2 > \frac{p_1}{2}$	$K_V = \dot{V}\sqrt{\frac{\rho}{1000\,\Delta p}}$	$K_V = \frac{W}{\sqrt{1000\rho\,\Delta p}}$	$K_V = \frac{\dot{V}_G}{519}\sqrt{\frac{\rho_G T_1}{\Delta p\ p_2}}$	$K_V = \frac{W}{519}\sqrt{\frac{T_1}{\rho_G \Delta p\ p_2}}$	$K_V = \frac{W}{31.62}\sqrt{\frac{v_2}{\Delta p}}$
$\Delta p < \frac{p_1}{2}$					
$p_2 < \frac{p_1}{2}$			$K_V = \frac{\dot{V}_G}{259.5\ p_1}\sqrt{\rho_G T_1}$	$K_V = \frac{W}{259.5\ p_1}\sqrt{\frac{T_1}{\rho_G}}$	$K_V = \frac{W}{31.62}\sqrt{\frac{2v^*}{p_1}}$
$\Delta p > \frac{p_1}{2}$					

where:

p_1 [bar] Absolute pressure p_{abs}
p_2 [bar] Absolute pressure p_{abs}
Δp [bar] Absolute pressure p_{abs} (differential pressure $p_1 - p_2$)
T_1 [K] $273 + \vartheta_1$
$\dot{V}_G$ [m³/h] Flow rate of gases, related to 0 °C and 1013 mbar
ρ [kg/m³] Density of liquids
ρ_G [kg/m³] Density of gases at 0 °C and 1013 mbar
v_1 [m³/kg] Specific volume (v´ found in the steam table) for p_1 and ϑ_1
v_2 [m³/kg] Specific volume (v´ found in the steam table) for p_2 and ϑ_1
v^* [m³/kg] Specific volume (v´ found in the steam table) for $\frac{p_1}{2}$ and ϑ_1

Notice the use of two formulas in the gaseous and steam cases. One is for critical and the lower one is for non-critical flows. Critical flow means that the pressure exceeds the so-called critical pressure and the valve enters a so-called chocked state. The flow thru a valve increases when the pressure difference is increased. This is valid until you reach the chocked state, where the flow through the valve has reached its maximum. This happens when the pressure difference is so high, that the fluid flowing through the valve is not affected anymore by the downstream pressure. The flow rate won't increase

anymore, even if you lower the downstream pressure. It is now only dependent of the upstream pressure of the valve.

As mentioned, this is for first sizing. The detailed sizing is usually done with equations found in IEC-60534-2 and is iterative, especially when pipe fittings are included. This sizing method also needs specific information from the valve manufacturer to precisely calculate the flow rates. Some manufacturers are offering those valve specific values (e.g. Fisher Catalogue 12 for Emerson Valves) others not.

Example:

Flow value sizing for a valve with three cases:

Nitrogen (Maintenance) Case, Pure Methane full flow and pure methane minimum flow

Case	**Nitrogen**	**Methane Full Flow**	**Methane Min. Flow**
Flow Rate W	6000 kg/h	3800 kg/h	150 kg/h
Inlet Temperature T1	45°C	45°C	45°C
Inlet Pressure p1	6.0 bara	14 bara	14 bara
Outlet Pressure p2	1.0 bara	1.0 bara	1.0 bara

This gives us the following cv values according the formula stated above

Case	**Nitrogen**	**Methane Full Flow**	**Methane Min. Flow**
	p2 > p1 / 2	p2 > p1 / 2	p2 > p1 / 2
Norm Density ρG	1.25 kg/m3	0.71 kg/m3	0.71 kg/m3
Kv (m3/h)	61.5	22.1	0.9
Cv (USGPM)	71.1	25.6	1.0

Selection of Valve characteristic

Control valves can be bought with different types of control valve characteristics. The characteristic selection is mainly driven by your application and how the process reacts. In recycle valves BC generally uses so called equal percentage characteristics or linear characteristics.

The basic difference between those two characteristics is the "controllability" or "rangeability". Controllability means by how much you can reduce the flow through a valve until a stable control is not feasible anymore. This is expressed by a ratio from minimum controllable cv to maximum cv of the valve. Note this is done on installed conditions, therefore any influence of the process and pipe system on maximum and minimum flow conditions must be respected.

Linear valves are usually restricted to a range of 1:10, while as equal percentage valves are enabling a much higher range from 1:50 or in extreme cases 1:100.

Even though a good valve characteristic selected will experience a linear behaviour in the installed condition (see Chapter 1), it can be impossible from time to time to achieve this. A slight variation is allowed and as presented before in the chapter 1 the gain rates are a indication if you will experience issues with the installed valve or not. However, there are ways to work around those issues (called "linearisation") where this variation is known by the control software and can be compensated.

Most of the time a recycle valve is not operating at full flow conditions and needs to be optimized for part-flow conditions. If there are contradicting requirements given and one valve can't meet the requirements for its intended operation point and the maximum flow conditions, a selection of two valves shall be checked (for example a manual bypass of the recycle valve for running in cases). To achieve maximum flow conditions both valves shall operate together, and one is optimized for operational flow control.

Example:

Valve characteristic selection

The flow values have already been established in the example above.

Case	**Nitrogen**	**Methane Full Flow**	**Methane Min. Flow**
Kv (m3/h)	61.5	22.1	0.9

Rangeability needed for a single valve is 1 : (61.5 / 0.9) = 1 : 68. That's only valid if we find a valve with a maximum Kv value of exactly 61.5 but it clearly indicates the use of an equal percentage characteristic or similar.

We know from a supplier that he has different valves available with the following sizes:

2" and 3" body sizes with kv100 of 40
2" body size with kv100 of 47.5
3" and 4" body size with kv100 of 63
3" and 4" body sizes with kv100 of 100

Looking at the two obvious candidates of kv = 63 and kv = 100, both won't be able to achieve a stable minimum flow with a standard valve (assuming 1:50 rangeability). kv_min = 100 * 1:50 = 2 and kv_min = 63 * 1:50 = 1.26.

This is prime example where two cases are contradicting the valve selection. Either the user needs sacrifice the minimum flow control, or the maximum flow regime. Now it depends if a user can adjust the minimum required flow or if he is able to install for example a secondary supplementary hand valve for the nitrogen case to divide the maximum flow through two valves instead of only one.

Another possibility is the use of special characteristics with higher rangeabilities or other valve types (e.g. axial valves) from vendors, which are usually more expensive.

Estimate opening ranges

Openings of valves can be estimated with the following formulas:

For equal percentage valves: $H = \ln(kv_{case} * \tau / kv_{max}) / \ln(\tau)$
For linear valves: $H = kv_{case} / kv_{max}$

Where
H = Opening of the valve in %
kv_{case} = the calculated kv value for the case
kv_{max} = the maximum available kv from the valve
τ = the rangeability of the valve (50 for standard globe valves)

Example:

For the example let's discard the Nitrogen Case and cover this one with a dedicated manual valve which supports the control valve in the maintenance case.

Now our supplier can offer us two different valves with equal percentage characteristics and 1:50 rangeability

2"	valve	with	kv	31.5
2"	valve	with	kv	25.0

Valve	**kv_max = 31.5**	**kv_max**	**=**	**25.0**
kv_case = 22.1	H = 91% open	H =	97%	open
kv_case = 0.9	H = 9% open	H = 15% open		

As previously mentioned, we need to select the valve to operate within 10%-90% regime. Otherwise we sacrifice a stable control on either end.

This shows us that the valve with kv=25.0 will experience on the high flow rates a stability issue and the kv31.5 valve probably on the lower end. It is now up to the engineer to speak to the supplier and select the valve suitable for his needs and choose which flow region is more important during operation.

Evaluation of Body size required

The body size depends mainly on flow speeds through the valve. If there are no other restrictions in place mostly noise and lifetime of the valve internals are a concern. Valve suppliers usually select a valve to operate with velocities up to 0.3 or in extreme cases 0.6 Mach at the downstream side of the valve at the maximum flow condition.

A limit of M=0.6 is intended for valves which are not installed in noise sensitive areas, while as M=0.3 is a reference value for valves which are installed in noise sensitive areas (sound pressure level requirements of <85 dBA).

Use the following formula to estimate the Mach speed.

$$M = m / (3600 * \rho_2 * (d^2/4) * \pi * 1/1000^2 * c)$$

Where

M = Mach Number
m = Mass flow through the valve in kg/h
ρ_2 = density at valve outlet (downstream) in kg/m3
d = valve diameter in DN (mm)
c = speed of sound of medium at valve outlet in m/s

Example:

We have selected the valve to cover only the maximum flow rate of 3800kg/h with pure methane from 6.0 bara inlet pressure to 1.0 bara outlet pressure with 45°C inlet temperature.

For this example, we neglect that the temperature drops at the outlet due to expansion effects. We obtain a speed of sound for Methane at 1.0 bara with 45°C of 461m/s. This gives us the possibly to calculate the flow speed at the valve outlet.

Valve size	**2"/DN50**	**4"/DN100**	**6"/DN150**
Mach at Outlet	1.92	0.48	0.21

Selecting a silent valve would mean we go for a 6" size, if the plant allows more noise, we can reduce the size to 4" and save costs.

A 2" valve would not be possible as speeds Mach >1.0 are not achievable and are resulting in a backpressure from the valve itself.

Definition of Design Temperatures and Pressures

Most of the time the pipeline where the valve is installed is already having a selected design condition for min/max design temperature and min/max design pressure. Those are being driven by process needs and safety consideration such as safety valve setpoints and similar. The recycle valve now is acting as a border between two design regions.

On the upstream side the valve has a higher-class rating of the pipeline with higher design pressures and on the downstream side the valve has also a different set of design limits from the lower stage. A valve must therefore include the extremes of both upstream and downstream pipeline.

Example:

The valve is connected to an upstream pipe with 0°C/+120°C design temperatures and 15 barg design pressure and an downstream pipe with -20/+75°C design temperatures and 5 barg design pressure.

Selecting the most extreme limits of each side, the valve must be designed for -20 / +120°C design temperatures and 15 barg design pressure.

An additional important effect is the temperature drop that happens during expansion of a gas. This effect is called Joule-Thomson Effect and plays an important role if we expand gas from a high pressure to a lower pressure.

Especially with gases close to the dew point, this effect needs to be checked (for example for pressure reducing valve in a propylene system or other heavy hydrocarbons). It must be prevented that the gas will condensate on the discharge side of the valve and form a vapour instead of only a gas phase. If this happens, the designer needs to either adjust the inlet temperature, the pressure drop, or heat trace the pipeline.

The J/T effect can either be estimated with Pressure-Enthalpy Charts or by using specialized software such as PlantCalc or PPDS.

Care shall also be taken when liquid could accumulate downstream in the closed bypass, as the sudden opening of the bypass on the flow of hot gas could lead to flashing of the liquid and serious mechanical damage to valve and piping.

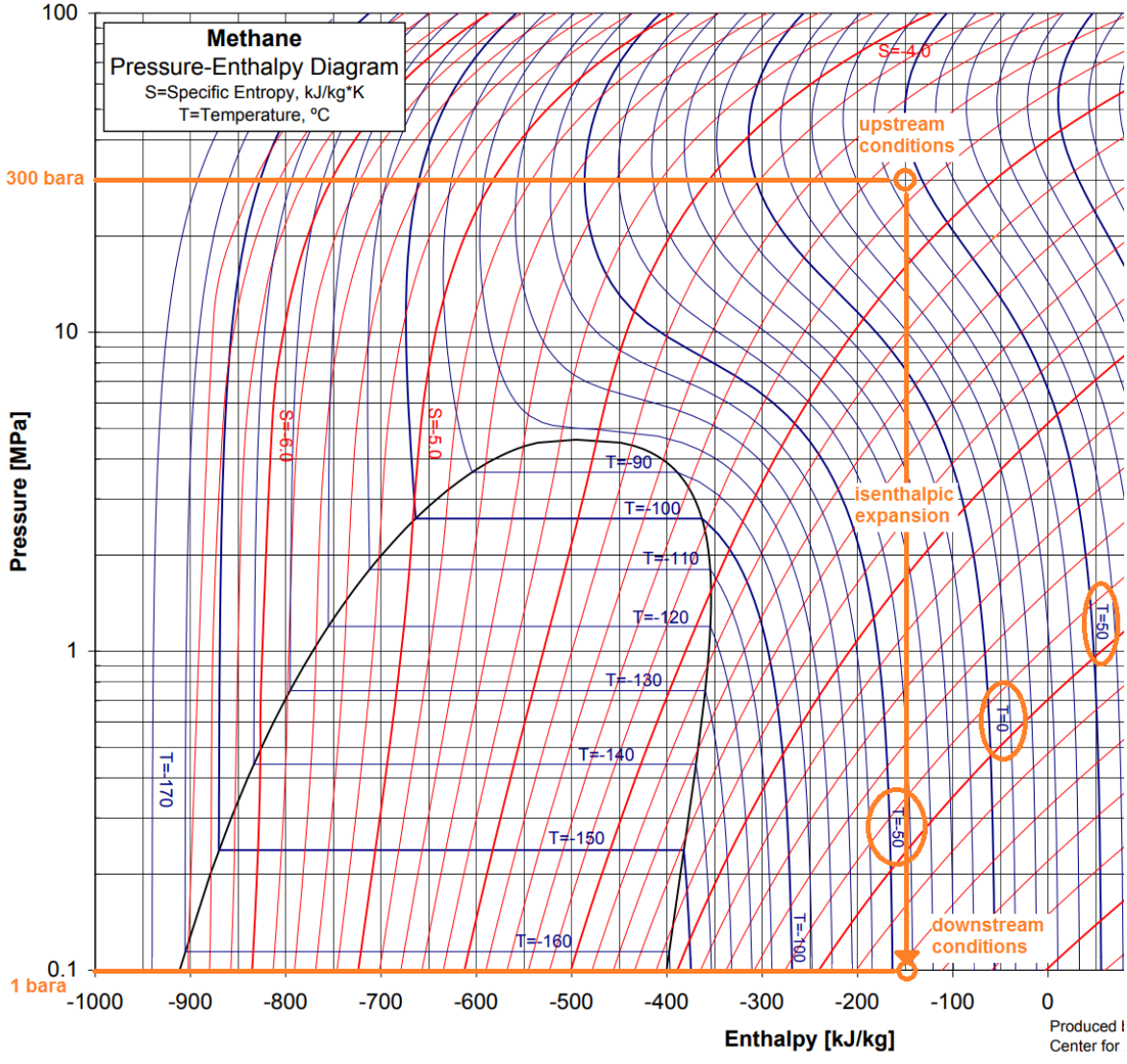
Additionally, ambient temperature has to be taken into consideration. For sake of clarity, the suppliers shall be provided with all upstream/downstream piping design conditions and the ambient temperature.

Example:

A valve is installed as a venting valve and is releasing gas from a 5th stage with a discharge pressure of 300bara to a vent mast with a pressure of 1 bara. Medium flowing through the valve is pure Methane with 45°C when it reaches the valve.

This valve will experience an inlet pressure of 300 bara, 45°C inlet temperature and an outlet pressure of 1 bara. What's the outlet temperature to be expected?

The Joule-Thompson Effect is keeping the Enthalpy of the Gas the same. This is also called isenthalpic expansion. With the help of the Pressure-Enthalpy Diagram (Mollier Diagram) we can find the outlet-temperature of the valve quite easily:



First, we obtain the point where the pressure on the valve inlet (300 bara) and the temperature lines (45°C) (isothermal lines, blue in the chart above) are meeting. This is the point described as "upstream conditions".

From there we draw a vertical line until we reach the outlet pressure (1 bara) and draw a point "downstream conditions". Now we can check the temperature line intersecting this point.

For this example, the result would be roughly -42°C outlet temperature from the valve. Possibly driving the selection of the lower design temperature and restricting the material selection to stainless steels or other non-brittle materials.

For our valve used in the previous example this would mean a need to update the design conditions to -50 / +120°C design temperatures with 15 barg design pressure.

2.3 Valve sizing of isolation valves

Isolation valves are used for another purpose as recycling/controlling valves and are sized differently. The main function doesn't lie anymore with controlling a flow, but rather shutting down or enabling a flow. During operation the pressure drop shall be as low as possible, while maintaining its overall function.

The process described below is broken down into the following steps:

1. Selection of design cases
2. Selection of minimum and maximum valve body size
3. Selection of a valve type
4. Definition of design temperatures and pressures

Selection of design cases

To judge the size of isolation valves cases with the highest flow coefficient requirement. In such a case the pressure drops over the valve will be biggest. To identify the cases, look for

- Low Pressure
  Pressure has a direct influence into the size of a valve as it affects the gas density directly.
- High mass flowrates
  Obviously, the higher the flowrate the bigger the valve needs to be

- Mol weight
  Even though the lower mol weight gases are increasing valve flow coefficients, the flow rate through the compressor itself tends to be higher with higher mol weights.

- High temperatures
  The temperature has much less influence as the factors state above, but still higher temperature gases are creating the need for bigger valves.

- Maximum pressure difference
  A valve is always equipped with an actuator. The maximum pressure difference is very important to ensure the tight shutoff and the position required can be held and achieved always.

The cases above are only one side of an isolation valve. The cases during flow through the valve in open state. The other equally important side of isolation valve is their state during the transition, meaning opening or closing. Some valves are used to shut off equipment during starting or operation of the compressor and are opened only after the compressor has reached its operational pressure. The higher the pressure difference on the two sides, the more important such cases are becoming. As soon as a valve is opening it will lead to a pressure drop on the high-pressure side, as the medium flows to the low-pressure side. The same effect can happen on the downstream side of the valve where a pressure increase can be seen.

The higher the differential pressure is (and the bigger the valve as well), the harsher pressure drop the high-pressure side will experience. This means especially for line filling operations with high differential pressures of the valve's sides, shutoff valves must either be open very slowly or chosen with smaller diameters as it would be necessary if we only regard an state where the medium flows through the valve steadily.

Selection of minimum and maximum valve body sizes

The first and easiest way to select an isolation valve size is to look at the line size where the valve will be installed. The BC regulations of pipe velocities is already leading to valves with small pressure drops. There is seldom the need to install bigger valves as the BC line sizes are designed for low pressure drops and relatively low flow speeds already.

On the other side for some cases it is possible to install a smaller valve as the line size to save some cost. A limit of 2 NPS or DN size ranges is recommended, as this can be covered usually with a single reducer and not adding much distance and welding work.

Smaller valves may be installed if:

- Pressure drop over the valve is still small during operation (usually >0.25% but must be in line with the process needs). For isolation valves which are open during a start-up, the pressure drops and resulting backpressure created shall be especially checked and acceptable.

- No noise level issues are arising due to the smaller valve size

- No turbulence/vibration sensitive equipment is downstream the valve within a distance of 20-40 times the pipe diameter (i.e. thermowells)
- Costs of the smaller valve are in favour of the added welding work on the pipe.

2.4 Valve sizing of self-regulating purge valves

The process to select a self-regulating purge PCV can be made the following way:

1. Selection of design cases
2. Definition of design temperatures
3. Definition of accessories
4. Calculation of the installed characteristic
5. Calculation of the installed gain

Selection of Design Cases

Selecting a PCV for purge applications is much easier as we mostly get one constant condition where the PCV will operate in. The difficulty in PCV's for purge applications is most of the time the small amount of flow delivered into the purged part. This will mostly reduce the size of a valve and an engineer need to be careful to not select too big valves in such a case.

1. Nominal flow case
   The most important part to be checked as the PCV will operate most of the time near this point constantly.
2. Maximum flow case and varying inlet conditions
   Pressure reducing valves (Discharge pressure regulating PCV's) are affected by an effect called "droop". Droop is a deviation from the effective regulated pressure to the wanted and set pressure. This effect takes place if the flow through the valve is higher or lower as when it was when the pressure has been set or inlet conditions are changing. If the flow increases through the valve, the controlled pressure on the discharge side tends to drop. In most systems this effect is negligible, as the variation of flow is not causing severe pressure deviations. If such pressure deviations are causing an issue, a pilot-operated PCV instead of standard-direct-driven PCV's or multiple PCV's in a row can be used to minimize such effects.
3. Check Composition and dew points
   Some purge gas mediums are operated near dew points and need to be heat traced. This includes especially the valve and orifices in the arrangement. The temperature drop during the expansion of the gas can lead to a forming of vapour instead of gas only.

Definition of design temperatures

See the equivalent chapter 2.2 for detailed instructions, as they are the same.

Calculation of installed characteristic

The standard Burckhardt installation for purging application is a valve followed by a restriction orifice. This restriction orifice is installed to warrant a constant and limited flow rate through the complete purge system, no matter the inlet conditions. This is especially important in applications where the pressure in the purged part (e.g. distance piece) can vary by quite a bit. The issue of the orifice is that it influences the characteristic of a control valve heavily. The orifice is increasing the backpressure onto the control valve as the flow increases through the system.

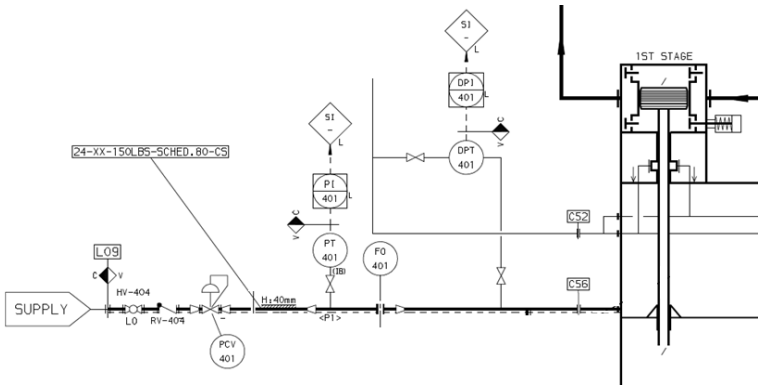


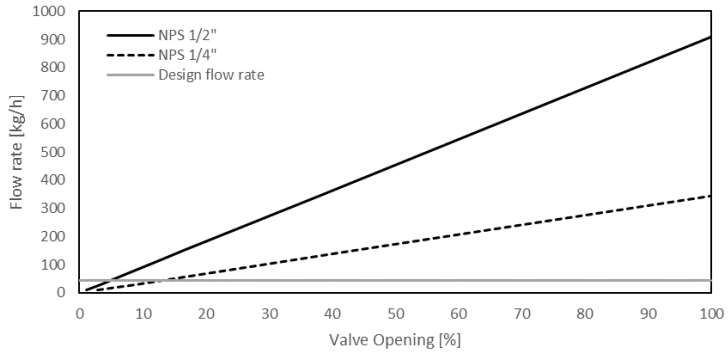
Figure 1: Example of a typical BC purge installation. C56 is the entry point of the purge medium into the compressor distance piece. From there it will flow through the last packing element and exit back into the process at C52.

For ease of calculation in this example the pipes, hand valve HV-404 and check valve RV-404 are neglected, although they will also slightly influence the PCV-401 behavior (depending on their size). For this example, we focus only on the self-regulating valve PCV-401 and the restriction orifice FO-401.

Example:

The purge medium is pure propylene supplied at 17.0 barg with 45°C and a norm density of 1.915 kg/m3. The required flow has been calculated to be 45kg/h for this compressor. The orifice has been sized to 15mm outer diameter with a 3.4mm bore. The PCV's design point is to reduce from 17.0 barg to 5.0 barg with a flow rate of 45kg/h.

Required is a Kv of 0.5. Our supplier presents us two available valves. A NPS1/2" valve with linear characteristic and Kv100 = 2.51 and a NPS1/4" valve with also a linear characteristic but with a Kv100 = 0.95. Without any restrictions in theory the inherent characteristic of the valves looks like on the chart below.



Step 1:
We first calculate the behaviour of the pipeline components, the orifice in this case. We can obtain by calculation the influence onto the process from the orifice itself.

With steps at a few different flow rates to obtain a picture how the backpressure is behaving. Since the orifice is for both available valves the same, we only need to calculate this once.

Flow rate [kg/h]	**10**	**30**	**45**	**60**	**120**	**150**
Orifice inlet pressure [bar g]	0.6	3.1	5.0	6.8	13.4	16.1

Step 2:
The required flow values need to be obtained from the valve for each of the above-mentioned flow rates. Calculation of the required cv-values for both valves can be done with the rough estimation formulas of chapter 2.2 or PlantCalc. Since the orifice is on the outlet of the valve, the orifice inlet pressure becomes the valve outlet pressure.

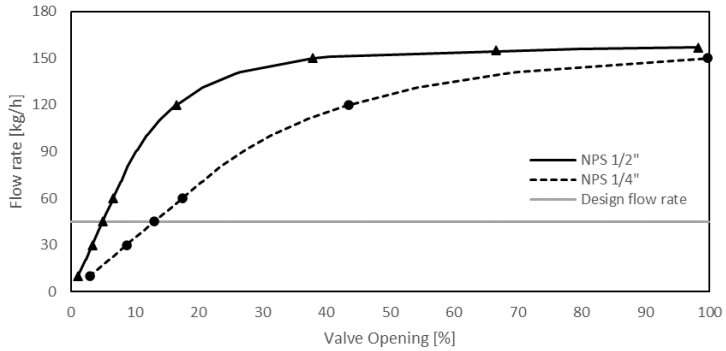
Flow Rate [kg/h]	**10**	**30**	**45**	**60**	**120**	**150**
Valve inlet pressure [bar g]	17.0	17.0	17.0	17.0	17.0	17.0
Valve inlet temperature [°C]	45	45	45	45	45	45
Valve outlet pressure [bar g]	0.6	3.1	5.0	6.8	13.4	16.1
Resulting Kv	**0.028**	**0.083**	**0.124**	**0.166**	**0.414**	**0.950**

Step 3:

The openings of the valve at the calculated Kv Values need to be found. Since the vendor offered linear valves, this is quite easy, and no specific characteristic curves need to be looked up. For the linear case, the opening can be estimated by dividing the required Kv by the Kv100 of the valve.

Flow Rate [kg/h]	**10**	**30**	**45**	**60**	**120**	**150**
Calc. opening NPS ½" Valve [%]	1	3	5	7	16	38
Calc. opening NPS ¼" Valves [%]	3	9	13	17	43	100

Plotting those data onto a chart the installed characteristic of the valve can now be seen. It is visible that the behaviour of the valve is not linear anymore. With the orifice in the back the flow rate starts to drop off at higher openings, instead of steadily increasing. This is a significant change and our maximum flow rate reduced from theoretical 900 kg/h to approximately 160kg/h.



The chart shows additionally two effects: Firstly, the difference at the required design point of 45 kg/h flow is quite significant. The NPS ½" valve operates at 5% opening, while as the NPS ¼" valve operates at roughly 13%.

Secondly the maximum possible flow rate through the complete is not very different of each other, even though the bigger valve has roughly 2.5 times more flow just looking on the Kv100 values. The influence of the downstream restriction orifice is well visible.

Calculation of the installed gain

Installed gain has a high effect on stability of the process. If a valve is oversized, it may cause instabilities as the change in flow rate is too fast and the valve won't be able to find a stable operation point. It may experience hunting, where the position is fluctuating and oscillating. To avoid those issues the installed gain needs to be checked.

The method described here is for controlled valves and can be assumed to be working as well for self-regulating valves. Self-regulating valves tend to be faster in control reactions, compared to controlled pneumatic valves.

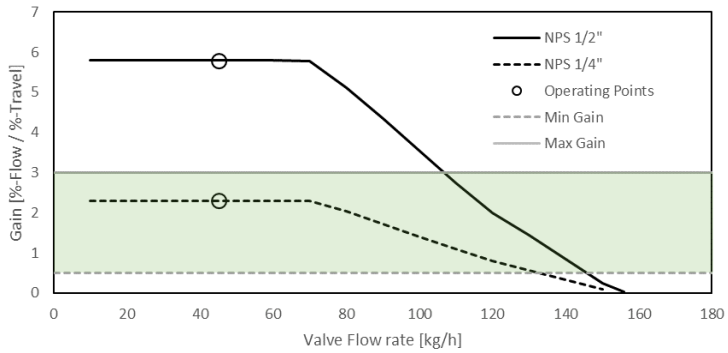
Example:

Using the above example and the definition of relative gain from chapter 0, we can obtain the slopes for the valve. An easy estimation is to calculate at the specified points an increase of the flow values by small increments or use the already calculated values in case a linear behaviour is found. In the example such a linear behaviour seems to happen between 0 – 60kg/h and it is easy to calculate the gain values in such a way.

Flow rate	**45kg/h**	**60kg/h**
Calc opening NPS ½" valve	4.9%	6.6%
Calc opening NPS ¼" valve	13.0%	17.4%

To determine the relative flow, increase the maximum flow rates of the valves is needed from the installed characteristic.

Valve size	**NPS ½"**	**NPS ¼"**
Maximum flow rate at 100%	157kg/h	150kg/h
Absolute flow increase	15kg/h	15kg/h
Relative flow increase	15kg/h / 157 kg/h = 9.6%	15kg/h / 150kg/h = 10 %
Relative travel increase	6.6% - 4.9% = 1.7%	13.0% – 8.7% = 4.3%
Relative gain	9.6% / 1.7% = 5.6	10% / 4.3% = 2.3



Step by step the complete valve gain can be calculated throughout the whole flow range. This plot above shows the different gain characteristics of the two offered valves. It is visible that at the operation point of 45kg/h the smaller valve has a nice operation in the recommended gain range, while the NPS ½" may encounter stability issues with such a high gain value.

3. Valve detailed sizing

3.1 Valve leakage class

Leakage class (leakage of the seat)

The leakage class defines the “internal” leakage of a valve. It measures the amount of gas/liquid flowing through the closed valve. Depending on the application a valve is allowed to have some leakage or none (almost none, since leakages can't be avoided to 100%).

There are several regulatory standards which are defining leakage rates and classes. The most important one are:

- IEC 60534-4 (mirrored from ANSI/FCI 70-2)
- API 598
- API 6D
- ISO 5208 (equivalent to API 6D but also mirrors API 598 and API 6D)
- DIN EN 1349

API 6D is generally used in pipeline valves and not of our interest for reciprocating compressor plants usually. The ISO 5208 and IEC 60534-4 are mostly used to define control valve leakages.

Both IEC 60534-4 and ISO 5208 can be used to classify a leakage rate for a valve. However, IEC 60534-4 (or FCI 70-2) is mostly used for control valves, while ISO 5208 is used for shut-off/isolation valves. A main difference between the two codes is the leakage rates specified and the test method.

API 598/ISO 5208 is generally used when a zero-leakage valve needs to be specified, as it allows for no visual leakage.

It is recommended to choose a propriate leakage for the function of the valve. In general BC uses the leakage class IEC 60534-4 / FCI 70-2 Class IV. The allowable leakage in this class is 0.01 % from the rated Kv value), independent of seat diameter. Note that this test is carried out with air or water at maximum of 3.4 bars differential pressure (50psid) and not the operational pressure. This is a special requirement to be mentioned if high shutoff pressures are expected in operation and the valve needs to isolate the process from another.

If you operate the valve in an isolation function and at high differential pressures, class V is recommended. This class is tested with water at max. service pressure drop and allows 0.0005ml/min per inch of orifice diameter. Class VI is only for soft seated valves and usually not of our concern as mostly metal seated valves are used.

A step further is the ISO5208 Rate A and API 598 "zero-leakage" valve ratings, where no visible leakage is allowed at test conditions. Test conditions vary on the valve type used, as they require sometimes a high-pressure closure test and not only a low-pressure closure test. For globe valves a high-pressure closure test is in those standards always required.

BCA generally specifies the leakage class of valves as per IEC 60534-4. A seat leak test is included and the relevant criteria for the test are also described in the above code.

Shut off leakages are in the following order:

- IEC 60534-4 / FCI 70-2 Class VI lies somewhere between ISO 5208 Rate A and AA
- IEC 60534-4 / FCI 70-2 Class V lies somewhere between ISO 5208 Rate D and E
- IEC 60534-4 / FCI 70-2 Class IV is the worst of all above mentioned leakage rates, however still suitable for recycle valves and similar and the BCA standard in this regard

Tightness class (leakage of the stem or shaft seals)

The tightness class defines the “external” leakage of a valve. It measures how much of gas flows from the pressurized part of the valve through the stem or shaft seal into the ambient. It is independent of the valve position.

BCA generally specifies the tightness class of valves as per ISO 15484-1, Class C

(≤ 10^{-2} mg / s m). This tightness typically achieved with flexible graphite-based packings.

Tightness class B (≤ 10^{-4} mg / s m) should be used for light gases (e.g. H2) and can typically be achieved with PTFE based packings or elastomeric seals.

Highest tightness class A (≤ 10^{-6} mg / s m) should be used in case of toxic gases or if client requests best possible tightness of the valves. Tightness class A typically can be achieved with below seals or equivalent stem (shaft) sealing systems for quarter turn valves.

In case of light process gas, tightness test should be done by the use of helium, which will be specified with the annex “H” to the character of the tightness class.

Example of tightness specification according ISO 15484-1 for a valve with tightness according Class B, tested with Helium: “BH”

3.2 Valve fail safe position

The fail-safe position is defined as the position in case of air or power failure. It is achieved by the location of the spring inside the actuator either inwards or outwards.

For all applications other than oxygen, the BCA fail safe position for recycle valves is one to unload the machine. For **oxygen**, the fail-safe position is closed, in order to avoid spreading of a potential fire across the bypass. Isolation valves usually have a closed position. If an isolation valve is installed up or downstream the compressor a high-pressure trip (discharge side isolation) and low-pressure trip (suction side isolation) must be included accordingly in the plant.

3.3 Valve noise

When expanding gas, a valve is emitting noise. This noise level is depending on the outlet speed reached inside the valve and the pressure drop itself. The higher the pressure drop the higher the noise. The same is valid for higher flow speeds at the outlet of the valve (respectively in the vena contracta, the narrowest stream diameter of the expanding stream). That's why valve manufacturers are limiting the valve speeds to 0.3 Mach usually.

If noise issues are encountered there are several possibilities to encounter them.

Noise reducing valve internals

Valve internals to reduce noise are most of the time either

- The division of a single stream into multiple smaller streams with less energy in it (drilled cages)
- A multistage throttling where a stream is throttled over multiple stages and the pressure drop is spread onto those multiple stages instead of a single one.
- A combination of the two above

Throttle cages enable noise reduction by up to 18 dB(A). However, they must be used for clean gases only, as else plugging could occur leading to collapse of the wire mesh cage. They must also not be used for **oxygen**, as complete degreasing is not attainable.

One stage throttle plugs may be used for dirty, non-abrasive fluids. Throttle plugs are typically executed as cylindrical cage with drilled holes welded to the plug. Check the size of the holes if such a cage is chosen for dirty fluids (e.g. PP).

Multi-stage throttle plugs enable noise reduction by up to 30 dB(A).

All noise reducing internals are prone to higher fouling and clogging when used in combination with dirty fluids.

External insulation

Valve insulation can effectively reduce noise of a valve. However, since the noise is transported with the stream, a big enough portion of the valve's discharge piping must be insulated to prevent noise emissions.

Valve size

A bigger valve is leading to lower flow speeds. This is most of the time in contrary with the used operation range of the valves, as they tend to be oversized for the application at hand.

External orifices, silencers, or silencer packs

As another option for noise reduction is to install a set of orifices with increasing diameters installed outside and downstream the valve to facilitate multi-stage expansion.

A big advantage is especially seen in recycle or vent valves. Most of the time the pressure drops over those valves are high and on the discharge side of the valve high flow speeds are existing. With a orifice installed downstream the valve not only noise is influenced, but (since it creates a defined backpressure) the density and therefore the flow speed as well. If a orifice is chosen also the valve size can be reduced in most of the times, thus saving costs and increasing the range of possible Kv-ratings a engineer can chose from.

If no influence on the valve's installed characteristic is required, the orifices and downstream piping shall be selected in way that the discharge pressure is not exceeding half the inlet pressure in all conditions (p/2 rule).

A drawback is the additional calculation needed for the orifices as they're influence can limit the maximum valve flow rate. Several valve suppliers are having such packs already in their standard portfolio and can calculate them together with the valve. Important: Include start-up conditions especially in this condition to keep the immediately built-up backpressure during start to a manageable level.

3.4 Cavitation and Flashing

Cavitation may occur in drain valves with heavy hydrocarbons. There are several papers from Samson to estimate the probability of cavitation and flashing. See the document L351ENv2.2.vp (samsongroup.com).

Cavitation means that the expanding liquid will drop during the expansion through the valve shortly below the vapor pressure. It will however after the full expansion return to be fully liquid. This drop is creating bubbles which then burst again. It leads to erosion and reduced capacity. Reduced capacity comes from the high change in density during the expansion in the valve.

Flashing means that the expanding liquid will drop during the complete expansion below the vapor pressure. In the contrary to cavitation the medium will transition from liquid to vapor and stay in the vapor phase.

3.5 Valve materials

In principle the body material of the valve shall be the same as the piping connected to it.

Wet and corrosive gases e.g. CO2 require stainless steel or even NACE compliant material.

Saline environment and high temperatures require use of duplex steels or alloys like Hastelloy, etc.

For all internal parts, stainless steel is the standard material as the stress upon the internals is much higher than on the body.

Oxygen service requires special consideration. As a minimum all parts shall be made of high-alloyed stainless steel. Depending on the service parameters and client specifications, e.g. the use of Monel for internal parts and bronze for the body needs to be considered. Special care shall be applied to non-

metallic material e.g. gaskets and seals that must be suitable for oxygen service as well and the degreasing of all internal surfaces.

In addition, for oxygen service valves shall fulfil the requirements of the EIGA Guidelines, e.g. 33/06 for oxygen cleaning. Valves for oxygen service are described more in detail in TDO 2023990 E08.

3.6 Seat

Normally metallic seats are used to obtain leak class IV without further action. For leak class V seat lapping and increased actuator force are required. Metallic seats can be bought with standard surfaces or hardened surfaces (e.g. Stellite coating). This is especially useful in abrasive applications or when encountering high pressure drops.

For higher rated leak classes (less leakage, e.g. leak class VI), soft seats made of PTFE (PTFE has limited temperature range, see stem packing) or UHMW-PE is required. They are rolled into the metallic plug. However, they shall be avoided due to their reduced durability in comparison to a small gain of additional tightness. Moreover, soft seats are normally not suitable for oxygen service.

For details on internal valve seat leakage, see chapter 3.1.

3.7 Stem packing

Friction in the stem greatly influences the control performance and actuator sizing and selection. Typical materials used for the packing are PTFE or Graphite. PTFE may be used for temperatures up to 180°C, with provisions up to 250°C. PTFE has low specific friction coefficients and is resistant against most fluids. However, for temperatures above that and for fire-safe applications, graphite must be used. Graphite tends to stick and increasing friction with the adverse effects already explained.

Note that for maintenance reasons, the packing must always be outside any insulation. Tightening of the packing is obtained with means of an integral nut or an outside latch. The latch is more flexible and allows the PTFE to expand, needing less maintenance. Spring-loaded latches provide constant pre-tension forces and are nearly maintenance free, but costly.

For details on leakage of the packing to the ambient, see chapter 3.1.

The leakage rate of the stem packing is independent of the seat leakage and is regulated in DIN EN 12266. Leakage rates of standard packings are largely dependent on application of the right torque to the packing and are hence susceptible to error, change upon wear, etc. Packings designed for low leakage as e.g. per “TA Luft” are designed with spring-loaded latches (see above) and obtain leakage rates of 10^{-4} mg / (l*m*s), if lower leakage rates are required, bellows are needed on the stem, which make leakage rates of 10^{-6} mg / (l*m*s) obtainable.

3.8 Bonnet extension

Bonnet extensions are required when the spindle packing needs to be elongated. This may be due to heating requirements, high temperatures (usually above 250°C), low temperatures (usually below -30°C medium temperature), toxic, strong smell or vacuum. Other reasons could also be double packing with gas detector for toxic gases such as CO, long flow packing for lightweight and flammable gases such as H_2 or low temperature applications.

In low temperature applications, it is important that it is ensured the cold fluid does not circulate within the bonnet - e.g. by means of displacement - to avoid icing of the bonnet and spindle that would lead to complete valve blockage. This is achieved by lengthening the bonnet accordingly. The same is achieved for bonnets for high temperature, to avoid overheating of the sealing elements.

Toxic mediums or with strong smell are usually fought with a bellows sealed bonnet, to prevent any loss of gas to the ambient.

4. Valve accessories

4.1 Actuators

Pneumatic/ hydraulic, spring opposed

The majority of control valves i.e. more than 80% used to control the process gas flow are actuated by pneumatic actuators. Pneumatic actuators have a simple design, an inherent fail-safe position and may be used within explosive zones.

The spindle is connected to a membrane that is on one side loaded with pressure from instrument air or nitrogen, on the other by a spring. High control forces require large membranes or double membranes i.e. two actuators in a row, making actuating forces up to ca. 100 kN possible.

Due to limitations of the membrane durability and the electronics, operating temperatures of the actuator must not exceed 80°C. If the fluid temperature is very high and may radiate to the actuator, this is also a consideration for the use of extended spindles.

For higher control forces (90-155 kN) and larger strokes, double acting piston actuators are available (in standard program of Flowserve). Due to smaller size of the actuator the more sophisticated construction of this type of actuator can be more economical.

Electrical / magnetic actuators require special provisions to obtain a fail-safe position and allow only comparatively low control speeds. Therefore, they are mostly limited to ON/OFF applications and not used for control purposes in our range of applications.

For even higher actuation forces, hydraulically actuated valves with solenoid valves are used (e.g. Booster/Primary for LDPE).

Fail safe position

The fail-safe position is defined as the position in case of air or power failure. It is achieved by the location of the spring inside the actuator either inwards or outwards.

For all applications other than oxygen, the BCA fail safe position is one in an effort to unload the machine. For oxygen, the fail-safe position is closed, in order to avoid spreading of a potential fire across the bypass.

Travel speed

Full stroke time of control valves shall be in the range of 10 to 50 seconds – depending on valve size - when controlled via the positioner. The large the stroke the longer the control time will be.

When quick opening or quick closing is required, such as e.g. for oxygen applications, the positioner shall be normally bypassed using appropriate solenoid valves, see below, and the actuator shall open or close the valve within 1.0 to 1.5 and maximum 2 seconds. The minimum time feasible depends on the Kv flow coefficient of the solenoid valve, the air tube diameter, membrane area and valve stroke – the larger the stroke and the actuator the longer the time. Large valves may need up to 3 seconds for quick action.

For large volume actuators i.e. above 700 cm2 of membrane area, the use of boosters may be considered to increase available air flow and reduce travel times.

4.2 Positioner

Standard positioner used have a 4...20 mA current/pressure signal or I/P- converter. The positioner gets a current signal that is converted into a certain pressure in the actuator. In relation with the back force from the spring a certain stroke, CV - value and hence flow is achieved.

Options include the possibility for a HART-protocol that allows readout of all valve parameters and functions in the field and the use of digital positioners such as foundation fieldbus (FF) or profibus.

Care should be taken when combining certain types of signals with certain types of protection as not all combinations are easily available.

The positioner shall be configured in a way that avoids frequent and fast control within a small range as this leads to excessive wear.

Additions for analogue positioner (as for the feedback and limit switches) are standardized by NAMUR, for digital positioners by VDI 3845/3847 – which is reputedly complicated –or by manufacturer standards.

4.3 Position Feedback

Generally, the achievement of the desired stroke is monitored via a position feedback. The analogue feedback is mechanically linked to the spindle via a lever. Turning the lever creates an electrical output signal that is generally the same as the input signal, i.e. analogue.

The feedback may principally be external or internal to the positioner, whereas internal is the rule as it provides compact design and protection.

Digital positioners are directly linked to the spindle and are feeding back a digital signal, which is integral to the positioner.

4.4 Limit Signals

If only the open and closed positions are important or in addition to the feedback signals increased reliability is needed, limit switches are built onto the valve. This could be either positioner built-in mechanical switches or proximity switches. In many cases, clients require the mounting arrangement and electrical connection as per the NAMUR standard, to guarantee the exchangeability of such switches.

4.5 Solenoid valves

Solenoid valves are required to achieve fast open and fast close functionalities. May be required where the speed of control exerted from the positioner is deemed to slow, e.g. for full travel at start-up or quick-close for shutdown.

This is achieved by adding a solenoid valve in parallel to the positioner, which is either depressurizing the actuator, or pressurizing with full pressure. Depending on the configuration of the valve this will open or close the valve immediately.

4.6 Air Set

An air set shall be integral part of the control valve assembly. It serves to set and monitor the pressure onto the positioner and ensure it is constant. The set pressure of the positioner must be larger or equal to the pressure required by the actuator and smaller than the minimum pressure of the supply. This is trivial but still a frequent source of errors.

For fast opening or closing, a booster can be helpful in order to provide the short time excess flow as tubing may be too small to allow the flow required.

An inlet filter and sinter metal silencer on the outlet is also deemed a standard accessory.

5. Installation notes

5.1 Pulsations

The valves which operate in the main process stream must be designed to withstand pulsations in the attached piping of 4% peak-to-peak of the line side pressure and residual vibration of the attached piping of 10 mm/s RMS.

5.2 Straight piping upstream and downstream of valves

There is quite some discussion going on for installation of straight pipe runs upstream and downstream of pipes (e.g. 3 or 10 diameters length). Reasoning is most of the time to allow the flow to settle the turbulence. This is especially useful in measurement applications, such as flow orifices. For control valves this is less of an issue, as there is no measurement in close areas. In a valve a high amount of turbulence is created, that it would take quite long to settle them just with pipe runs.

Exceptions are self-controlled valves with pressure tapping downstream the valve and turbulence sensitive equipment (e.g. heavy thermowells).

For pressure tapings, obstructions which influence the measurement directly shall be avoided within 10 diameters of the valve (e.g. flow limiting orifices, which create a high-pressure peak on the orifice inlet). Pressure sensitive equipment shall be installed as far away as possible.

For noise sensitive applications it is preferred to achieve a long straight pipe run downstream of the valve. But other noise reducing measures are more efficient and a straight pipe length should not be governed by noise reduction measurements.

5.3 Installation

Suppliers provide clear guidance on how valves shall be installed, and how not. Often, that information is already supplied together with the offer. If not, ask your supplier to additionally provide it. Afterwards, align with CAD so that the valves are installed in the correct direction. Check if actuators are allowed to be hanging.

5.4 High- and very high-pressure applications

For high differential pressures across the control valve, i.e. above 50 bar, special attention shall be paid toward the rigidity of the design of the internals, especially the guidance of the control plug and spindle to avoid breakage of internals. Guiding diameter of the spindle and distance from the force at the plug must be considered. Throttle plugs that guide the plug in the seat across the complete stroke are an alternative to tail-rod spindles guided at both ends. This requires the use of four-flange bodies that are more expensive.

This may also necessitate the use of multiple actuators.

For very high differential pressures above approximately 150 bar, control valves of the angular type (design similar to PSV) valves are recommended.

5.5 Bypass heating and cooling

Most gases – except gases with low molecular weight such as H2 or He – will cool down due to the isentropic expansion in the valve.

Depending on the valve inlet temperature, e.g. when after cooling is not available, additional cooling of the bypass may be required in order to avoid an increase of suction temperature.

On the other hand, when the cooling down effect due to expansion is large, e.g. with ethylene at high pressure, heating of the bypass may be required to avoid condensation.

Care shall also be taken when liquid could accumulate downstream in the closed bypass, as the sudden opening of the bypass on the flow of hot gas could lead to flashing of the liquid and serious mechanical damage to valve and piping.

6. Applicable Standards and Codes

General testing of valves is standardized in DIN EN 12266. IEC 60534 parts 1-6 covers all aspects of design, sizing, dimensions, testing, marking, mounting of attachments and noise evaluation of control valves. Of course, mandatory regulations such as PED and ATEX need to be considered if applicable.

7. Other Requirements for Completing Specifications

7.1 Name plates

- As a standard, TAG number shall be mentioned on the valve nameplate in addition to what is specified by the valve design standard. Fixation of nameplates to valves shall be permanent.
- Although as a standard practice, the technical specification calls for stainless steel nameplates and TAG plates, plastic plates with TAG numbers engraved are acceptable.

7.2 Surface treatment

- Stringent control & specification is required for critical gases like oxygen and new vendors.
- Painting – Generally, manufacturer's standard painting system could be acceptable. Special painting procedure or colours will have impact on cost and delivery.
- Preservation – Manufacturer's standard could be used after review of his procedures. Oxygen service valves should be sealed in plastic bags for protection after cleaning.

7.3 Packing

- Normal road worthy packing for delivery to BC –Oberwinterthur is sufficient for BCAG deliveries.

- Take special care for oxygen cleaned parts. They are packed and sealed. The sealing must not be opened before installation in the plant and warning signs are recommended to be placed on the packing to avoid early opening (for example for packing inspections or goods receiving inspection).

7.4 Inspection & Documentation

Client's requirements should be followed. As a minimum it shall include testing as per IEC 60534-4, i.e. hydraulic testing of the valve body, seat leak testing. For pressurized components and internals, a 3.1 certificate shall be provided.

For complex valves, testing along with the control unit or panel is recommended and a standard at Burckhardt Compression.

8. Economic Considerations

Apart from the material selection as required by the gas and special requirements, the nominal size of the valve will define its cost. Accordingly, this needs to be considered appropriately.

For the design flow, consider that normally a bypass valve will not have the full flow, but will operate at part load conditions only. Also consider combination with other means of flow control and the minimum and maximum differential pressure in operation (cf. above point 3.1). The valve shall be optimised for the flow most likely to be controlled.

Further on, the manufacturer shall consider that a part of the expansion will not be realised within the valve, but in the associated downstream piping due to the backpressure that will build up from pressure loss in piping and overcritical flow. The backpressure considered can be up to - but shall not be larger than -half of the inlet pressure (p/2 rule).

If valves with differential pressures up to 50 bar are to be evaluated, only valves with equal guaranteed noise levels can be sensibly compared with each other.

For high differential pressures, different technical solutions need to be evaluated for their overall suitability, cf. paragraph **Error! Reference source not found.**.

9. References / Standards

API618	Reciprocating Compressor for Petroleum, Chemical, and Gas Industry Services (5th edition 2007)
PlantCalc	Calculation module available
KV5036	Cleaning Requirements for Valves
TDO 2023990 E08 Rev.0	White Book Oxygen Control Valves