CONTROL VALVE (GAS) SIZING CALCULATOR

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Introduction

This document describes the basis and operation of the Blackmonk Engineering Control Valve (Gas) Sizing Calculator.

The calculation methodology is based on that described in Emerson Control Valve Handbook 4th Edition. This methodology uses the International Electrotechnical Commission (IEC) procedure.

The calculator determines the control valve flow coefficient (Cv) required to pass a specified flow rate given the upstream and downstream pressure of the control valve, the fluid properties, the valve pressure drop ratio factor and the pipe geometry factor.

The calculator also determines the ratio of specific heats factor, the effective pressure drop ratio factor, the expansion factor and determines if the flow through the valve is choked.

The calculator is applicable to the sizing of gas and vapour control valves for non-choked and choked flow.

Calculation Inputs

The following parameters are user specified inputs to the calculation:

Input	Description	Units
Gas mass flow rate	Mandatory user specified mass flow rate of gas through the control valve	kg/hr
Upstream pressure	Mandatory user specified upstream pressure	bara
Downstream pressure	Mandatory user specified downstream pressure	bara
Fluid density	Mandatory user specified fluid density	kg/m^3
Gas ratio of specific heat capacities	Mandatory user specified gas ratio of specific heat capacities	N/A
Pressure drop ratio factor	Mandatory user specified valve pressure drop ratio factor	N/A
Piping geometry factor	Mandatory user specified piping geometry factor to account for pipe fittings installed immediately upstream and/or downstream of the valve	N/A

Calculation Outputs

The following parameters are calculated by the software and displayed to the user:

Output	Description	Units
Ratio of specific heats factor	Ratio of the gas ratio of specific heat capacities to 1.4	N/A
Pressure drop across valve	Upstream pressure – Downstream pressure	bara
Pressure drop ratio	Ratio of pressure drop across valve to upstream pressure	N/A
Critical flow?	If the pressure drop ratio is less than the product of ratio specific heats factor and pressure drop ratio factor the flow is sub-critical, otherwise the flow is critical (also known as choked)	N/A
Effective pressure drop ratio	The lower of pressure drop ratio and the product of ratio specific heats factor and pressure drop ratio	N/A
Expansion factor	Gas expansion factor based on the effective pressure drop ratio	N/A
Valve flow coefficient	Calculated valve flow coefficient	N/A

Flow of Liquids Through a Control Valve

The valve flow coefficient for a liquid control valve is determined from the following equation:

$$Cv = \frac{w}{27.3 F_P Y \sqrt{X_{eff} P_1 \rho}}$$ **Equation 1**

Effective Pressure Drop Ratio, X_{eff}

The effective pressure drop ratio across the control valve is the ratio of the pressure drop across the valve to the upstream pressure for sub-critical flow or the product of the ratio of specific heats factor and pressure drop ratio factor for critical flow.

The flow is sub-critical if:

$$X < F_k X_T$$ **Equation 2**

Where:

$$X = \frac{(P_1 - P_2)}{P_1}$$ **Equation 3**

For sub-critical flow:

$$X_{eff} = \frac{(P_1 - P_2)}{P_1}$$ **Equation 4**

For critical flow:

$$X_{eff} = F_k X_T$$ **Equation 5**

Ratio of Specific Heats Factor

The ratio of specific heats factor is defined by the following equation:

$$F_k = \frac{k}{1.4}$$ **Equation 6**

Expansion Factor, Y

The expansion factor accounts for the expansion of gas flowing through the valve as the pressure reduces from inlet to outlet. The expansion factor is the ratio of flow coefficients for a gas to that for a liquid at the same Reynolds number. The expansion factor must be less than or equal to a value of 0.667. The following equation defines the expansion factor:

$$Y = 1 - \frac{X_{eff}}{3F_k X_T}$$ **Equation 7**

Pressure Drop Ratio Factor, X_T

The pressure drop ratio factor is the pressure drop ratio required to produce critical flow through the valve when F_k is equal to 1.

The valve pressure drop ratio is measured experimentally and is tabulated in valve manufacturers catalogues.

Piping Geometry Factor, F_P

The piping geometry factor is an allowance for the pressure drop associated with fittings that may be connected directly upstream and/or downstream of the valve. Most commonly, the fittings connected to a control valve are an upstream and downstream reducers. If no fittings are connected to the valve, the piping geometry factor is 1.

The piping geometry factor is often listed in valve manufacturers catalogues. It can also be calculated using:

$$F_P = \left[1 + \frac{\Sigma K}{0.00214}\left(\frac{Cv}{d_{valve}^2}\right)^2\right]^{-0.5}$$ **Equation 8**

For a valve installed with identical upstream and downstream reducers, the total resistance coefficient is given by:

$$\Sigma K = 1.5\left(1 - \frac{d_{valve}^2}{d_{pipe}^2}\right)^2$$ **Equation 9**

Calculation of Valve Flow Coefficient

The required valve flow coefficient is determined from the specified flow rate, upstream and downstream pressures, fluid density, ratio of specific heat capacities, pressure drop ratio factor and the piping geometry factor.

First, the calculator determines the ratio of specific heats factor using Equation 6. Then the calculator determines the pressure drop across the valve and the pressure drop ratio using Equation 3. The calculator then checks if the flow is critical using Equation 2. The effective pressure drop ratio is then calculated using Equation 4 if the flow is sub-critical or Equation 5 if the flow is critical. The expansion factor is then calculated using Equation 7.

The valve flow coefficient is then determined using Equation 1.

The calculation routine is described in the following steps:

1. Calculate ratio of specific heats factor, F_K
2. Calculate pressure drop across the valve
3. Calculate pressure drop ratio, X
4. Calculate if flow is sub-critical or critical
5. Calculate effective pressure drop ratio, X_{eff}
6. Calculate expansion factor, Y
7. Calculate valve flow coefficient, Cv

Nomenclature

$\rho =$ Density of fluid (kg.m^{-3})
$d_{pipe} =$ Pipe nominal diameter (in)
$d_{valve} =$ Valve nominal diameter (in)
$Cv =$ Valve flow coefficient (dimensionless)
$F_P =$ Piping geometry factor (dimensionless)
$X_T =$ Pressure drop ratio factor (dimensionless)
$F_k =$ Ratio of specific heats factor (dimensionless)
$w =$ Flow rate through valve (kg.h^{-1})
$\Delta P =$ Pressure drop across valve (bar)
$X =$ Pressure drop ratio (dimensionless)
$X_{eff} =$ Effective pressure drop ratio (dimensionless)
$P_1 =$ Upstream pressure (bara)
$P_2 =$ Downstream pressure (bara)
$k =$ Gas ratio of specifi c heat capacities (dimensionless)
$Y =$ Expansion factor (dimensionless)
$\Sigma K =$ Total resitance coefficient of upstream and downstream fittings (dimensionless)

Example

The following example was taken from Emerson Control Valve Handbook 4th Edition Page 121.

Description:

Find the valve flow coefficient for a control valve in liquid propane service given the following data:

$q = 6 \times 10^6$ scfh = 169900 m^3/hr
P_1 = 214.7 psia = 14.81 bara
P_2 = 64.7 psia = 4.46 bara
ΔP = 150 psi = 10.34 bara
T_1 = 60F = 15.6C
Mol Wt. = 17.38
G_g = 0.60
k = 1.31
X_T = 0.137
F_P = 1

Solution:

Density of gas at inlet conditions = $(14.81 \times 10^5 \times 17.78) / (8314 \times 288.6)$ = 10.72 kg/m^3

Mass flow rate of liquid, w = 169900 x 10.72 = 124536.7 kg/hr

Calculated valve flow coefficient = 1517 (cf: Emerson published result of 1515)

Control Valve (Gas) Sizing Calculator Screenshot:

INPUTS

Gas mass flow rate	w	124536.7	kg/hr
Upstream pressure	P_1	14.81	bara
Downstream pressure	P_2	4.46	bara
Fluid density	ρ	10.7	kg/m^3
Gas ratio of specific heat capacities	k	1.31	
Pressure drop ratio factor	X_T	0.137	
Piping geometry factor	F_P	1.00	

OUTPUTS

Ratio of specific heats factor	F_k	0.9357	
Pressure drop across valve	ΔP	10.3500	bar
Pressure drop ratio	X	0.70	
Critical flow?		YES	
Effective pressure drop ratio	X_{eff}	0.128	
Expansion factor	Y	0.667	
Valve flow coefficient	**Cv**	**1516.7679**	