CONTROL VALVE (LIQUID) SIZING CALCULATOR

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Contents

Introduction

This document describes the basis and operation of the Blackmonk Engineering Control Valve (Liquid) 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 liquid recovery factor and the geometry factor.

The calculator also determines the liquid critical pressure ratio factor, the maximum allowable sizing pressure drop, the effective pressure drop and determines if the flow through the valve is choked.

The calculator is applicable to the sizing of liquid control valves for non-flashing and flashing flow of liquids.

Calculation Inputs

The following parameters are user specified inputs to the calculation:

Input	Description	Units
Liquid mass flow rate	Mandatory user specified mass flow rate of liquid 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
Fluid vapour pressure	Mandatory user specified fluid vapour pressure at the upstream temperature	bara
Fluid critical pressure	Mandatory user specified fluid critical pressure	bara
Valve liquid pressure recovery factor	Mandatory user specified valve liquid pressure recovery 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
Liquid critical pressure ratio factor	Factor used to determine the pressure drop across the valve at which critical flow occurs	N/A
Maximum allowable sizing pressure drop	Pressure drop across the valve at which critical flow occurs	bara
Critical flow?	If maximum allowable sizing pressure drop is less than (Upstream pressure – Downstream pressure), the flow is critical (also known as choked)	N/A
Effective pressure drop	The lower of (Upstream pressure – Downstream pressure) and the maximum allowable sizing pressure drop	bara
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:

$$Cv = \frac{w}{27.3 F_P \sqrt{\Delta P_{eff}\,\rho}}$$ **Equation 1**

Where ΔP_{eff} is the effective pressure drop across the control valve.

Effective Pressure Drop

The effective pressure drop across the control valve is the difference between the upstream pressure and the downstream pressure for sub-critical flow or the maximum allowable sizing pressure drop for critical flow.

The flow is sub-critical if:

$$P_1 - P_2 < \Delta P_{max}$$ **Equation 2**

For sub-critical flow:

$$\Delta P_{eff} = P_1 - P_2$$ **Equation 3**

For critical flow:

$$\Delta P_{eff} = \Delta P_{max}$$ **Equation 4**

The maximum allowable sizing pressure drop is the pressure drop corresponding to critical flow of liquid through the valve:

$$\Delta P_{max} = F_L^2 \left(P_1 - F_F P_v \right)$$ **Equation 5**

Liquid Critical Pressure Ratio Factor, F_F

The liquid critical pressure ratio factor is a means of estimating the pressure at the vena contracta of the valve under critical flow conditions. It is used in the determination of the maximum allowable sizing pressure drop. The liquid critical pressure ratio factor is given by:

$$F_F = 0.96 - 0.28\sqrt{\frac{P_v}{P_c}}$$ **Equation 6**

Valve Liquid Pressure Recovery Factor, F_L

The valve liquid pressure recovery factor is the ratio of effective pressure drop to the pressure difference between the upstream pressure and the vena contracta pressure.

The valve liquid pressure recovery factor is usually measure 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 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 7**

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 8**

Calculation of Valve Flow Coefficient

The required valve flow coefficient is determined from the specified flow rate, upstream and downstream pressures, fluid density, vapour pressure and critical pressure, the valve liquid pressure recovery factor and the piping geometry factor.

First, the calculator determines the liquid critical pressure ratio factor using Equation 6. Then the calculator determines the maximum allowable sizing pressure drop using Equation 5. The calculator then checks if the flow is critical using Equation 2. The effective pressure drop is then calculated using Equation 3 if the flow is sub-critical or Equation 4 if the flow is critical.

The valve flow coefficient is then determined using Equation 1.

The calculation routine is described in the following steps:

1. Calculate liquid critical pressure ratio factor, F_F
2. Calculate maximum allowable sizing pressure drop
3. Calculate if flow is sub-critical or critical
4. Calculate effective pressure drop
5. Calculate valve flow coefficient

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)

$F_L =$ Valve liquid pressure recovery factor (dimensionless)

$F_F =$ Liquid critical pressure ratio factor (dimensionless)

$w =$ Flow rate through valve (kg.h^{-1})

$\Delta P_{eff} =$ Effective pressure drop across valve (bar)

$\Delta P_{\max} =$ Maximum allowable sizing pressure drop across valve (bar)

$P_1 =$ Upstream pressure (bara)

$P_2 =$ Downstream pressure (bara)

$P_v =$ Fluid vapour pressure (bara)

$P_c =$ Fluid critical pressure (bara)

$\Sigma K =$ Total resitance coefficient of upstream and downstream fittings (dimensionless)

Example

The following example was taken from Emerson Control Valve Handbook 4th Edition Page 117.

Description:

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

q = 800 gpm = 181.8 m^3/hr
P_1 = 300 psig = 314.7 psia = 21.70 bara
P_2 = 275 psig = 289.7 psia = 19.98 bara
ΔP = 25 psi = 1.72 bara
T_1 = 70F = 21C
G_f = 0.50 => ρ = 500 kg/m^3
P_v = 124.3 psia = 8.57 bara
P_c = 616.3 psia = 42.50 bara
F_P = 0.97
F_L = 1.0

Solution:

Mass flow rate of liquid, w = 181.8 x 500 = 90987 kg/hr

Calculated valve flow coefficient = 117.0 (cf: Emerson published result of 116.2)

Control Valve (Liquids) Sizing Calculator Screenshot:

INPUTS

Liquid mass flow rate	w	90897.0	kg/hr
Upstream pressure	P_1	21.70	bara
Downstream pressure	P_2	19.98	bara
Fluid density	ρ	500.0	kg/m^3
Fluid vapour pressure	P_v	8.57	bara
Fluid critical pressure	P_c	42.50	bara
Valve liquid pressure recovery factor	F_L	1.00	
Piping geometry factor	F_P	0.97	

OUTPUTS

Liquid critical pressure ratio factor	F_F	0.8343	
Maximum allowable sizing pressure drop	ΔP_{max}	14.55	bar
Critical flow?		NO	
Effective pressure drop	ΔP_{eff}	1.72	bar
Valve flow coefficient	**Cv**	**117.0485**	