RESTRICTION ORIFICE PLATE (LIQUID) SIZING CALCULATOR

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Introduction

This document describes the basis and operation of the Blackmonk Engineering Restriction Orifice Plate (Liquid) Sizing Calculator.

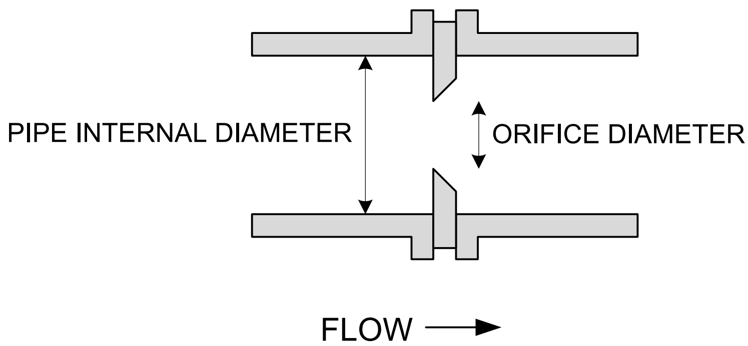
The calculation methodology is based on that described in Crane Technical Paper 410M “The Flow of Fluids Through Valves, Fittings and Pipes”.

The calculator determines the orifice size required to limit the flow of a liquid to a specified flow rate given the permanent pressure loss across the orifice and the pipe diameter in which the restriction orifice plate is to be installed.

The calculator also determines the orifice flow coefficient, orifice velocity head loss coefficient and the pressure difference across the orifice between 1 pipe diameter upstream and 0.5 pipe diameters downstream of the orifice plate.

The calculator is applicable to the flow of incompressible fluids through square and sharp-edged orifices.

System Diagram



Calculation Inputs

The following parameters are user specified inputs to the calculation:

Input	Description	Units
Permanent pressure loss across orifice	Mandatory user specified permanent pressure loss across the orifice plate	bar
Fluid density	Mandatory user specified fluid density	kg/m^3
Fluid viscosity	Mandatory user specified fluid viscosity	cP
Flow rate	Mandatory user specified flow rate	m^3/hr
Pipe internal diameter	Mandatory user specified pipe internal	mm

	diameter	

Calculation Outputs

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

Output	Description	Units
Orifice velocity head loss coefficient	Permanent pressure loss across orifice expressed in terms of velocity head loss	N/A
Beta ratio	Ratio of the calculated orifice diameter to the pipe internal diameter	N/A
Reynolds number	Fluid Reynolds number based on the pipe internal diameter	N/A
Flow coefficient	Orifice flow coefficient	N/A
Pressure difference across orifice	Unrecovered pressure loss across orifice equivalent to the pressure difference between 1 pipe diameter upstream and 0.5 pipe diameters downstream of the orifice plate	bar
Orifice flow area	Cross sectional area of the orifice	m^2
Calculated orifice diameter	Calculated orifice diameter	mm

Flow of Liquids Through an Orifice

The flow of an incompressible fluid through an orifice is determined from the following equation:

$$Q = CA\sqrt{\frac{2\Delta P_{orifice}}{\rho}}$$ **Equation 1**

Where $\Delta P_{orifice}$ is the pressure difference across the orifice between 1 pipe diameter upstream and 0.5 pipe diameters downstream of the orifice. This downstream location approximates to the position of the vena contracta of the flowing fluid where the fluid pressure is at a minimum.

Permanent Pressure Loss Across Orifice

Some pressure is recovered downstream of the vena contracta as the fluid velocity reduces as the fluid returns to flowing in the full cross-section of the pipe. The fully recovered downstream pressure, typically 4 to 8 pipe diameters downstream of the orifice, is therefore higher than the pressure 0.5 pipe diameter downstream of the orifice.

The permanent pressure loss across the orifice can be approximated by (Ref: Perry's Chemical Engineering Handbook 7th Ed, Page 10-16):

$$\Delta P_{permanent} = \Delta P_{orifice}\left(1 - \mathrm{B}^2\right)$$ **Equation 2**

In designing a restriction orifice plate, it is the permanent pressure loss that is specified. The pressure difference across the orifice must then be estimated using by rearranging the above equation:

$$\Delta P_{orifice} = \frac{\Delta P_{permanent}}{\left(1 - \mathrm{B}^2\right)}$$ **Equation 3**

Alternatively, the permanent pressure loss across the orifice can be expressed as a velocity head loss coefficient (Ref: Crane Technical Paper 410M "Flow of Fluids Through Valves, Fittings and Pipes" Page A-20):

$$K_{permanent} = \frac{\left(1 - \mathrm{B}^2\right)}{C^2 \mathrm{B}^4}$$ **Equation 4**

Flow Coefficient

The flow coefficient, C, accounts for the reduction in effective flow area through the vena contracta as a fluid flows through an orifice and frictional effects. The flow coefficient is a function of:

- Reynolds number
- Beta ratio (orifice diameter : pipe internal diameter)

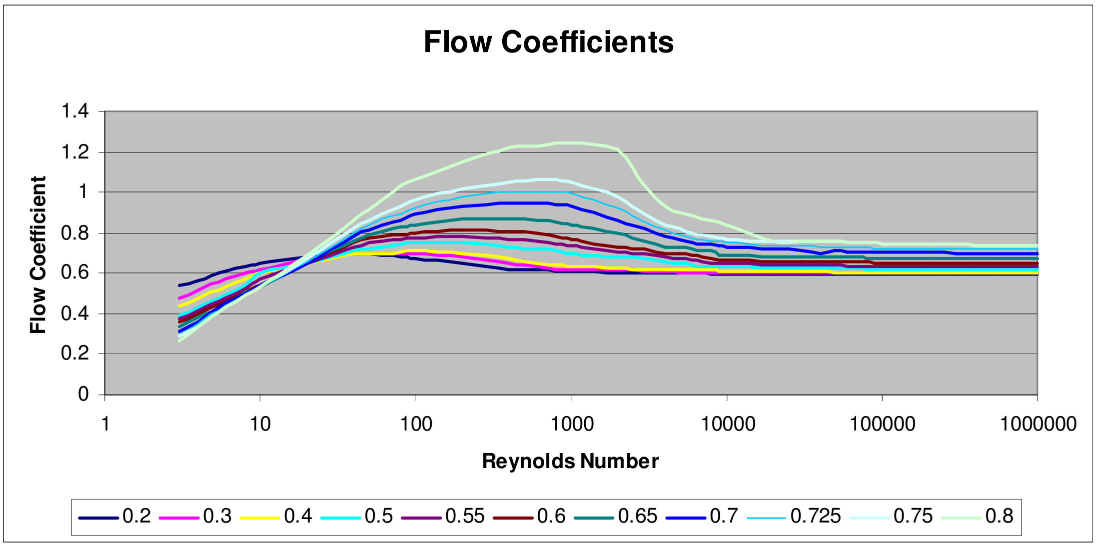
Flow coefficients are determined experimentally.

Various numerical correlations have been developed for determining the flow coefficient through orifices but each correlation is only accurate for a specific range of Reynolds number and beta ratios.

This calculator uses a database of flow coefficients derived from the curves presented in Crane Technical Paper 410M representing all Reynolds numbers greater than 3 and Beta ratios from 0 to 0.8.

Note: Reynolds number used in this calculation is the pipe Reynolds number based on the pipe internal diameter and fluid velocity in the pipe.

Chart 1: Flow Coefficients for Orifices



Beta Ratio

The beta ratio is defined as the ratio of the orifice diameter to the pipe internal diameter:

$$B = \frac{d_{orifice}}{d_{pipe}}$$ **Equation 5**

Reynolds Number

Reynolds number is determined using the relationship:

$$Re = \frac{4Q\rho}{\pi\mu d_{pipe}}$$ **Equation 6**

Orifice Flow Area

The orifice flow area is given by:

$$A_{orifice} = \frac{\pi d_{orifice}^{\ 2}}{4}$$ **Equation 7**

Calculation of Orifice Diameter

The required orifice diameter is determined from the specified permanent pressure loss across the orifice, the fluid density, fluid viscosity, the specified flow rate and the internal diameter of the pipe in which the orifice plate is to be located.

First, the calculator determines the Reynolds number using Equation 6. Then the calculator makes an initial estimate of the beta ratio. The calculator then estimates the flow coefficient based on the Reynolds number and beta ratio. Next, the calculator estimates the pressure difference across the orifice using Equation 3.

The orifice diameter is then estimated using the beta ratio directly according to Equation 8 below:

$$d_{orifice} = \mathrm{B} d_{pipe}$$ **Equation 8**

The orifice diameter is also estimated using the rearranged orifice equation:

$$d_{orifice} = \left[\frac{4Q}{\pi C} \sqrt{\frac{\rho}{2\Delta P_{orifice}}} \right]^{0.5}$$ **Equation 9**

The 2 estimates of the orifice diameter generated by Equation 8 and Equation 9 are then compared. If the 2 values are equivalent within the tolerance of 0.01 mm, the orifice diameter is defined and the calculation routine is complete. If the 2 values are not within the specified tolerance, the beta ratio is re-estimated and the calculation steps are reiterated until the 2 estimates of the orifice diameter are within tolerance.

The orifice velocity head loss coefficient and orifice flow area are calculated for information during each iteration.

The calculation routine is described in the following steps:

1. Calculate Reynolds number
2. Estimate Beta ratio
3. Estimate flow coefficient using Beta ratio estimate
4. Estimate orifice velocity head loss coefficient
5. Estimate orifice diameter using Beta ratio estimate directly
6. Estimate pressure difference across orifice
7. Estimate orifice diameter using the estimated flow coefficient in the orifice equation
8. Compare calculated orifice diameters from Step 5 and Step 7
9. If the 2 calculated orifice diameters are equal, the orifice diameter is defined and the calculation has been solved.
10. Re-estimate Beta ratio
11. Re-iterate calculation procedure from Step 3 to Step 9 until orifice diameter is defined

To solve the calculation accurately, the beta ratio must be ≤ 0.8. The calculator generates a warning if the beta ratio is out of this range.

Nomenclature

$\rho =$ Density of fluid (kg.m^{-3})
$\mu =$ Viscosity of fluid (Pa.s)
$d_{pipe} =$ Pipe internal diameter (m)
$d_{orifice} =$ Orifice diameter (m)
$\mathrm{Re} =$ Reynolds number (dimensionless)
$C =$ Flow coefficient (dimensionless)
$A_{orifice} =$ Orifice flow area (m^2)
$Q =$ Flow rate through orifice (m^3.s^{-1})
$\Delta P_{orifice} =$ Pressure difference across orifice (Pa) $= P_1 - P_2$
$\Delta P_{permanent} =$ Permanent pressure loss across orifice (Pa) $= P_1 - P_3$
$P_1 =$ Upstream pressure [1 pipe diameter upstream of orifice] (Pa)
$P_2 =$ Downstream pressure [0.5 pipe diameter downstream of orifice] (Pa)
$P_3 =$ Fully recovered downstream pressure [4 to 8 pipe diameters downstream of orifice] (Pa)
$K_{permanent} =$ Orifice velocity head loss coefficient (dimensionless)
$\mathrm{B} =$ Orifice diameter : Pipe internal diameter (dimensionless)

Example

The following example was taken from Crane Technical Paper 410M "Flow of Fluids Through Valves, Fittings and Pipes" Example 4-12.

Description:

Find the diameter of a thin-plate orifice that must be installed in a pipe to restrict the velocity of water to 3 m/s at 15C.

The system consists of:

- 12" nominal size ISO 336 steel pipe with 11 mm wall thickness
- Orifice velocity head loss coefficient: 4.91

Fluid density = 999 kg/m^3
Fluid viscosity = 1.1 cP

Pipe internal diameter = 301.9 mm

Flow rate = $\pi/4 \times (0.3019)^2 \times 3 = 0.21475\ m^3/s = 773.1\ m^3/hr$

Permanent pressure loss across orifice = $4.91 \times 3^2 / 2 \times 999 = 22073$ Pa = 0.22 bar

Solution:

Calculated orifice diameter = 207.7 mm (cf: Crane published result of 208 mm)

Restriction Orifice Plate (Liquids) Calculator Screenshot:

INPUTS

Permanent pressure loss across orifice	$\Delta P_{permanent}$	0.22	bar
Fluid density	ρ	999	kg/m3
Fluid viscosity	μ	1.10	cP
Flow rate	Q	773.10	m3/hr
Pipe internal diameter	d_{pipe}	301.9	mm

OUTPUTS

Orifice velocity head loss coefficient	$K_{permanent}$	4.894	
Beta ratio	B	0.688	
Reynolds number	Re	822532	
Flow coefficient	C	0.693	
Pressure difference across orifice	$\Delta P_{orifice}$	0.418	bar
Orifice flow area	$A_{orifice}$	0.03388	m2
Estimated orifice diameter		207.7	mm
Calculated orifice diameter	$d_{orifice}$	**207.7**	**mm**