Sizing Equations

This document provides the following sizing equations:

1 Nomenclature

A	Required effective discharge area, $inch^2$
A1	Exposed surface area, $inch^2$
B	Diameter at tip, in
C	Discharge coefficient
CV	Valve flow coefficient, US gallon per minute of water (60 °F) at 1 psi pressure drop
C_r	Coefficient for critical flow equation, dimensionless
C_s	Speed of sound, m/s
C_p	Speed of sound in pipe wall, m/s
D	Internal pipe diameter (upstream) at flow temperature, mm
D_0	Internal pipe diameter (upstream) at ambient temperature, mm
D_t	Nominal size of sensing element, in
D_1	Inlet internal diameter of the pipe, mm
D_2	Outlet internal diameter of the pipe, mm
D_{d2}	Outlet outside diameter of the pipe, m
DP	Pressure differential, P_1-P_2 , or differential pressure transmitter range, bar
DP_A	Maximum allowable pressure drop , bar
DP_{loss}	Pressure loss, bar
DP_n	Differential pressure at normal flow rate, bar
Dbh	Bleed/Vent hole diameter, mm
D_j	Diameter of the jet, m
d	Valve inlet diameter or orifice (throat) diameter at flow temperature, mm
d_0	Orifice (throat) diameter at ambient temperature, mm
E	Module of Elasticity at 70 °F, psi-g

E_f	Acoustical efficiency factor, dimensionless
Eps	Gas expansion factor, ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number, dimensionless
F	Environment Factor, dimensionless
F1	Heat Absorption Factor, dimensionless
F_2	Coefficient for subcritical flow equation, dimensionless
F_d	Valve style modifier, dimensionless
F_F	Liquid critical pressure ratio factor, dimensionless
F_k	Ratio of specific heats factor, 1/K, dimensionless
F_L	Liquid pressure recovery factor, dimensionless
F_{LP}	Product of the liquid pressure recovery factor of a valve with attached fittings and the piping geometry factor, dimensionless
F_p	Piping geometry factor, dimensionless
F_R	Reynolds number factor, dimensionless
F_s	Correction factor for steam quality, dimensionless
f_p	Peak frequency, Hz
f_o	Coincidence or Natural frequency, Hz
f_r	Ring frequency, Hz
f_w	Wake frequency, Hz
G_f	Liquid specific gravity (ratio of density of liquid at flowing temperature to density of water at 15.6 °C), dimensionless
G_g	Gas specific gravity (ratio of density of flowing gas to density of air with both at standard conditions, which is equal to the ratio of molecular weight of gas to the molecular weight of air), dimensionless
HS	Segmental height at flow temperature, mm
HS_0	Segmental height at ambient temperature, mm
HV	Heat of vaporization, J/kg
K	Specific Heat Ratio, C_p/C_v dimensionless

K_1,K_2,K_{b1},K_{b2}	Effective velocity head coefficients, dimensionless
K_C	Cavitation index, dimensionless
K_{CD}	Relative capacity, CV/d^2
K_{CV}	Valve cavitation index, dimensionless
K_b	Capacity correction factor due to back pressure, dimensionless
K_{cc}	Combination capacity factor for rupture disk at the relief valve inlet, dimensionless
K_d	Effective coefficient of discharge, dimensionless
K_f	Constant for thermowell calculation, dimensionless
K_n	Correction factor for Napier equation, dimensionless
K_p	Correction factor for overpressure, dimensionless
K_{sh}	Superheat steam correction factor, dimensionless
K_v	Correction factor for viscosity, dimensionless
K_w	Correction factor for back pressure, dimensionless
L	Maximum thermowell length, in
L_a	"A"-weighted sound level, dB(A)
L_g	Correction for pipe Mach number, dB
L_{pi}	Internal sound pressure level, dB
M	Molecular weight, atomic mass units
MN	Mach number in pipe, dimensionless
MN_0	Mach number in valve outlet, dimensionless
M_j	Mach number in the jet, dimensionless
N_o	Number of flow passages , dimensionless
P	Absolute static pressure, bar
P_C	Absolute thermodynamic critical pressure, bar
P_V	Absolute vapor pressure of liquid at inlet temperature, bar

P_{VC}, P_{VCC}	Absolute pressure in vena contracta at subsonic and critical flow conditions, Pa
P_{2c}, P_{2b}, P_{2ce}	Border pressures for different noise regimes, Pa
P_a	Absolute outside pipe pressure, Pa
P_b	Total back pressure, psi-g
P_{b1}	Constant back pressure, psi-g
P_{b2}	Variable back pressure, psi-g
P_{cf}	Critical flow throat pressure, psi-a
P_{over}	Overpressure, %
P_s	Set pressure, psi-g
P_{up}	Upstream relieving pressure, psi-a
R	Limitation on Wake to Natural frequency ratio, dimensionless
RO	Density at flow conditions (upstream), kg/m^3
RO_p	Density of pipe material, kg/m^3
R_f	Ratio of frequency at fluid temperature to frequency at 70 °F, dimensionless
RS_0	Segmental radius at ambient temperature, mm
Re	Valve (pipe) Reynolds number, dimensionless
Re_{max}, Re_n	Pipe Reynolds number at maximum and normal flow rate, dimensionless
Rq	Radius of upstream profile of Quarter of circle orifice, mm
SRF	Scale reading factor, $10 \times W_n/W_{max}$
St	Water in steam, %wt
T	Flow temperature, K
T1	Gas temperature at relieving conditions, °R
T_0	Ambient temperature, K
T_c	Thermodynamic critical temperature, K
T_L	Transmission loss, dB

T_{Lfo}	Transmission loss at coincidence frequency, dB
T_{Lfr}	Transmission loss across the pipe wall at the ring frequency, dB
T_w	Vessel Wall Temperature, °R
U	Velocity, m/s
V	Velocity, ft/s
W	Flow rate, kg/h
W_{max}, W_n	Maximum and normal flow rate, kg/s
W_a	Sound power, W
W_m, W_{ms}	Stream powers, W
wall	Pipe wall thickness, m
X	Ratio of pressure drop to absolute inlet pressure (DP/P_1), dimensionless
X_T	Pressure drop ratio factor, dimensionless
X_{TP}	Value of X_T for valve-fitting assembly, dimensionless
Z	Compressibility at operating conditions, dimensionless
Z_b	Compressibility at base conditions, dimensionless
α_p, α_{pe}	Linear expansion coefficient of pipe and primary element material, 1/°C
β	Diameter ratio of orifice or throat and inside diameter of line
ΔL_f	Correction value for cavitating flow, dB
ΔT_{Lfp}	Correction for ratio of peak frequency and coincidence frequency, dB
η	Acoustic efficiency factor, dimensionless
μ	Absolute (dynamic) viscosity, Pa×s
ν	Kinematic viscosity, centistokes

Subscripts

0	First estimate
1	Upstream conditions
2	Downstream conditions
VC	Vena Contracta

2 Control Valve Sizing

2.1 Liquid, Water.

2.1.1 Calculate F_F:

$$F_F = 0.96 - 0.28\sqrt{\frac{P_V}{P_C}}$$

2.1.2 Calculate ν:

$$\nu = 10^6 \cdot \mu / RO$$

2.1.3 Calculate K_C:

$$K_C = \frac{P_1 - P_2}{P_1 - P_V}$$

2.1.4 Calculate effective velocity head coefficients:

$$K_1 = 0.5 \cdot \left(1 - d^2 / D_1^2\right)^2 \qquad K_2 = \left(1 - d^2 / D_2{}^2\right)^2$$

$$K_{b1} = 1 - \left(d / D_1\right)^4 \qquad K_{b2} = 1 - \left(d / D_2\right)^4$$

$$\sum K = K_1 + K_2 + K_{b1} - K_{b2} \qquad K_i = K_1 + K_{b1}$$

2.1.5 Calculate first value of CV:

$$CV_0 = \frac{W}{27.3 \cdot \sqrt{\left(P_1 - P_2\right) \cdot RO}}$$

2.1.6 Calculate F_P:

$$F_P = \left(\frac{\sum K \cdot CV_0{}^2}{0.00214 \cdot d^4} + 1\right)^{-1/2}$$

2.1.7 Calculate K_{CV}:

$$K_{CV} = F_L\left(F_L\left(1.66667 F_L - 2.428571\right) + 1.869048\right) - 0.3077143$$

2.1.8 Calculate F_{LP}:

$$F_{LP} = F_L \cdot \left[\frac{K_i \cdot F_L^{\ 2} \cdot CV_0^{\ 2}}{0.00214 \cdot d^4} + 1 \right]^{-1/2}$$

2.1.9 Calculate Re:

$$\mathrm{Re} = \frac{76000 \cdot F_D \cdot W}{\nu \cdot RO \cdot \left(F_L \cdot CV_0\right)^{0.5}} \cdot \left(\frac{\left(F_L \cdot CV_0\right)^2}{0.00214 \cdot d^4} + 1 \right)^{0.25}$$

2.1.10 Calculate DP_A:

$$DP_A = \left(\frac{F_{LP}}{F_P} \right)^2 \left(P_1 - F_F P_V\right)$$

2.1.11 Calculate F_R.

At this stage, the following cases for different *Re* are possible

2.1.11.1 Case $\mathrm{Re} \le 56$ **- Laminar flow**

$$F_R = 0.019 \cdot \mathrm{Re}^{0.67}$$

2.1.11.2 Case $56 < \mathrm{Re} < 40000$ **- Transitional flow**

2.1.11.2.1 $56 < \mathrm{Re} \le 620$ $Az = \mathrm{Re}/56 - 1$

$$F_R = -6.082774 \cdot 10^{-5} \cdot Az^4 + 2.212891 \cdot 10^{-3} \cdot Az^3 - 2.844539 \cdot 10^{-2} \cdot Az^2 + 0.1708764 \cdot Az + 0.2925969$$

2.1.11.2.2 $620 < \mathrm{Re} \le 2470$ $Az = \mathrm{Re}/620 - 1$

$$F_R = -9.121 \cdot 10^{-3} \cdot Az^2 + 6.684 \cdot 10^{-2} \cdot Az + 0.7614$$

2.1.11.2.3 $2470 < \mathrm{Re} \le 10200$ $Az = \mathrm{Re}/2470 - 1$

$$F_R = -9.184 \cdot 10^{-3} \cdot Az^2 + 5.43 \cdot 10^{-2} \cdot Az + 0.88$$

2.1.11.2.4 $10200 < \mathrm{Re} \le 20000$ $F_R = 0.97$

2.1.11.2.5 $20000 < \mathrm{Re} \le 30000$ $F_R = 0.98$

2.1.11.2.6 $30000 < \mathrm{Re} \le 40000$ $F_R = 0.99$

2.1.11.3 Case $\mathrm{Re} \ge 40000$ **- Turbulent flow**

$$F_R = 1$$

2.1.12 The condition $P_1 - P_2 \rangle DP_A$ determines:

Case A - Cavitation and Flashing

A1 Cavitation case takes place if $P_2 \rangle P_V$, otherwise flashing case takes place.

A2 Calculate new CV .

A2.1 ISA standard:

$$CV = \frac{W}{27.3 \cdot F_{LP} \cdot \sqrt{(P_1 - F_F \cdot P_V) \cdot RO}}$$

A2.2 IEC standard:

$$CV = \frac{W}{27.3 \cdot F_R \cdot F_{LP} \cdot \sqrt{(P_1 - F_F \cdot P_V) \cdot RO}}$$

Case B ($P_1 - P_2 \le DP_A$) **- Usual**

B1 ISA standard:

B1.1 $F_R \ne 1$

$$CV = \frac{W}{27.3 \cdot F_R \cdot \sqrt{\left(P_1 - P_2\right) \cdot RO}}$$

B1.2 $F_R = 1$

$$CV = \frac{W}{27.3 \cdot F_P \cdot \sqrt{\left(P_1 - P_2\right) \cdot RO}}$$

B2 IEC standard:

$$CV = \frac{W}{27.3 \cdot F_R \cdot F_P \cdot \sqrt{\left(P_1 - P_2\right) \cdot RO}}$$

2.1.13 Calculate the relative change in the *CV*:

$$\Delta CV = \left| \frac{CV_0 - CV}{CV_0} \right|; CV_0 = CV$$

2.1.14 Paragraphs **2.1.6 - 2.1.13** are repeated until the relative change in the CV is less than 0.001.

2.1.15 Define "Incipient" case. The "Incipient" case takes place if

$$P_1 - P_2 \leq DP_A \text{ and } K_C > K_{CV}$$

2.1.16 Calculate outlet pipe velocity:

*W [kg/s], D_2 [m]

$$U_2 = \frac{W}{3.1416 \cdot (D_2 / 2)^2 \cdot RO}$$

2.2 Gas, Steam

2.2.1 Calculate X_T :

$$X_T = 0.84 \cdot F_L^2$$

2.2.2 Calculate effective velocity head coefficients:

$$K_1 = 0.5 \cdot \left(1 - d^2 / D_1^2\right)^2 \qquad K_2 = \left(1 - d^2 / D_2{}^2\right)^2$$

$$K_{b1} = 1 - \left(d / D_1\right)^4 \qquad K_{b2} = 1 - \left(d / D_2\right)^4$$

$$\sum K = K_1 + K_2 + K_{b1} - K_{b2} \qquad K_i = K_1 + K_{b1}$$

2.2.3 Calculate F_K:

$$F_K = K / 1.4$$

2.2.4 Calculate X :

$$X = \left(P_1 - P_2\right) / P_1$$

2.2.5 Calculate first value of CV:

*d [in]

$$CV_0 = K_{CD} \cdot d^2$$

2.2.6 Calculate F_P:

$$F_P = \left(\frac{\sum K \cdot CV_0^{\ 2}}{0.00214 \cdot d^4} + 1 \right)^{-1/2}$$

2.2.7 Calculate X_{TP}:

$$X_{TP} = \frac{X_T}{F_P^2} \left(\frac{X_T \cdot K_i \cdot CV_0^{\ 2}}{0.00241 \cdot d^4} + 1 \right)^{-1}$$

2.2.8 The condition $X > F_K \cdot X_{TP}$ determines: .

Case A - Critical flow

A1 $Eps = 0.667$.

A2 Calculate new CV :

$$CV = \frac{W}{27.3 \cdot F_P \cdot Eps \cdot \sqrt{F_k \cdot X_{TP} \cdot P_1 \cdot RO}}$$

Case B ($X \le F_K \cdot X_{TP}$) - Usual

B1 $Eps = 1 - \dfrac{X}{3 \cdot F_K \cdot X_{TP}}$.

B2 Calculate new CV :

$$CV = \frac{W}{27.3 \cdot F_P \cdot Eps \cdot \sqrt{X \cdot P_1 \cdot RO}}$$

2.2.9 Calculate the relative change in CV:

$$\Delta CV = \left| \frac{CV_0 - CV}{CV_0} \right| ; CV_0 = CV$$

2.2.10 Paragraphs **2.2.6 - 2.2.9** are repeated until the relative change in CV is less than 0.001.

2.2.11 Calculate F_{LP}:

$$F_{LP} = F_L \cdot \left(\frac{K_i \cdot F_L^2 \cdot CV^2}{0.00214 \cdot d^4} + 1 \right)^{-1/2}$$

2.2.12 Calculate outlet pipe velocity:

*W [kg/s], D_2 [m]

$$RO_2 = RO \cdot \frac{P_2}{P_1}$$

$$U_2 = \frac{W}{3.1416 \cdot (D_2 \,/\, 2)^2 \cdot RO_2}$$

2.2.13 Calculate Mach number:

$$C_{s2} = \sqrt{8314 \cdot K \cdot T \,/\, M}$$

$$MN = U_2 \,/\, C_{s2}$$

3 NOISE CALCULATION

3.1 Hydrodynamic Noise : Masoneilan Standard

3.1.1 Calculate dP_i, dP_C:

$$dP_i = K_{CV} \cdot (P_1 - P_V)$$

$$dP_C = F_L^{\ 2} \cdot (P_1 - P_V)$$

3.1.2 Calculate hydrodynamic noise.

3.1.2.1 Case $DP < dP_i$ - Flow Noise:

$$L_a = 10 \cdot \log CV + 20 \cdot \log DP - 30 \cdot \log(wall) + 70.5$$

3.1.2.2 Case $dP_i < DP < dP_C$ - Incipient Cavitation Noise:

$$L_a = 10 \cdot \log CV + 20 \cdot \log DP - 30 \cdot \log(wall) + 5 \cdot \left[\frac{\dfrac{DP}{P_1 - P_V} - K_{CV}}{F_L^2 - K_{CV}} \right] \cdot \log 14.5 \cdot \left(P_2 + 0.07 - P_V \right) + 70.5$$

3.1.2.3 Case $DP > dP_C$ and $P_2 > P_V$ - Cavitation Noise:

$$L_a = 10 \cdot \log CV + 20 \cdot \log DP - 30 \cdot \log(wall) + 5 \cdot \left[\frac{\dfrac{DP}{P_1 - P_V} - K_{CV}}{F_L^2 - K_{CV}} \right] \cdot \log 14.5 \cdot \left(P_2 + 0.07 - P_V \right) + 70.7 - [5 \cdot \log(\mathrm{DP} + 0.07 - \mathrm{dP_C}) + 6]$$

3.1.2.4 Case $P_2 < P_V$ - Flashing Noise:

There is no method to predict Noise for flashing case.

3.2 Hydrodynamic Noise : IEC Standard

*D_2 [m], P_1 [Pa-a], P_2 [Pa-a], P_v [Pa-a], P_c [Pa-a], W[kg/s]

3.2.1 Calculate the downstream speed of sound:

$$C_{s2} = \frac{8314 \cdot K \cdot T_1}{M}$$

3.2.2 Calculate Characteristic pressure ratio

$$X_{fz} = 0.84 \cdot F_L{}^2$$

3.2.3 Calculate Differential pressure ratio

$$X_f = \frac{P_1 - P_2}{P_1 - P_v}$$

3.2.4 Calculate Ring frequency

$$F_{fz} = \frac{C_p}{3.1416 \cdot D_{d2}}$$

3.2.5 Calculate Internal sound power level

3.2.5.1 Case $X_f < X_{fz}$ - Non-cavitating flow

$$L_{wi} = 120 + 10 \cdot \log(E_f) + 10 \cdot \log(W) + 10 \cdot \log(P1 - P2) - 10 \cdot \log(RO)$$

3.2.5.2 Case $X_f \Rightarrow X_{fz}$ - Cavitating flow

3.2.5.2.1 Calculate Liquid critical pressure ratio factor

$$F_f = 0.96 - 0.28 \cdot \sqrt{(P_v / P_c)}$$

3.2.5.2.2 Calculate Differential pressure

3.2.5.2.2.1 **Case** $P_1 - P_2 \le F_L{}^2 \cdot \left(P_1 - F_F \cdot P_v\right)$

$$DP = P_1 - P_2$$

3.2.5.2.2.2 **Case** $P_1 - P_2 > F_L{}^2 \cdot \left(P_1 - F_F \cdot P_v\right)$

$$DP = F_L{}^2 \cdot \left(P_1 - F_F \cdot P_v\right)$$

3.2.5.2.3 Calculate L_{wi}.

$$L_{wi} = 120 + 10 \cdot \log(E_f) + 10 \cdot \log(W) + 10 \cdot \log(P_1 - P_2) - 10 \cdot \log(RO) + \Delta \mathrm{L}_\mathrm{f} + 180 \cdot \frac{X_{fz}{}^{0.0625}}{X_f{}^{X_{fz}}} \cdot \left(1 - X_f\right)^{0.8} \cdot \log\frac{1 - X_{fz}}{1 - X_f}$$

3.2.6 Calculate Unweighted external sound power levels

$$T_{L1} = 10 + 10 \cdot \log\frac{C_p \cdot RO_p \cdot wall}{C_{s2} \cdot RO \cdot D_{d2}} + 20 \cdot \log\left[\frac{F_{fr}}{500} + \left(\frac{500}{F_{fr}}\right)^{1.5}\right]$$

$$L_{wi1} = L_{wi} - 2.9$$

$$L_{we1} = L_{wi1} - 17.37 \cdot \frac{1.5}{D_{d2}} \cdot 10^{-0.1 \cdot T_{L1}} - T_{L1} + 10 \cdot \log\frac{12}{D_{d2}}$$

$$T_{L2} = 10 + 10 \cdot \log\frac{C_p \cdot RO_p \cdot wall}{C_{s2} \cdot RO \cdot D_{d2}} + 20 \cdot \log\left[\frac{F_{fr}}{1000} + \left(\frac{1000}{F_{fr}}\right)^{1.5}\right]$$

$$L_{wi2} = L_{wi} - 10 \cdot \log\left(2\right) - 2.9$$

$$L_{we2} = L_{wi2} - 17.37 \cdot \frac{1.5}{D_{d2}} \cdot 10^{-0.1 \cdot T_{L2}} - T_{L2} + 10 \cdot \log\frac{12}{D_{d2}}$$

$$T_{L3} = 10 + 10 \cdot \log \frac{C_p \cdot RO_p \cdot wall}{C_{s2} \cdot RO \cdot D_{d2}} + 20 \cdot \log \left[\frac{F_{fr}}{2000} + \left(\frac{2000}{F_{fr}} \right)^{1.5} \right]$$

$$L_{wi3} = L_{wi} - 10 \cdot \log(4) - 2.9$$

$$L_{we3} = L_{wi3} - 17.37 \cdot \frac{1.5}{D_{d2}} \cdot 10^{-0.1 \cdot T_{L3}} - T_{L3} + 10 \cdot \log \frac{12}{D_{d2}}$$

$$T_{L4} = 10 + 10 \cdot \log \frac{C_p \cdot RO_p \cdot wall}{C_{s2} \cdot RO \cdot D_{d2}} + 20 \cdot \log \left[\frac{F_{fr}}{4000} + \left(\frac{4000}{F_{fr}} \right)^{1.5} \right]$$

$$L_{wi4} = L_{wi} - 10 \cdot \log(8) - 2.9$$

$$L_{we4} = L_{wi4} - 17.37 \cdot \frac{1.5}{D_{d2}} \cdot 10^{-0.1 \cdot T_{L4}} - T_{L4} + 10 \cdot \log \frac{12}{D_{d2}}$$

$$T_{L5} = 10 + 10 \cdot \log \frac{C_p \cdot RO_p \cdot wall}{C_{s2} \cdot RO \cdot D_{d2}} + 20 \cdot \log \left[\frac{F_{fr}}{8000} + \left(\frac{8000}{F_{fr}} \right)^{1.5} \right]$$

$$L_{wi5} = L_{wi} - 10 \cdot \log(16) - 2.9$$

$$L_{we5} = L_{wi5} - 17.37 \cdot \frac{1.5}{D_{d2}} \cdot 10^{-0.1 \cdot T_{L5}} - T_{L5} + 10 \cdot \log \frac{12}{D_{d2}}$$

3.2.7 Calculate External A-weighted sound power level

$$L_{wae} = 10 \cdot \log \cdot \left[10^{0.1 \cdot (L_{we1} - 3.2)} + 10^{0.1 \cdot (L_{we2} + 0.0)} + 10^{0.1 \cdot (L_{we3} + 1.2)} + 10^{0.1 \cdot (L_{we4} + 1.0)} + 10^{0.1 \cdot (L_{we5} - 1.1)} \right]$$

3.2.8 Calculate External A-weighted sound pressure level

$$L_a = L_{wae} - 10 \cdot \log \left[3.1416 \cdot 3 \cdot \left(\frac{D_2}{D_{d2}} + 1 \right) \right]$$

3.3 Aerodynamic Noise : ISA Standard

*D_2 [m], P_1 [Pa-a], P_2 [Pa-a], W[kg/s]

*$F_L=F_{LP}/F_p$

3.3.1 Calculate the downstream parameters:

$$RO_2 = RO \cdot P_2 / P_1$$
$$C_{s2} = \frac{8314 \cdot K \cdot T_1}{M}$$
$$U_2 = \frac{W}{3.1416 \cdot RO_2 \cdot (D_2 / 2)^2}$$
$$MN_2 = U_2 / C_{s2}$$

3.3.2 Calculate the following pressures:

$$P_{vc} = P_1 - (P_1-P_2)/F_L^2$$

$$P_{VCC} = P_1 \cdot \left(\frac{2}{K+1}\right)^{\left(\frac{K}{K-1}\right)}$$

$$P_{2c} = P_1 - F_L^2(P_1-P_{vcc})$$

$$\alpha = P_{vcc}/P_{2c}$$

$$P_{2b} = \frac{P_1}{\alpha} \cdot \left(\frac{1}{K}\right)^{\left(\frac{K}{K-1}\right)}$$

$$P_{2ce} = P_1/(22\alpha)$$

3.3.3 Calculate F_d, D_j, M_j:

$$F_d = N_o^{-1/2}$$

$$D_j = 0.0046 \cdot F_d \sqrt{CV \cdot F_L}$$

$$M_j = \left\{ \left(\frac{2}{K-1} \right) \left[\left(\frac{P_1}{\alpha \cdot P_2} \right)^{\frac{K-1}{K}} - 1 \right] \right\}^{1/2}$$

3.3.4 Now 5 regimes are possible:

3.3.4.1 Regime I - $P_1 > P_2 \geq P_{2c}$

$$T_{VC} = T_1 \left(\frac{P_{VC}}{P_1} \right)^{\left(\frac{K-1}{K} \right)}$$

$$C_{sVC} = \left(\frac{8314 \cdot K \cdot T_{VC}}{M} \right)^{0.5}$$

$$U_{VC} = \left\{ \frac{2K}{K-1} \left[1 - \left(\frac{P_{VC}}{P_1} \right)^{\left(\frac{K-1}{K} \right)} \right] \frac{P_1}{RO} \right\}^{1/2}$$

$$W_m = \frac{W \cdot U_{VC}{}^2}{2}$$

$$MN = \frac{U_{VC}}{C_{sVC}}$$

$$\eta = 0.0001 MN^{3.6}$$

$$W_a = \eta \cdot W_m \cdot F_L{}^2$$

$$f_P = 0.2 \cdot U_{VC} \,/\, D_j$$

3.3.4.2 Common calculations for II-V Regimes:

$$T_{VCC} = \frac{2T_1}{K+1}$$

$$C_{sVCC} = \left(\frac{8314KT_{VCC}}{M}\right)^{0.5}$$

$$U_{VCC} = \left\{\left(\frac{2K}{K-1}\right)\left[1-\left(\frac{P_{VCC}}{P_1}\right)^{\left(\frac{K-1}{K}\right)}\right]\frac{P_1}{RO}\right\}^{1/2}$$

$$W_{ms} = \frac{W \cdot U_{VCC}^2}{2}$$

3.3.4.3 Regime II - $P_{2c} > P_2 \geq P_{vcc}$:

$$\eta = 0.0001 \cdot M_j^{6.6 \cdot F_L^2}$$

$$W_a = \eta \cdot W_{ms}\left(\frac{P_1 - P_2}{P_1 - P_{VCC}}\right).$$

$$f_P = \frac{0.2\,M_j C_{sVCC}}{D_j}$$

3.3.4.4 Regime III - $P_{vcc} > P_2 \geq P_{2b}$:

$$\eta = 0.0001 \cdot M_j^{6.6 \cdot F_L^2}$$

$$W_a = \eta \cdot W_{ms}$$

$$f_P = \frac{0.2\,M_j C_{sVCC}}{D_j}$$

3.3.4.5 Regime IV - $P_{2b} > P_2 \geq P_{2ce}$:

$$\eta = 0.0001 \cdot \frac{M_j^{\ 2}}{2} \sqrt{2}^{\,6.6 \cdot F_L^{\ 2}}$$

$$W_a = \eta \cdot W_{ms}$$

$$f_P = \frac{0.35 C_{sVCC}}{1.25 D_j \left(M_j^{\ 2} - 1 \right)^{1/2}}$$

3.3.4.6 Regime V - $P_{2ce} > P_2 \geq 0$:

$$M_j = \left\{ \left(\frac{2}{K-1} \right) \left[22^{\left(\frac{K-1}{K} \right)} - 1 \right] \right\}^{1/2}$$

$$\eta = 0.0001 \cdot \frac{M_j^{\ 2}}{2} \sqrt{2}^{\,6.6 \cdot F_L^{\ 2}}$$

$$W_a = \eta \cdot W_{ms}$$

$$f_P = \frac{0.35 C_{sVCC}}{1.25 D_j \left(M_j^{\ 2} - 1 \right)^{1/2}}$$

3.3.5 Calculate $L_{pi:}$:

$$L_{pi} = 10 \cdot \log\left(8 \cdot 10^8 \cdot W_a \cdot RO_2 \cdot C_{s2} \ / \ D_2^{\ 2} \right)$$

3.3.6 Calculate T_{Lfo} :

$$T_{Lfo} = 10 \log \left[\frac{1.1 \cdot 10^{-7} \cdot D_2^3}{\left(1 + D_2 \ / \ 2 \right) \cdot \left(wall \right)^2} \frac{P_a}{(P_2 + 101325)} \right]$$

3.3.7 Calculate f_o :

$f_o = 5000/(12.5664D_2)$

3.3.8 Three cases are possible when calculating ΔT_{Lfp}:

3.3.8.1 $f_p \leq f_o$

$\Delta T_{Lfp} = 20log(f_o/f_p)$

3.3.8.2 $f_o < f_p \leq 4f_o$

$\Delta T_{Lfp} = 13log(f_p/f_o)$

3.3.8.3 $f_p > 4f_o$

$\Delta T_{Lfp} = 20log(f_p/4f_o) + 7.8$

3.3.9 Calculate transmission loss:

$T_L = T_{Lfo} - \Delta T_{Lfp}$

3.3.10 Calculate L_g :

$$L_g = 16\log\left[\frac{1}{1 - \frac{1.3 \cdot 10^{-5} \cdot P_1 \cdot CV \cdot F_L}{(D_2)^2 \cdot P_2}}\right]$$

3.3.11 Calculate sound level

$L_a = 5 + L_{pi} + T_L + L_g$

3.4 Aerodynamic Noise : IEC Standard

*D_2 [m], d [m], P_1 [Pa-a], P_2 [Pa-a], W[kg/s]

*$F_L=F_{LP}/F_p$

3.4.1 Calculate the downstream parameters:

$$RO_2 = RO \cdot P_2 \ / \ P_1$$

$$C_{s2} = \frac{8314 \cdot K \cdot T_1}{M}$$

$$MN_2 = \frac{4 \cdot W}{3.1416 \cdot C_{s2} \cdot RO_2 \cdot D_2{}^2}$$

$$MN_0 = \frac{4 \cdot W}{3.1416 \cdot C_{s2} \cdot RO_2 \cdot d^2}$$

3.4.2 Calculate the following pressures:

$$P_{vc} = P_1 - (P_1 - P_2)/F_L^2$$

$$P_{VCC} = P_1 \cdot \left(\frac{2}{K+1}\right)^{\left(\frac{K}{K-1}\right)}$$

$$P_{2c} = P_1 - F_L^2(P_1 - P_{vcc})$$

$$\alpha = P_{vcc}/P_{2c}$$

$$P_{2b} = \frac{P_1}{\alpha} \cdot \left(\frac{1}{K}\right)^{\left(\frac{K}{K-1}\right)}$$

$$P_{2ce} = P_1/(22\alpha)$$

3.4.3 Calculate F_d, D_j, M_j:

$$F_d = N_o^{-1/2}$$

$$D_j = 0.0046 \cdot F_d \sqrt{CV \cdot F_L}$$

$$M_j = \left\{ \left(\frac{2}{K-1} \right) \left[\left(\frac{P_1}{\alpha \cdot P_2} \right)^{\frac{K-1}{K}} - 1 \right] \right\}^{1/2}$$

3.4.4 Now 5 regimes are possible:

3.4.4.1 Regime I - $P_1 > P_2 \geq P_{2c}$

$$T_{VC} = T_1 \left(\frac{P_{VC}}{P_1} \right)^{\left(\frac{K-1}{K} \right)}$$

$$C_{sVC} = \left(\frac{8314 \cdot K \cdot T_{VC}}{M} \right)^{0.5}$$

$$U_{VC} = \left\{ \frac{2K}{K-1} \left[1 - \left(\frac{P_{VC}}{P_1} \right)^{\left(\frac{K-1}{K} \right)} \right] \frac{P_1}{RO} \right\}^{1/2}$$

$$W_m = \frac{W \cdot {U_{VC}}^2}{2}$$

$$MN = \frac{U_{VC}}{C_{sVC}}$$

$$\eta = 0.0001 MN^{3.6}$$

$$W_a = \eta \cdot W_m \cdot {F_L}^2$$

$$f_P = 0.2 \cdot U_{VC} \,/\, D_j$$

3.4.4.2 Common calculations for II-V Regimes:

$$T_{VCC} = \frac{2 \cdot T_1}{K+1}$$

$$C_{sVCC} = \left(\frac{8314 \cdot K \cdot T_{VCC}}{M} \right)^{0.5}$$

$$W_{ms} = \frac{W \cdot C_{sVCC}^2}{2}$$

3.4.4.3 Regime II - $P_{2c} > P_2 \geq P_{vcc}$:

$$\eta = 0.0001 \cdot M_j^{6.6 \cdot F_L^2}$$

$$W_a = \eta \cdot W_{ms}\left(\frac{P_1 - P_2}{P_1 - P_{VCC}}\right).$$

$$f_P = \frac{0.2\, M_j C_{sVCC}}{D_j}$$

3.4.4.4 Regime III - $P_{vcc} > P_2 \geq P_{2b}$:

$$\eta = 0.0001 \cdot M_j^{6.6 \cdot F_L^2}$$

$$W_a = \eta \cdot W_{ms}$$

$$f_P = \frac{0.2\, M_j C_{sVCC}}{D_j}$$

3.4.4.5 Regime IV - $P_{2b} > P_2 \geq P_{2ce}$:

$$\eta = 0.0001 \cdot \frac{M_j^{\,2}}{2} \sqrt{2}^{\,6.6 \cdot F_L^2}$$

$$W_a = \eta \cdot W_{ms}$$

$$f_P = \frac{0.35 \cdot C_{sVCC}}{1.25 \cdot D_j \cdot \left(M_j^{\,2} - 1\right)^{1/2}}$$

3.4.4.6 Regime V - $P_{2ce} > P_2 \geq 0$:

$$M_j = \left\{\left(\frac{2}{K-1}\right)\left[22^{\left(\frac{K-1}{K}\right)} - 1\right]\right\}^{1/2}$$

$$\eta = 0.0001 \cdot \frac{M_j^{\,2}}{2} \sqrt{2}^{\,6.6 \cdot F_L^2}$$

$$W_a = \eta \cdot W_{ms}$$

$$f_P = \frac{0.35 \cdot C_{sVCC}}{1.25 \cdot D_j \cdot \left(M_j^{\,2} - 1\right)^{1/2}}$$

3.4.5 Calculate L_{pi} :

$$L_{pi} = 10 \cdot \log\left(8 \cdot 10^8 \cdot W_a \cdot RO_2 \cdot C_{s2} \;/\; {D_2}^2\right)$$

3.4.6 Calculate T_{Lfr}:

$$T_{Lfr} = 10 \cdot \log\left[\frac{3 \cdot 10^{-13} \cdot {C_{s2}}^2 \cdot {D_2}^2}{\left(1 + C_{s2} \cdot RO_2 \;/\; 415\right) \cdot \left(wall\right)^2} \frac{P_a}{101325}\right]$$

3.4.7 Calculate f_r and f_o :

$f_r = 5000/(3.1416D_2)$

$f_o = f_r \, C_{s2}/1372$

3.4.8 Three cases are possible when calculating ΔT_{Lfp}:

3.4.8.1 $f_p < f_o$

$\Delta T_{Lfp} = 20\log(f_o/f_p) + 13\log(f_o/f_r)$

3.4.8.2 $f_o \leq f_p \leq f_r$

$\Delta T_{Lfp} = 13\log(f_p/f_r)$

3.4.8.3 $f_p > f_r$

$\Delta T_{Lfp} = 20\log(f_p/f_r)$

3.4.9 Calculate transmission loss:

$T_L = T_{Lfr} - \Delta T_{Lfp}$

3.4.10 Calculate L_g :

$$L_g = 16 \cdot \log\left[\frac{1}{1 - M_2}\right]$$

3.4.11 Calculate sound level at the outside diameter of the pipe

$L_{a0} = 5 + L_{pi} + T_L + L_g$

3.4.12 Calculate sound level at a distance of 1 m from the pipe wall

$$L_a = L_{a0} - 10 \cdot \log \frac{D_2 + 2}{D_2}$$

4 Flow Meter Sizing

4.1 Calculation of b - ratio

4.1.1 Calculate Internal pipe diameter at flow temperature:

$$D = D_0 \cdot \left[1 + \alpha_p \left(T - T_0\right)\right]$$

4.1.2 Calculate Correction factor for Steam quality (For Liquid, Water, and Steam, Fs=1):

$$F_s = 1 + 0.0074 \cdot S_t$$

4.1.3 Calculate Scale reading factor:

$$SRF = 10 \cdot W_n \ / \ W_{\max}$$

4.1.4 Calculate Differential pressure at normal flow rate:

$$DP_n = DP \cdot \left(SRF / 10\right)^2$$

4.1.5 Calculate Pipe Reynolds number at normal flow rate:

$$\mathrm{Re}_n = \frac{1.2732 \cdot 10^3 \cdot W_n}{\mu \cdot D}$$

4.1.6 Calculate first estimate for β - ratio.

4.1.6.1 For Venturi tubes:

$$\beta_0 = \left(\frac{W_n^2}{1.23 \cdot 10^{-7} \cdot D^4 \cdot DP_n \cdot RO + W_n^2}\right)^{0.25}$$

4.1.6.2 For other Flow meters:

$$\beta_0 = \left(\frac{W_n^2}{4.6 \cdot 10^{-8} \cdot D^4 \cdot DP_n \cdot RO + W_n^2}\right)^{0.25}$$

4.1.7 Calculate Gas expansion factor (for Liquid and Water, $Eps = 1$).

4.1.7.1 For square edge orifice with 2½D & 8D pipe taps:

$$Eps = 1 - \left[0.333 + 1.145 \cdot \left(\beta_0^{\,2} + 0.7\beta_0^{\,5} + 12\beta_0^{\,13}\right)\right] \cdot \left(DP_n / P_1\right) \cdot K^{-1}$$

4.1.7.2 For Lo-Loss tube, Venturi tubes and Nozzles:

$$Eps = \left[\left(\frac{K \cdot (Q)^{\frac{2}{K}}}{K-1}\right)\left(\frac{1-\beta_0^{\,4}}{1-\beta_0^{\,4} \cdot (Q)^{\frac{2}{K}}}\right)\left(\frac{1-(Q)^{\frac{K-1}{K}}}{1-Q}\right)\right]^{0.5}$$

where $Q = \dfrac{P_1 - DP_n}{P_1}$

4.1.7.3 For Eccentric orifices:

$$Eps = 1 - \left(0.1926 + 0.574 \cdot \beta_0 + 0.9675 \cdot \beta_0^{\,2} - 4.24 \cdot \beta_0^{\,3} + 3.62 \cdot \beta_0^{\,4}\right) \cdot (DP_n \;/\; P_1) \cdot K^{-1}$$

4.1.7.4 For other Flow meters:

$$Eps = 1 - \left(0.41 + 0.35 \cdot \beta_0^{\,4}\right) \cdot (DP_n \;/\; P_1) \cdot K^{-1}$$

4.1.8 Calculate Discharge coefficient. See **Attachment.**

4.1.9 Calculate new β - ratio:

$$\beta = \left[\frac{2847.05 \cdot W_n \cdot \sqrt{1-\beta_0^{\,4}}}{D^2 \cdot Eps \cdot F_s \cdot C \cdot \sqrt{DP_n \cdot RO}}\right]^{0.5}$$

4.1.10 Calculate the relative change in β - ratio:

$$\Delta\beta = \left|\frac{\beta_0 - \beta}{\beta_0}\right|; \beta_0 = \beta$$

4.1.11 Paragraphs **4.1.7 - 4.1.10** are repeated until the relative change in the β - ratio is less than 0.0001.

4.1.12 Calculate Orifice diameter at flow temperature.

4.1.12.1 For all Flow Meters except Segmental orifices:

$$d = D \cdot \beta$$

4.1.12.2 Segmental orifices.

4.1.12.2.1 Calculate Segmental radius:

$$RS_0 = 0.49 \cdot D_0$$

4.1.12.2.2 Calculate Segmental height at flow temperature using the equation:

$$\beta = \left\{ \frac{1}{\pi} \left[\arccos\left(1 - \frac{2 \cdot HS}{D}\right) - 2 \cdot \left(1 - \frac{2 \cdot HS}{D}\right) \cdot \sqrt{\left[\frac{HS}{D} - \left(\frac{HS}{D}\right)^2\right]} \right] \right\}^{0.5}$$

For further calculation of Segmental orifices, HS and HS_0 are analogous to d and d_0 respectively.

4.1.13 Calculate Orifice diameter at ambient temperature.

4.1.13.1 For Lo-Loss tube, Nozzles, and Venturi tubes:

$$d_0 = \frac{d}{1 + \alpha_{pe} \cdot (T - T_0)}$$

4.1.13.2 For other orifices:

$$d_0 = d \cdot \frac{1 - 0.55 \cdot (Dbh/d)^2}{1 + \alpha_{pe} \cdot (T - T_0)}$$

4.1.14 For Quarter of circle orifice, calculate Radius of upstream profile:

$$R_q = d \cdot \left(\frac{0.07571 \cdot \beta - 0.06253}{\beta - 0.68286} \right)$$

4.2 Calculation of Flow rate

4.2.1 Calculate Internal pipe diameter at flow temperature:

$$D = D_0 \cdot \left[1 + \alpha_p \left(T - T_0\right)\right]$$

4.2.2 Calculate Correction factor for Steam quality (For Liquid, Water, and Steam, Fs=1):

$$F_s = 1 + 0.0074 \cdot S_t$$

4.2.3 Calculate Orifice diameter at flow temperature.

4.2.3.1 For Lo-Loss tube, Nozzles, and Venturi tubes:

$$d = d_0 \cdot \left[1 + \alpha_{pe} \cdot \left(T - T_0\right)\right]$$

4.2.3.2 For other orifices:

$$d = d_0 \cdot \left[1 + 0.55 \cdot \left(Dbh/d_0\right)^2\right] \cdot \left[1 + \alpha_{pe} \cdot \left(T - T_0\right)\right]$$

4.2.4 Calculate β - ratio.

4.2.4.1 For all Flow Meters except Segmental orifices:

$$\beta = \frac{d}{D}$$

4.2.4.2 Segmental orifices.

4.2.4.2.1 Calculate Segmental radius:

$$RS_0 = 0.49 \cdot D_0$$

4.2.4.2.2 Calculate β - ratio:

$$\beta = \left\{ \frac{1}{\pi} \left[\arccos\left(1 - \frac{2 \cdot HS}{D}\right) - 2 \cdot \left(1 - \frac{2 \cdot HS}{D}\right) \cdot \sqrt{\left[\frac{HS}{D} - \left(\frac{HS}{D}\right)^2\right]} \right] \right\}^{0.5}$$

Note: HS is calculated with the help of HS_0 in accordance with paragraph **4.2.3.2**.

4.2.5 Calculate Gas expansion factor (for Liquid and Water, $Eps = 1$).

4.2.5.1 For square edge orifice with 2½D & 8D pipe taps:

$$Eps = 1 - \left[0.333 + 1.145 \cdot \left(\beta^2 + 0.7\beta^5 + 12\beta^{13}\right)\right] \cdot \left(DP / P_1\right) \cdot K^{-1}$$

4.2.5.2 For Lo-Loss tube, Venturi tubes and Nozzles:

$$Eps = \left[\left(\frac{K \cdot (Q)^{\frac{2}{K}}}{K - 1}\right)\left(\frac{1 - \beta^4}{1 - \beta^4 \cdot (Q)^{\frac{2}{K}}}\right)\left(\frac{1 - (Q)^{\frac{K-1}{K}}}{1 - Q}\right)\right]^{0.5}$$

where $Q = \dfrac{P_1 - DP}{P_1}$

4.2.5.3 For Eccentric orifices:

$$Eps = 1 - \left(0.1926 + 0.574 \cdot \beta + 0.9675 \cdot \beta^2 - 4.24 \cdot \beta^3 + 3.62 \cdot \beta^4\right) \cdot (DP / P_1) \cdot K^{-1}$$

4.2.5.4 For other Flow meters:

$$Eps = 1 - \left(0.41 + 0.35 \cdot \beta^4\right) \cdot (DP / P_1) \cdot K^{-1}$$

4.2.6 Calculate first estimate for Flow rate:

*W_0 [kg/s]

$$W_0 = 2.107 \cdot 10^{-4} \cdot Eps \cdot d^2 \cdot \sqrt{\frac{DP \cdot RO}{1 - \beta^4}}$$

4.2.7 Calculate Pipe Reynolds number:

*W_0 [kg/s]

$$\mathrm{Re} = \frac{1.2732 \cdot 10^3 \cdot W_0}{\mu \cdot D}$$

4.2.8 Calculate Discharge coefficient. See **Attachment.**

4.2.9 Calculate new Flow rate:

*W [kg/s]

$$W = 3.5124 \cdot 10^{-4} \cdot C \cdot F_s \cdot Eps \cdot d^2 \cdot \sqrt{\frac{DP \cdot RO}{1-\beta^4}}$$

4.2.10 For Quarter of circle orifices, Lo-loss tube, Venturi tubes, and Segmental orifices, go to the paragraph **4.2.13.**

4.2.11 Calculate the relative change in Flow rate:

$$\Delta W = \left|\frac{W_0 - W}{W_0}\right|; W_0 = W$$

4.2.12 Paragraphs **4.2.7 - 4.2.11** are repeated until the relative change in the β - ratio is less than 0.0001.

4.2.13 For Quarter of circle orifice, calculate Radius of upstream profile:

$$R_q = d \cdot \left(\frac{0.07571 \cdot \beta - 0.06253}{\beta - 0.68286}\right)$$

4.3 Calculation of Differential range

4.3.1 Calculate Internal pipe diameter at flow temperature:

$$D = D_0 \cdot \left[1 + \alpha_p \left(T - T_0\right)\right]$$

4.3.2 Calculate Correction factor for Steam quality (For Liquid, Water, and Steam, Fs=1):

$$F_s = 1 + 0.0074 \cdot S_t$$

4.3.3 Calculate Orifice diameter at flow temperature.

4.3.3.1 For Lo-Loss tube, Nozzles, and Venturi tubes:

$$d = d_0 \cdot \left[1 + \alpha_{pe} \cdot \left(T - T_0\right)\right]$$

4.3.3.2 For other orifices:

$$d = d_0 \cdot \left[1 + 0.55 \cdot \left(Dbh/d_0\right)^2\right] \cdot \left[1 + \alpha_{pe} \cdot \left(T - T_0\right)\right]$$

4.3.4 Calculate Pipe Reynolds number:

*W [kg/s]

$$\mathrm{Re} = \frac{1.2732 \cdot 10^3 \cdot W}{\mu \cdot D}$$

4.3.5 Calculate β - ratio.

4.3.5.1 For all Flow Meters except Segmental orifices:

$$\beta = \frac{d}{D}$$

4.3.5.2 Segmental orifices.

4.3.5.2.1 Calculate Segmental radius:

$$RS_0 = 0.49 \cdot D_0$$

4.3.5.2.2 Calculate β - ratio:

$$\beta = \left\{\frac{1}{\pi}\left[\arccos\left(1 - \frac{2 \cdot HS}{D}\right) - 2 \cdot \left(1 - \frac{2 \cdot HS}{D}\right) \cdot \sqrt{\left[\frac{HS}{D} - \left(\frac{HS}{D}\right)^2\right]}\right]\right\}^{0.5}$$

Note: HS is calculated with the help of HS_0 in accordance with paragraph **4.3.3.2**.

4.3.6 Calculate Discharge coefficient. See **Attachment.**

4.3.7 First estimate for Differential range:

$$DP_0 = P_1$$

4.3.8 Calculate Gas expansion factor (for Liquid and Water, $Eps = 1$).

4.3.8.1 For square edge orifice with 2½D & 8D pipe taps:

$$Eps = 1 - \left[0.333 + 1.145 \cdot \left(\beta^2 + 0.7\beta^5 + 12\beta^{13}\right)\right] \cdot \left(DP / P_1\right) \cdot K^{-1}$$

4.3.8.2 For Lo-Loss tube, Venturi tubes and Nozzles:

$$Eps = \left[\left(\frac{K \cdot (Q)^{\frac{2}{K}}}{K-1} \right) \left(\frac{1-\beta^4}{1-\beta^4 \cdot (Q)^{\frac{2}{K}}} \right) \left(\frac{1-(Q)^{\frac{K-1}{K}}}{1-Q} \right) \right]^{0.5}$$

where $Q = \dfrac{P_1 - DP}{P_1}$

4.3.8.3 For Eccentric orifices:

$$Eps = 1 - \left(0.1926 + 0.574 \cdot \beta + 0.9675 \cdot \beta^2 - 4.24 \cdot \beta^3 + 3.62 \cdot \beta^4\right) \cdot (DP / P_1) \cdot K^{-1}$$

4.3.8.4 For other Flow meters:

$$Eps = 1 - \left(0.41 + 0.35 \cdot \beta^4\right) \cdot (DP / P_1) \cdot K^{-1}$$

4.3.9 Calculate new Differential range:

*W [kg/s]

$$DP = \left[\frac{W \cdot \sqrt{1-\beta^4}}{3.5124 \cdot 10^{-4} \cdot C \cdot Eps \cdot (\beta \cdot D)^2 \cdot F_s} \right]^2 \cdot RO^{-1}$$

4.3.10 For Liquid and Water, go to paragraph **4.3.13.**

4.3.11 Calculate the relative change in Differential range:

$$\Delta DP = \left| \frac{DP_0 - DP}{DP_0} \right| ; DP_0 = DP$$

4.3.12 Paragraphs **4.3.8 - 4.3.11** are repeated until the relative change in the β - ratio is less than 0.0001.

4.3.13 For Quarter of circle orifice, calculate Radius of upstream profile:

$$R_q = d \cdot \left(\frac{0.07571 \cdot \beta - 0.06253}{\beta - 0.68286} \right)$$

5 Restriction Device Sizing

5.1 Calculation of ḅ - ratio

5.1.1 Calculate Internal pipe diameter at flow temperature:

$$D = D_0 \cdot \left[1 + \alpha_p \left(T - T_0\right)\right]$$

5.1.2 Calculate Correction factor for Steam quality (For Liquid, Water, and Steam, Fs=1):

$$F_s = 1 + 0.0074 \cdot S_t$$

5.1.3 Calculate Scale reading factor:

$$SRF = 10 \cdot W_n \; / \; W_{\max}$$

5.1.4 Calculate Differential pressure at normal flow rate:

$$DP_n = DP_{loss} \cdot \left(SRF / 10\right)^2$$

5.1.5 Calculate Pipe Reynolds number at normal flow rate:

$$\mathrm{Re}_n = \frac{1.2732 \cdot 10^3 \cdot W_n}{\mu \cdot D}$$

5.1.6 Checking for Critical flow.

5.1.6.1 Liquid / Water case

If $P_1 - DP_{loss} < P_v$

then the flow is critical.

5.1.6.2 Gas/Steam case

5.1.6.2.1 Calculate first estimate for β - ratio.

For Venturi tubes:

$$\beta_0 = \left(\frac{W_n^2}{1.23 \cdot 10^{-7} \cdot D^4 \cdot DP_n \cdot RO + W_n^2} \right)^{0.25}$$

For other Restriction Devices:

$$\beta_0 = \left(\frac{W_n^2}{4.6 \cdot 10^{-8} \cdot D^4 \cdot DP_n \cdot RO + W_n^2} \right)^{0.25}$$

5.1.6.2.2 Calculate Critical Pressure Ratio and define whether the flow is critical.

$$DP_{rat} = \frac{P_1 - DP_{loss}}{F_{ttp} \cdot P_1}$$

$$A = \left(\frac{2}{k+1} \right)^{k/(k+1)}$$

$$F_{ttp} = \left(1 - \left(\frac{k}{2} \right) \cdot \left(\frac{2}{k+1} \right)^{(k+1)/(k-1)} \cdot \beta_0^{\;4} \right)^{-1}$$

If $\quad A \geq DP_{rat}$

then the flow is critical. If not, the flow is SubCritical.

5.1.7 Calculate β - ratio.

Case A. Liquid / Water – Critical flow

A1 Calculate DP.

$$DP = P_1 - P_v$$

A2 Calculate first estimate for β - ratio

For Venturi tubes:

$$\beta_0 = \left(\frac{W_n^2}{1.23 \cdot 10^{-7} \cdot D^4 \cdot DP_n \cdot RO + W_n^2} \right)^{0.25}$$

For other Restriction Devices:

$$\beta_0 = \left(\frac{W_n^2}{4.6 \cdot 10^{-8} \cdot D^4 \cdot DP_n \cdot RO + W_n^2} \right)^{0.25}$$

A3 Eps = 1.

A4 Calculate Discharge coefficient. See **Attachment.**

A5 Calculate new β - ratio:

$$\beta = \left[\frac{2847.05 \cdot W_n \cdot \sqrt{1 - \beta_0^{\,4}}}{D^2 \cdot Eps \cdot F_s \cdot C \cdot \sqrt{DP_n \cdot RO}} \right]^{0.5}$$

A6 Calculate the relative change in β - ratio:

$$\Delta\beta = \left| \frac{\beta_0 - \beta}{\beta_0} \right|; \beta_0 = \beta$$

A7 Paragraphs **A4 – A6** are repeated until the relative change in the β - ratio is less than 0.0001.

Case B. Gas / Steam – Critical flow

B1 Calculate Gas expansion factor

$$Eps = \left(\left(\frac{k}{Z} \right) \cdot \left(\frac{2}{k+1} \right)^{(k+1)/(k-1)} \right)^{1/2}$$

B2 Calculate Discharge coefficient. See **Attachment.**

B3 Calculate first estimate for β - ratio (Wn[lb/h], T[R], P1[psi-a], D[in]):

$$aa = \frac{W_n \cdot \sqrt{T}}{2195.591 \cdot C \cdot \sqrt{(M / 28.9625)} \cdot P_1 \cdot D^4 \cdot Eps}$$

$$am = aa \cdot \left(\frac{k}{2} \right) \cdot \left(\frac{2}{k+1} \right)^{(k+1)/(k-1)}$$

$$cm = -aa \cdot D^4$$

$$d2 = \sqrt{\frac{-1 + \sqrt{1 - 4 \cdot am \cdot cm}}{2 \cdot am}}$$

$$\beta = \frac{d2}{D}$$

B4 Calculate Orifice diameter at flow temperature:

$$d = D \cdot \beta$$

B5 Calculate Bore Reynolds number at normal flow rate:

$$\mathrm{Re}_n = \frac{1.2732 \cdot 10^3 \cdot W_n}{\mu \cdot d}$$

B6 Calculate Discharge coefficient. See **Attachment.**

B7 Calculate new β - ratio in accordance with equations in paragraph **B3**.

Case C. SubCritical flow

C1 First estimate for DPn:

$$DPn_0 = DP_{loss}$$

C2 Calculate first estimate for β - ratio

For Venturi tubes:

$$\beta_0 = \left(\frac{W_n^2}{1.23 \cdot 10^{-7} \cdot D^4 \cdot DPn_0 \cdot RO + W_n^2} \right)^{0.25}$$

For other Restriction Devices:

$$\beta_0 = \left(\frac{W_n^2}{4.6 \cdot 10^{-8} \cdot D^4 \cdot DPn_0 \cdot RO + W_n^2} \right)^{0.25}$$

C3 Calculate Gas expansion factor (for Liquids/Water, Eps = 1)

For Venturi tubes and Nozzles:

$$Eps = \left[\left(\frac{K \cdot (Q)^{\frac{2}{K}}}{K - 1} \right) \left(\frac{1 - \beta_0^4}{1 - \beta_0^4 \cdot (Q)^{\frac{2}{K}}} \right) \left(\frac{1 - (Q)^{\frac{K-1}{K}}}{1 - Q} \right) \right]^{0.5}$$

where $Q = \dfrac{P_1 - DP_n}{P_1}$

For Orifice Plates:

$$Eps = 1 - \left(0.41 + 0.35 \cdot \beta_0^4\right) \cdot (DP_n \ / \ P_1) \cdot K^{-1}$$

C4 Calculate Discharge coefficient. See **Attachment.**

C5 Calculate new β - ratio:

$$\beta = \left[\frac{2847.05 \cdot W_n \cdot \sqrt{1-\beta_0{}^4}}{D^2 \cdot Eps \cdot F_s \cdot C \cdot \sqrt{DP_n \cdot RO}} \right]^{0.5}$$

C6 Calculate new DP

For Classical Venturi Tube:

$$DP = \frac{DP_{loss}}{0.218 - 0.42 \cdot \beta + 0.38 \cdot \beta^2}$$

For Nozzles:

$$DP = \frac{DP_{loss}}{1 + 0.014 \cdot \beta - 2.06 \cdot \beta^2 + 1.18 \cdot \beta^3}$$

For Orifice Plates:

$$DP = \frac{DP_{loss} \cdot \left(\left(1-\beta^4\right)^{0.5} + C \cdot \beta^2\right)}{\left(\left(1-\beta^4\right)^{0.5} - C \cdot \beta^2\right)}$$

$$DP_n = DP \cdot \left(\frac{W_n}{W_{\max}} \right)^2$$

C7 Calculate new DPn:

C8 Calculate the relative change in DPn:

$$\Delta DP_n = \left| \frac{DPn_0 - DP_n}{DPn_0} \right| ; DPn_0 = DP_n ; \beta_0 = \beta$$

C9 Paragraphs **C3 – C8** are repeated until the relative change in the DPn is less than 0.0001

5.1.8 Calculate Orifice diameter at flow temperature:

$$d = D \cdot \beta$$

5.1.9 Calculate Orifice diameter at ambient temperature.

For Venturi tubes and Nozzles:

$$d_0 = \frac{d}{1 + \alpha_{pe} \cdot (T - T_0)}$$

For Orifice Plates:

$$d_0 = d \cdot \frac{1 - 0.55 \cdot (Dbh/d)^2}{1 + \alpha_{pe} \cdot (T - T_0)}$$

5.2 Calculation of Flow rate

5.2.1 Calculate Internal pipe diameter at flow temperature:

$$D = D_0 \cdot \left[1 + \alpha_p (T - T_0)\right]$$

5.2.2 Calculate Correction factor for Steam quality (For Liquid, Water, and Steam, Fs=1):

$$F_s = 1 + 0.0074 \cdot S_t$$

5.2.3 Calculate Orifice diameter at flow temperature.

For Venturi tubes and Nozzles:

$$d = d_0 \cdot \left[1 + \alpha_{pe} \cdot (T - T_0)\right]$$

For Orifice Plates:

$$d = d_0 \cdot \left[1 + 0.55 \cdot (Dbh/d_0)^2\right] \cdot \left[1 + \alpha_{pe} \cdot (T - T_0)\right]$$

5.2.4 Calculate β - ratio:

$$\beta = \frac{d}{D}$$

5.2.5 Checking for Critical flow and some initial calculations.

5.2.5.1 Liquid / Water case

5.2.5.1.1 Calculate downstream pressure:

$$P_2 = P_1 - DP_{loss}$$

5.2.5.1.2 Identify Critical flow:

If $P_2 \leq P_v$

then the flow is critical. If not, the flow is SubCritical

5.2.5.1.3 Calculate Differential Pressure to be used in Flow Rate calculation.

For Critical flow:

$$DP = P_1 - P_v$$

For SubCritical flow:

Classical Venturi Tube:

$$DP = \frac{DP_{loss}}{0.218 - 0.42 \cdot \beta + 0.38 \cdot \beta^2}$$

Nozzles:

$$DP = \frac{DP_{loss}}{1 + 0.014 \cdot \beta - 2.06 \cdot \beta^2 + 1.18 \cdot \beta^3}$$

Orifice Plates:

$$DP = \frac{DP_{loss} \cdot \left(\left(1 - \beta^4\right)^{0.5} + C \cdot \beta^2\right)}{\left(\left(1 - \beta^4\right)^{0.5} - C \cdot \beta^2\right)}$$

5.2.5.1.4 Calculate first estimate for Flow Rate (W_0 [kg/s]):

$$W_0 = 2.107 \cdot 10^{-4} \cdot d^2 \cdot \sqrt{\frac{DP \cdot RO}{1-\beta^4}}$$

5.2.5.2 Gas/Steam case

5.2.5.2.1 Calculate Critical Pressure Ratio and define whether the flow is critical.

$$F_{ttp} = \left(1 - \left(\frac{k}{2}\right) \cdot \left(\frac{2}{k+1}\right)^{(k+1)/(k-1)} \cdot \beta^4\right)^{-1}$$

$$DP_{rat} = \frac{P_1 - DP_{loss}}{F_{ttp} \cdot P_1}$$

$$A = \left(\frac{2}{k+1}\right)^{k/(k+1)}$$

If $A \geq DP_{rat}$

then the flow is critical. If not, the flow is SubCritical

5.2.5.2.2 Initial calculations for Critical flow.

Gas expansion factor:

$$Eps = \left(\left(\frac{k}{Z}\right) \cdot \left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}\right)^{1/2}$$

First estimate for Flow Rate (W_0 [lb/h], T[R], D[in], P1[psi-a]):

$$W_0 = 2195.591 \cdot d^2 \cdot \left(\frac{M}{28.9625 \cdot T}\right)^{0.5} \cdot P_1 \cdot Eps \cdot F_{ttp}$$

5.2.5.2.3 Initial calculations for SubCritical flow.

Differential Pressure to be used in Flow Rate calculation:

For Classical Venturi Tube:

$$DP = \frac{DP_{loss}}{0.218 - 0.42 \cdot \beta + 0.38 \cdot \beta^2}$$

For Nozzles:

$$DP = \frac{DP_{loss}}{1 + 0.014 \cdot \beta - 2.06 \cdot \beta^2 + 1.18 \cdot \beta^3}$$

For Orifice Plates:

$$DP = \frac{DP_{loss} \cdot \left(\left(1 - \beta^4 \right)^{0.5} + C \cdot \beta^2 \right)}{\left(\left(1 - \beta^4 \right)^{0.5} - C \cdot \beta^2 \right)}$$

Gas expansion factor:

For Venturi tubes and Nozzles:

$$Eps = \left[\left(\frac{K \cdot (Q)^{\frac{2}{K}}}{K - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 \cdot (Q)^{\frac{2}{K}}} \right) \left(\frac{1 - (Q)^{\frac{K-1}{K}}}{1 - Q} \right) \right]^{0.5}$$

where $Q = \dfrac{P_1 - DP}{P_1}$

For Orifice Plates:

$$Eps = 1 - \left(0.41 + 0.35 \cdot \beta^4 \right) \cdot (DP / P_1) \cdot K^{-1}$$

First estimate for Flow Rate (W_0 [kg/s]):

$$W_0 = 2.107 \cdot 10^{-4} \cdot d^2 \cdot \sqrt{\frac{DP \cdot RO}{1 - \beta^4}}$$

5.2.6 Calculate Reynolds number.

For Gas / Steam Critical flow (Bore Reynolds number):

$$\mathrm{Re} = \frac{1.2732 \cdot 10^3 \cdot W_0}{\mu \cdot d}$$

For Liquid / Water and Gas / Steam SubCritical flow (Pipe Reynolds number):

$$\mathrm{Re} = \frac{1.2732 \cdot 10^3 \cdot W_0}{\mu \cdot D}$$

5.2.7 Calculate Discharge coefficient. See **Attachment.**

5.2.8 For Orifices in the case of Gas / Steam SubCritical flow, calculate DP and Gas Expansion factor:

$$DP = \frac{DP_{loss} \cdot \left(\left(1-\beta^4\right)^{0.5} + C \cdot \beta^2 \right)}{\left(\left(1-\beta^4\right)^{0.5} - C \cdot \beta^2 \right)}$$

$$Eps = 1 - \left(0.41 + 0.35 \cdot \beta^4\right) \cdot (DP / P_1) \cdot K^{-1}$$

5.2.9 Calculate new Flow rate:

For Gas / Steam at Critical flow:

$$W = 2195.591 \cdot C \cdot d^2 \cdot \left(\frac{M}{28.9625 \cdot T} \right)^{0.5} \cdot P_1 \cdot Eps \cdot F_{ttp}$$

For other cases (W [kg/s]):

$$W = 3.5124 \cdot 10^{-4} \cdot C \cdot F_s \cdot Eps \cdot d^2 \cdot \sqrt{\frac{DP \cdot RO}{1-\beta^4}}$$

5.2.10 Calculate the relative change in Flow rate:

$$\Delta W = \left| \frac{W_0 - W}{W_0} \right| ; W_0 = W$$

5.2.11 Paragraphs **5.2.6 – 5.2.10** are repeated until the relative change in the Flow rate is less than 0.0001.

5.3 Calculation of Pressure Loss

5.3.1 Calculate Internal pipe diameter at flow temperature:

$$D = D_0 \cdot \left[1 + \alpha_p \left(T - T_0\right)\right]$$

5.3.2 Calculate Correction factor for Steam quality (For Liquid, Water, and Steam, Fs=1):

$$F_s = 1 + 0.0074 \cdot S_t$$

5.3.3 Calculate Orifice diameter at flow temperature.

For Venturi tubes and Nozzles:

$$d = d_0 \cdot \left[1 + \alpha_{pe} \cdot \left(T - T_0\right)\right]$$

For Orifice plates:

$$d = d_0 \cdot \left[1 + 0.55 \cdot \left(Dbh/d_0\right)^2\right] \cdot \left[1 + \alpha_{pe} \cdot \left(T - T_0\right)\right]$$

5.3.4 Calculate Pipe Reynolds number (W [kg/s]):

$$\text{Re} = \frac{1.2732 \cdot 10^3 \cdot W}{\mu \cdot D}$$

5.3.5 Calculate β - ratio.

$$\beta = \frac{d}{D}$$

5.3.6 Calculate Discharge coefficient. See **Attachment.**

5.3.7 Calculate Critical flow rate.

For Liquid / Water:

$$DP = P_1 - P_v$$

$$W_{cr} = 3.5124 \cdot 10^{-4} \cdot C \cdot F_s \cdot Eps \cdot d^2 \cdot \sqrt{\frac{DP \cdot RO}{1 - \beta^4}}$$

For Gas / Steam

$$Eps = \left(\left(\frac{k}{Z} \right) \cdot \left(\frac{2}{k + 1} \right)^{(k+1)/(k-1)} \right)^{1/2}$$

$$W_{cr} = 2195.591 \cdot C \cdot d^2 \cdot \left(\frac{M}{28.9625 \cdot T} \right)^{0.5} \cdot P_1 \cdot Eps \cdot F_{ttp}$$

5.3.8 Checking for Critical flow and Pressure Loss calculation.

Case A. Critical flow: W>0.999*Wcr and W<1.001*Wcr.

For this case, Pressure Loss:

$$DP_{loss} = P_1 - P_v$$

Case B. Wrong data: W=>1.001*Wcr.

Flow rate can not be achieved. User has to check his data.

Case C. SubCritical flow: W<=0.999*Wcr

C1 First estimate for Differential range:

$$DP_0 = P_1 - P_v$$

C2 Calculate Discharge coefficient. See **Attachment.**

C3 Calculate Gas expansion factor (for Liquid and Water, $Eps = 1$).

For Venturi tubes and Nozzles:

$$Eps = \left[\left(\frac{K \cdot (Q)^{\frac{2}{K}}}{K - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 \cdot (Q)^{\frac{2}{K}}} \right) \left(\frac{1 - (Q)^{\frac{K-1}{K}}}{1 - Q} \right) \right]^{0.5}$$

where $Q = \dfrac{P_1 - DP_0}{P_1}$

For Orifice Plates:

$$Eps = 1 - \left(0.41 + 0.35 \cdot \beta^4\right) \cdot (DP_0 / P_1) \cdot K^{-1}$$

C4 Calculate new Differential range (W [kg/s]):

$$DP = \left[\frac{W \cdot \sqrt{1 - \beta^4}}{3.5124 \cdot 10^{-4} \cdot C \cdot Eps \cdot (\beta \cdot D)^2 \cdot F_s} \right]^2 \cdot RO^{-1}$$

C5 Calculate the relative change in Differential range:

$$\Delta DP = \left| \frac{DP_0 - DP}{DP_0} \right| ; DP_0 = DP$$

C6 Paragraphs **C3 – C5** are repeated until the relative change in the DP is less than 0.0001.

C7 Calculate Pressure Loss

$$DP_{loss} = \frac{DP \cdot \left(\left(1 - \beta^4\right)^{0.5} - C \cdot \beta^2 \right)}{\left(\left(1 - \beta^4\right)^{0.5} + C \cdot \beta^2 \right)}$$

Relief Valve Sizing

5.1 Blocked Flow : Liquid Relief

5.1.1 Requiring ASME capacity certification

5.1.1.1 Calculate Total back pressure:

$$P_b = P_{b1} + P_{b2}$$

5.1.1.2 Effective coefficient of discharge: $K_d = 0.65$ (if K_d is not entered by user).

5.1.1.3 Determine Correction factor for back pressure.

5.1.1.3.1 For Conventional and Pilot operated valves, $K_w = 1$.

5.1.1.3.2 For Bellows valve:

Case $P_b / P_s < 0.16$: $K_w = 1$

Case $0.16 \le P_b / P_s \le 0.5$: $K_w = 1.152 - 0.95 \cdot P_b / P_s$

Case $P_b / P_s > 0.5$: $K_w = 0.677$

5.1.1.4 Calculate Upstream relieving pressure:

*P_{up} [psi-g]

$$P_{up} = \left(1 + 0.01 \cdot P_{over}\right) \cdot P_s$$

5.1.1.5 Estimate Required effective discharge area:

*W [US gal/min], P_{up} [psi-g]

$$A_0 = \frac{W}{38 \cdot K_d \cdot K_W} \cdot \sqrt{\frac{G_f}{p_{up} - p_b}}$$

5.1.1.6 Calculate Reynolds number:

*W [US gal/min], μ [cP]

$$\mathrm{Re} = \frac{2800 \cdot W \cdot G_f}{\mu \cdot \sqrt{A_0}}$$

5.1.1.7 Calculate Correction factor for viscosity:

$$Y = \ln(\mathrm{Re}) / \ln(10)$$

Case $\mathrm{Re} \le 35$: $K_v = 0.3$

Case $35 < \mathrm{Re} \le 100$: $K_v = 0.62838 \cdot Y - 0.6611$

Case $100 < \mathrm{Re} \le 50000$:

$$K_v = -0.023362 \cdot Y^4 + 0.35578 \cdot Y^3 - 2.037 \cdot Y^2 + 5.2507 \cdot Y - 4.2228$$

Case $\mathrm{Re} > 50000$: $K_v = 1.$

5.1.1.8 Calculate Required effective discharge area.

5.1.1.8.1 With Rupture disk:

$$A = A_0 / (K_v \cdot K_{cc})$$

5.1.1.8.2 Without Rupture disk:

$$A = A_0 / K_v$$

5.1.2 Not requiring ASME capacity certification

5.1.2.1 Calculate Total back pressure:

$$P_b = P_{b1} + P_{b2}$$

5.1.2.2 Effective coefficient of discharge: $K_d = 0.62$ (if K_d is not entered by user).

5.1.2.3 Determine Correction factor for back pressure.

5.1.2.3.1 For Conventional and Pilot operated valves,
$K_w = 1$.

5.1.2.3.2 For Bellows valve:

Case $P_b / P_s < 0.16$: $K_w = 1$

Case $0.16 \le P_b / P_s \le 0.5$: $K_w = 1.152 - 0.95 \cdot P_b / P_s$

Case $P_b / P_s > 0.5$: $K_w = 0.677$

5.1.2.4 Calculate correction factor for overpressure:

$$Y = P_{over} / 10$$

Case $Y \le 1$: $K_p = -0.2 \cdot Y^2 + 0.8 \cdot Y$

Case $1 < Y < 2.5$:

$$K_p = 0.037641 \cdot Y^3 - 0.30196 \cdot Y^2 + 0.95464 \cdot Y - 0.08544$$

Case $2.5 \le Y \le 5$: $K_p = 0.034664 \cdot Y + 0.91334$

Case $Y > 5$: $K_p = 1.086$

5.1.2.5 Estimate Required effective discharge area:

*W [US gal/min]

$$A_0 = \frac{W}{38 \cdot K_d \cdot K_W \cdot K_p} \cdot \sqrt{\frac{G_f}{1.25 \cdot p_s - p_b}}$$

5.1.2.6 Calculate Reynolds number:

*W [US gal/min], μ [cP]

$$\mathrm{Re} = \frac{2800 \cdot W \cdot G_f}{\mu \cdot \sqrt{A_0}}$$

5.1.2.7 Calculate Correction factor for viscosity:

$$Y = \ln(\mathrm{Re}) / \ln(10)$$

Case $\mathrm{Re} \le 35$: $K_v = 0.3$

Case $35 < \mathrm{Re} \le 100$: $K_v = 0.62838 \cdot Y - 0.6611$

Case $100 < \mathrm{Re} \le 50000$:

$$K_v = -0.023362 \cdot Y^4 + 0.35578 \cdot Y^3 - 2.037 \cdot Y^2 + 5.2507 \cdot Y - 4.2228$$

Case $\mathrm{Re} > 50000$: $K_v = 1.$

5.1.2.8 Calculate Required effective discharge area.

5.1.2.8.1 With Rupture disk:

$$A = A_0 / (K_v \cdot K_{cc})$$

5.1.2.8.2 Without Rupture disk:

$$A = A_0 / K_v$$

5.2 Blocked Flow: Gas Relief

5.2.1 Calculate Upstream relieving pressure:

*P_a [psi-a]

$$P_{up} = (1 + 0.01 \cdot P_{over}) \cdot P_s + P_a$$

5.2.2 Calculate Total back pressure:

$$P_b = P_{b1} + P_{b2}$$

5.2.3 Calculate Critical flow throat pressure:

$$P_{cf} = P_{up} \cdot \left[\frac{2}{K + 1} \right]^{K/(K-1)}$$

5.2.4 Effective coefficient of discharge: $K_d = 0.975$.

5.2.5 The condition $P_b \le P_{cf}$ (P_b [psi-a]) determines:

Case A - Critical flow.

A1 Calculate Coefficient for critical flow equation:

Case $K \le 1.01$: $C_r = 317$

Case $1.01 < K < 2$: $C_r = 520 \cdot \sqrt{K \cdot \left(\frac{2}{K+1} \right)^{\frac{K+1}{K-1}}}$

Case $K \ge 2$: $C_r = 400$

A2 Calculate Capacity correction factor due to back pressure (if K_b is not entered by user).

A2.1 For Conventional and Pilot operated valves, $K_b = 1$.

A2.2 For Bellows valve:

A2.2.1 $Y = P_b / P_s$

A2.2.2 Case $Y > 0.315$: $K_{b10} = 1.53 - 1.68 \cdot Y$

Case $Y \le 0.315$: $K_{b10} = 1.$

A2.2.3 Case $Y > 0.325$: $K_{b20} = 1.14 - 0.43 \cdot Y$

Case $Y \le 0.325$: $K_{b20} = 1.$

A2.2.4 Case $P_{over} \ge 20$: $K_b = K_{b20}$

Case $10 < P_{over} < 20$:

$$K_b = K_{b10} + 0.1 \cdot \left(P_{over} - 10 \right) \cdot \left(K_{b20} - K_{b10} \right)$$

Case $P_{over} \le 10$: $K_b = K_{b10}$

A3 Estimate Required effective discharge area:

*W [lb/h], T [°R]

$$A_0 = \frac{W}{C_r \cdot K_d \cdot P_{up} \cdot K_b} \cdot \sqrt{\frac{T \cdot Z}{M}}$$

Case B ($P_b > P_{cf}$) - Subcritical flow: Bellows valve.

B1 Calculate C_r:

Case $K \le 1.01$: $C_r = 317$

Case $1.01 < K < 2$: $C_r = 520 \cdot \sqrt{K \cdot \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$

Case $K \ge 2$: $C_r = 400$

B2 If Capacity correction factor due to back pressure is not entered by user, $K_b = 1$.

B3 Estimate Required effective discharge area:

*W [lb/h], T [°R]

$$A_0 = \frac{W}{C_r \cdot K_d \cdot P_{up} \cdot K_b} \cdot \sqrt{\frac{T \cdot Z}{M}}$$

Case C ($P_b > P_{cf}$) - Subcritical flow: Conventional and Pilot operated valves.

C1 Calculate Coefficient for subcritical flow equation:

*P_b [psi-a]

C1.1 $R = P_b \;/\; P_{up}$

C1.2 $F_2 = \sqrt{\left(\frac{K}{K-1}\right) \cdot R^{2/K} \cdot \left[\frac{1 - R^{(K-1)/K}}{1-R}\right]}$

C2 Estimate Required effective discharge area:

*W [lb/h], P_b [psi-a], T [°R]

$$A_0 = \frac{W}{735 \cdot F_2 \cdot K_d} \cdot \sqrt{\frac{T \cdot Z}{M \cdot P_{up} \cdot \left(P_{up} - P_b\right)}}$$

5.2.6 For Rupture disk application, calculate Required effective discharge area:

$A = A_0 \;/\; K_{cc}$

5.3 Blocked Flow: Steam Relief

5.3.1 Calculate Upstream relieving pressure:

*P_a [psi-a]

$$P_{up} = \left(1 + 0.01 \cdot P_{over}\right) \cdot P_s + P_a$$

5.3.2 Calculate Correction factor for Napier equation:

Case $P_{up} \leq 1515$: $K_n = 1$

Case $1515 < P_{up} \leq 3215$:

$$K_n = \left(0.1916 \cdot P_{up} - 1000\right) / \left(0.2292 \cdot P_{up} - 1061\right)$$

Case $P_{up} > 3215$: $K_n = 1$

5.3.3 Calculate Superheat steam correction factor:

5.3.3.1 $Y1 = \left[\left(T - 273.16\right) \cdot 1.8 + 32\right] / 1000$

5.3.3.2 $Y2 = P_{up} / 1000$

5.3.3.3

$$K_{sh} = 0.201 \cdot Y1^2 \cdot Y2^2 - 0.168 \cdot Y1^2 \cdot Y2 + 0.291 \cdot Y1^2 - 0.389 \cdot Y1 \cdot Y2^2 + 0.256 \cdot Y1 \cdot Y2 - 0.838 \cdot Y1 + 0.164 \cdot Y2^2 - 0.025 Y2 + 1.276$$

5.3.4 Effective coefficient of discharge: $K_d = 0.975$.

5.3.5 Estimate Required effective discharge area:

*W [lb/h]

$$A_0 = \frac{W}{51.5 \cdot P_{up} \cdot K_d \cdot K_n \cdot K_{sh}}$$

5.3.6 For Rupture disk application, calculate Required effective discharge area:

$$A = A_0 / K_{cc}$$

5.4 Fire case: Gas Expansion

5.4.1 Calculate Upstream relieving pressure:

*P_a [psi-a]

$$P_{up} = \left(1 + 0.01 \cdot P_{over}\right) \cdot P_s + P_a$$

5.4.2 Calculate Coefficient for critical flow equation:

Case $K \le 1.01$: $C_r = 317$

Case $1.01 < K < 2$: $C_r = 520 \cdot \sqrt{K \cdot \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$

Case $K \ge 2$: $C_r = 400$

5.4.3 If Heat absorption factor is entered, go to paragraph **5.4.8.**

5.4.4 If Normal pressure is not enetered or Normal temperature is not entered, a message appears: “Please enter Heat absorption factor or Normal pressure and Normal temperature”.

5.4.5 Calculate Gas temperature at relieving conditions:

*P_a [psi-a], T [°R]

$$T1 = T \cdot \frac{P_{up}}{P}$$

5.4.6 If Vessel Wall temperature is not enetered, the following message appears:

“Please enter Heat absorption factor or Vessel wall temperature”.

5.4.7 Calculate Heat absorption factor:

T [°R]

$$F1 = 0.1406 \cdot \frac{\left(T_w - T1\right)^{1.25}}{C_r \cdot K_d \cdot T1^{0.6506}}$$

5.4.8 Estimate Required effective discharge area:

*W [lb/h], T [°R]

$$A_0 = \frac{F1 \cdot A1}{\sqrt{P_{up}}}$$

5.4.9 If Normal pressure is not entered or Normal temperature is not entered

or Molecular Mass is not entered or Vessel wall temperature is not entered, a message appears: "Maximum discharge can not be calculated

because Normal pressure or Normal temperature or Molecular Mass or

Vessel wall temperature is not entered". Then go to paragraph **5.4.11.**

5.4.10 Calculate Maximum discharge:

*P_a [psi-a], W[lb/h]

$$W = 0.1406 \cdot A1 \cdot \sqrt{\left(M \cdot P_{up}\right)} \cdot \frac{\left(T_w - T1\right)^{1.25}}{T1^{1.1506}}$$

5.4.11 For Rupture disk application, calculate Required effective discharge area:

$$A = A_0 \; / \; K_{cc}$$

5.5 Fire case : Liquid Filled Vessel

5.5.1 Calculate Maximum discharge:

*HV [Btu/lb], W[lb/h]

$$W = 21000 \cdot \frac{F \cdot \left(A1\right)^{0.82}}{HV}$$

5.5.2 Calculate Upstream relieving pressure:

*P_a [psi-a]

$$P_{up} = \left(1 + 0.01 \cdot P_{over}\right) \cdot P_s + P_a$$

5.5.3 Calculate Total back pressure:

$$P_b = P_{b1} + P_{b2}$$

5.5.4 Calculate Critical flow throat pressure:

$$P_{cf} = P_{up} \cdot \left[\frac{2}{K+1} \right]^{K/(K-1)}$$

5.5.5 Effective coefficient of discharge: $K_d = 0.975$.

5.5.6 The condition $P_b \le P_{cf}$ (P_b [psi-a]) determines:

Case A - Critical flow.

A1 Calculate Coefficient for critical flow equation:

Case $K \le 1.01$: $C_r = 317$

Case $1.01 < K < 2$: $C_r = 520 \cdot \sqrt{K \cdot \left(\frac{2}{K+1} \right)^{\frac{K+1}{K-1}}}$

Case $K \ge 2$: $C_r = 400$

A2 Calculate Capacity correction factor due to back pressure (if K_b is not entered by user).

A2.1 For Conventional and Pilot operated valves, $K_b = 1$.

A2.2 For Bellows valve:

A2.2.1 $Y = P_b \ / \ P_s$

A2.2.2 Case $Y > 0.315$: $K_{b10} = 1.53 - 1.68 \cdot Y$

Case $Y \leq 0.315$: $K_{b10} = 1.$

A2.2.3 Case $Y > 0.325$: $K_{b20} = 1.14 - 0.43 \cdot Y$

Case $Y \leq 0.325$: $K_{b20} = 1.$

A2.2.4 Case $P_{over} \geq 20$: $K_b = K_{b20}$

Case $10 < P_{over} < 20$:

$$K_b = K_{b10} + 0.1 \cdot \left(P_{over} - 10\right) \cdot \left(K_{b20} - K_{b10}\right)$$

Case $P_{over} \leq 10$: $K_b = K_{b10}$

A3 Estimate Required effective discharge area:

*W [lb/h], T [°R]

$$A_0 = \frac{W}{C_r \cdot K_d \cdot P_{up} \cdot K_b} \cdot \sqrt{\frac{T \cdot Z}{M}}$$

Case B ($P_b > P_{cf}$) - Subcritical flow: Bellows valve.

B1 Calculate C_r:

Case $K \leq 1.01$: $C_r = 317$

Case $1.01 < K < 2$: $C_r = 520 \cdot \sqrt{K \cdot \left(\frac{2}{K + 1}\right)^{\frac{K+1}{K-1}}}$

Case $K \geq 2$: $C_r = 400$

B2 If Capacity correction factor due to back pressure is not entered by user, $K_b = 1$.

B3 Estimate Required effective discharge area:

*W [lb/h], T [°R]

$$A_0 = \frac{W}{C_r \cdot K_d \cdot P_{up} \cdot K_b} \cdot \sqrt{\frac{T \cdot Z}{M}}$$

Case C ($P_b > P_{cf}$) - Subcritical flow: Conventional and Pilot operated valves.

C1 Calculate Coefficient for subcritical flow equation:

*P_b [psi-a]

C1.1 $R = P_b \;/\; P_{up}$

C1.2 $F_2 = \sqrt{\left(\frac{K}{K-1}\right) \cdot R^{2/K} \cdot \left[\frac{1 - R^{(K-1)/K}}{1 - R}\right]}$

C2 Estimate Required effective discharge area:

*W [lb/h], P_b [psi-a], T [°R]

$$A_0 = \frac{W}{735 \cdot F_2 \cdot K_d} \cdot \sqrt{\frac{T \cdot Z}{M \cdot P_{up} \cdot \left(P_{up} - P_b\right)}}$$

5.5.7 For Rupture disk application, calculate Required effective discharge area:

$A = A_0 \;/\; K_{cc}$

6 Thermowell Calculation

6.1 Define initial value of K_f constant:

If D_t=1/4 then K_f=2.075

If D_t=3/8 then K_f=2.445

If D_t=9/16 then K_f=3.02

If D_t=11/16 then K_f=3.40

If D_t=7/8 then K_f=3.965

6.2 Calculate Ratio of frequency at fluid temperature to frequency at 70 °F:

* T[°F]

For Austenitic steel,

$$R_f = 0.99996 - 0.0000036111 \cdot \mathrm{T} - 0.0000000742 \cdot \mathrm{T}^2$$

For Ferritic steel,

$$R_f = 1.0101 - 0.000138 \cdot \mathrm{T} + 0.000000267 \cdot \mathrm{T}^2 - 0.000000000336 \cdot \mathrm{T}^3$$

6.3 Calculate Maximum thermowell length:

* $\mathrm{RO}_{\mathrm{material}}[\mathrm{lb/in}^3]$

$$L_1 = \sqrt{(R \cdot K_f \cdot \sqrt{E} \cdot B \cdot R_f)/(2.64 \cdot \sqrt{ROmaterial} \cdot V)}$$

6.4 Define K_f constant:

Case $\mathrm{L} \leq 3.5$

If D_t=1/4 then K_f=2.06

If D_t=3/8 then K_f=2.42

If D_t=9/16 then K_f=2.97

If D_t=11/16 then K_f=3.32

If D_t=7/8 then K_f=3.84

Case 3.5<L≤6

If D_t=1/4 then K_f=2.07

If D_t=3/8 then K_f=2.45

If D_t=9/16 then K_f=3.01

If D_t=11/16 then K_f=3.39

If D_t=7/8 then K_f=3.96

Case 6<L≤9

If D_t=1/4 then K_f=2.08

If D_t=3/8 then K_f=2.46

If D_t=9/16 then K_f=3.05

If D_t=11/16 then K_f=3.44

If D_t=7/8 then K_f=4.03

Case 9<L≤13.25

If D_t=1/4 then K_f=2.09

If D_t=3/8 then K_f=2.47

If D_t=9/16 then K_f=3.06

If D_t=11/16 then K_f=3.46

If D_t=7/8 then K_f=4.06

Case 13.25<L≤20

If D_t=1/4 then K_f=2.09

If D_t=3/8 then K_f=2.47

If D_t=9/16 then K_f=3.07

If D_t=11/16 then K_f=3.47

If D_t=7/8 then K_f=4.08

Case 20<L

If D_t=1/4 then K_f=2.09

If D_t=3/8 then K_f=2.47

If D_t=9/16 then K_f=3.07

If D_t=11/16 then K_f=3.48

If D_t=7/8 then K_f=4.09

6.5 Paragraphs **7.3 - 7.4** are repeated until current K_f value equals previous

K_f value.

6.6 Calculate Natural Frequency for L=L1:

* $RO_{material}$[lb/in^3]

$$fn = \frac{K_f \cdot \sqrt{E} \cdot R_f}{\left(L_1^{\,2} \cdot \sqrt{ROmaterial}\right)}$$

6.7 Calculate Wake Frequency:

$$f_W = 2.64 \cdot \frac{V}{B}$$

6.8 Calculate Magnification Factor for $L_1(R \leq 0.8)$:

$$F_M = \frac{\left(\frac{f_w}{f_n}\right)^2}{1-\left(\frac{f_w}{f_n}\right)^2} = \frac{R^2}{1-R^2}$$

6.9 Define K_1, K_2, K_3 constants:

If D_t=1/4 then {K_1=0.412; K_2=37.5; K_3=0.116}

If D_t=3/8 then {K_1=0.334; K_2=42.3; K_3=0.205}

If D_t=9/16 then {K_1=0.223; K_2=46.8; K_3=0.389}

If D_t=11/16 then {K_1=0.202; K_2=48.7; K_3=0.548}

If D_t=7/8 then {K_1=0.155; K_2=50.1; K_3=0.864}

6.10 Calculate Maximum Allowable Static Gage Pressure:

*Pmax [psi-g]. Convert to OUM used for pressure.

*S [psi-g]

$$P\max = K_1 \cdot S$$

6.11 Calculate Maximum thermowell length based on Steady State Stress Consideration:

*L_2 [inch]

*RO_{fluid} [lb/ft^3]

*P [psi-g] – operating pressure

$$L_2 = \frac{K_2}{V} \cdot \sqrt{\frac{(S - K_3 P)}{ROfluid \cdot (1 + F_M)}}$$

7 Standards

7.1 Control valve sizing

ISA S75.01 (1995)

IEC 534-2 (1978)

IEC 534-2-2 (1980)

7.2 Noise calculation

Masoneilan OZ 3000E (1984) - Hydrodynamic Noise

ISA S75.17 (1991) - Aerodynamic Noise

IEC 534-8-3 (1995)

IEC 534-8-4 (1994)

7.3 Flow meter sizing

Standard

7.3.1 Square Edge Orifice

Flange Tappings	ISO*/ Miller**
Corner Tappings	ISO / Miller
Radius Tappings	ISO / Miller
Small-Bore Honed-Orifice Meter Run with Corner Tappings	Miller
Small-Bore Honed-Orifice Meter Run with Flange Tappings	Miller
Pipe Tappings (2.5D & 8D)	Miller
AGA Report 3 (Flange Tappings)	AGA Rep.3***
AGA Report 3 (Pipe Tappings)	AGA Rep.3

7.3.2 Quarter of Circle Orifice

Flange Tappings	BS 1042****
Corner Tappings	BS 1042
Radius Tappings	BS 1042

7.3.3 Conical Entrance Orifice — Miller

7.3.4 Lo-Loss Tube — Miller

7.3.5 Venturi Tube

Classical venturi tube with an "as cast" convergent section	ISO / Miller
Classical venturi tube with a machined convergent section	ISO / Miller
Classical venturi tube with a rough-welded sheet-iron convergent section	ISO / Miller
Universal Venturi Tube	Miller

7.3.6 Nozzle

ISO Long Radius Nozzle	ISO
ASME Long Radius Nozzle	Miller
ISA 1932 Nozzle	ISO / Miller
Venturi Nozzle	ISO / Miller

7.3.7 Eccentric Orifice

Diametrically Opposite Flange Tappings	Miller
Side (90°) Flange Tappings	Miller
Diametrically Opposite Vena Contracta Tappings	Miller
Side (90°) Vena Contracta Tappings	Miller

7.3.8 Segmental Orifice

Flange Tappings	Miller
Vena Contracta Tappings	Miller

Note:
- * ISO 5167-1 (1991)
- ** Flow Measurement Engineering Handbook by R.W. Miller, 3rd edition (1996)
- *** ANSI/API 2530 (1991) [AGA Report 3]
- **** British standard 1042. Section 1.2 (1989)

7.4 Relief valve sizing

API RP 520, seventh edition (January 2000)

7.5 Thermowell calculation

ASME PTC 19.3 (1974)

9 Attachment

Formulae for Discharge Coefficient

Notation

B β - ratio

C Discharge Coefficient

D Internal Pipe Diameter, mm

Di Internal Pipe Diameter, inch

Re Pipe Reynolds Number at Normal Flow Rate

Rd Bore Reynolds Number at Normal Flow Rate

1 Square Edge Orifice

1.1 Flange Tappings

If *D<58.62*

C = 0.5959+0.0312*B^2.1-0.184^B^8+0.0029*B^2.5*(10^6/Re)^0.75-0.85598*B^3/D+ 0.039*B^4/(1-B^4)

Else C = 0.5959+0.0312*B^2.1-0.184^B^8+0.0029*B^2.5*(10^6/Re)^0.75-0.85598*B^3/D+ 2.286*B^4/(D*(1-B^4))

1.2 Corner Tappings

C = 0.5959+0.0312*B^2.1-0.184^B^8+0.0029*B^2.5*(10^6/Re)^0.75

1.3 Radius Tappings

C = 0.5959+0.0312*B^2.1-0.184^B^8+0.0029*B^2.5*(10^6/Re)^0.75+0.039*B^4/(1-B^4)-0.015839*B^3

1.4 Small-Bore Honed-Orifice Meter Run with Corner Tappings

C = (0.5991+0.0044/Di+(0.3155+0.0175/Di)*(B^4+2^B^16)+(0.52/Di-0.192+

(16.48-1.16/Di)*(B^4+4*B^16))*(Re^(-0.5)))*((1-B^4)^0.5)

1.5 Small-Bore Honed-Orifice Meter Run with Flange Tappings

C = (0.5980+0.468*(B^4+10^B^12)+(0.87+8.1*B^4)*(Re^(-0.5)))*((1-B^4)^0.5)

1.6 Pipe Tappings (2.5D & 8D)

C = 0.5959+0.461*B^2.1+0.48^B^8+0.039*B^4/(1-B^4)+0.0029*B^2.5*(10^6/Re)^0.75

1.7 AGA Report 3 (Flange Tappings)

A0 = 830-5000*B+9000*B^2-4200*B^3+530/Di^0.5

A1 = 0.5993+0.007/Di+(0.364+0.076/Di^0.5)*B^4

A2 = 0

If *B<(0.07+0.5/Di)* A2 = 0.4*(1.6-1/Di)^5*(0.07+0.5/Di-B)^(5/2)

A3 = 0

If *B<0.5* A3 = (0.5-B)^(3/2)*(0.009+0.034/Di)

A4 = 0

If *B>0.7* A4 = (B-0.7)^(5/2)*(65/Di^2+3)

K0 = (A1+A2-A3+A4)/(1+0.000015*A0)

EF = A0*Di*B

C = (1-B^4)^0.5*K0*(1+EF*B/Re)

1.8 AGA Report 3 (Pipe Tappings)

A0 = 905-5000*B+9000*B^2-4200*B^3+875/Di

A1 = 0

If *B<0.25* A1 = (0.25-B)^(5/2)*(1.43/Di^0.5)

K0 = 0.5925+0.0182/Di+(0.440-0.06/Di)*B^2+(0.935+0.225/Di)*B^5+1.35*B^14+A1

EP = A0*Di*B

C = (1-B^4)^0.5*K0*(1+EP*B/Re)

2 Quarter of Circle Orifice

C = 0.73823+0.3309*B-1.1615^B^2+1.5084*B^3

3 Conical Entrance Orifice

If *Re≤ 5000*B* C = 0.734

Else C = 0.730

4 Lo-Loss Tube

C = 1.005-0.471*B+0.564^B^2-0.514*B^3

5 Venturi Tube

5.1 Classical venturi tube with an "as cast" convergent section

C = 0.984

5.2 Classical venturi tube with a machined convergent section

C = 0.995

5.3 Classical venturi tube with a rough-welded sheet-iron convergent section

C = 0.985

5.4 Universal Venturi Tube

C = 0.9797

6 Nozzle

6.1 ISO Long Radius Nozzle

C = 0.9965-0.00653*(B^0.5)*(10^6/Re)^0.5

6.2 ASME Long Radius Nozzle

C = 0.9975-6.53*B^0.5*Re^-0.5

6.3 ISA 1932 Nozzle

C = 0.99-0.2262*B^4.1-(0.00175*B^2-0.0033*B^4.15)*(10^6/Re)^1.15

6.4 Venturi Nozzle

C = 0.9558-0.196*B^4.5

7 Eccentric Orifice

7.1 Diametrically Opposite Flange Tappings

If $D \leq 100$ C = 0.5875+0.3813*B^2.1+0.6898^B^8-0.1963*B^4/(1-B^4)-0.3366*B^3+

(7.3-15.7*B+170.8^B^2-399.7*B^3+332.2*B^4)/(Re)^0.75

Else C = 0.5949+0.4078*B^2.1+0.0547^B^8+0.0955*B^4/(1-B^4)-0.5608*B^3+

(-139.7+1328.8*B-4228.2^B^2+5691.9*B^3-2710.4*B^4)/(Re)^0.75

7.2 Side (90°) Flange Tappings

If $D \leq 100$ C = 0.6284+0.1462*B^2.1-0.8464^B^8+0.2603*B^4/(1-B^4)-0.2886*B^3+

(69.1-469.4*B+1245.6^B^2-1287.5*B^3+486.2*B^4)/(Re)^0.75

Else C = 0.6276+0.0828*B^2.1+0.2739^B^8-0.0934*B^4/(1-B^4)-0.1132*B^3+

(-103.2+898.3*B-2557.3^B^2+2977*B^3-1131.3*B^4)/(Re)^0.75

7.3 Diametrically Opposite Vena Contracta Tappings

If *D ≤ 100* *Dp1 ≤ 100*

DC = 0.6261+0.1851*Bet0^2.1-0.2879*Bet0^8+0.1170*Bet0^4/(1-

Bet0^4)- 0.2845*Bet0^3+(23.3 - 207*Bet0+821.5*Bet0^2-

1388.6*Bet0^3+900.3*Bet0^4)/(Re1)^0.75

Else DC = 0.6276+0.0828*Bet0^2.1+0.2739*Bet0^8-0.0934*Bet0^4/(1-Bet0^4)-

0.1132*Bet0^3+(55.7-471.4*Bet0+1721.8*Bet0^2-2722.6*Bet0^3+

1569.4*Bet0^4)/(Re1)^0.75

7.4 Side (90°) Vena Contracta Tappings

If *D ≤ 100* DC = 0.5917+0.3061*Bet0^2.1+0.3406*Bet0^8-0.1019*Bet0^4/(1-Bet0^4)-

0.2715*Bet0^3+(-69.3+556.9*Bet0-1332.2*Bet0^2+1303.7*Bet0^3-

394.8*Bet0^4)/(Re1)^0.75

Else DC = 0.6016+0.3312*Bet0^2.1-1.5581*Bet0^8+0.6510*Bet0^4/(1-Bet0^4)-

0.7308*Bet0^3+(52.8-434.2*Bet0+1571.2*Bet0^2-2460.9*Bet0^3+

1420.2*Bet0^4)/(Re1)^0.75

8 Segmental Orifice

8.1 Flange Tappings

If *D ≤ 100* C = 0.5866+0.3917*B^2.1+0.7586^B^8-0.2273*B^4/(1-B^4)-0.3343*B^3

Else C = 0.6037+0.1598*B^2.1-0.2918^B^8+0.0244*B^4/(1-B^4)-0.0790*B^3

8.2 Vena Contracta Tappings

If $D \leq 100$ C = 0.5925+0.3380*B^2.1+0.4016^B^8-0.1046*B^4/(1-B^4)-0.3212*B^3

Else C = 0.5922+0.3932*B^2.1+0.3412^B^8-0.0569*B^4/(1-B^4)-0.4628*B^3

9 Restriction Device

9.1 Critical Flow

9.1.1 **Square Edge Orifice** (Liquid/Water)

C = 0.6

9.1.2 **Thick Plate Square Edge Orifice** (Liquid/Water)

C = 0.899

9.1.3 **Classical Venturi Tube**

C = 0.985

9.1.4 **Square Edge Orifice** (Gas/Steam)

C = 0.83932

9.1.5 **Toroidal Throat Venturi Nozzle**

C = 0.99354 - 1.525/Rd^0.5

9.1.6 **Cylindrical Throat Venturi Nozzle**

If Rd<3.5*10^5 C = 1 - 7.21/Rd^0.5
If 3.5*10^5<=Rd<2.5*10^6 C = 0.9887

If 2.5*10^6<Rd C = 1 - 0.222/Rd^0.2

9.1.7 **ASME Long Radius Nozzle**

If Rd<3.5*10^5 C = 1 - 7.21/Rd^0.5
If 3.5*10^5<=Rd<2.5*10^6 C = 0.9887

If 2.5*10^6<Rd C = 1 - 0.222/Rd^0.2

9.2 SubCritical Flow

9.2.1 Square Edge Orifice (Liquid/Water), **Thick Plate Square Edge Orifice** (Liquid/Water) , and **Square Edge Orifice** (Gas/Steam)

L1 = 25.4/D

L2 = 25.4/D

A = (19000 * B/Re)^0.8

M = 2 * L2 / (1 - B)

C = 0.5961 + 0.0261*B^2 - 0.216 *B^8 + 0.000521*(1000000*B/Re)^0.7 +

(0.0188+0.0063*A) * B^3.5 * (1000000/Re)^0.3 + (0.043+0.080*exp(-10*L1) -

0.123*exp(-7*L1)) * (1 - 0.11*A)*(B^4/(1 - B^4)) - 0.031*(M - 0.8*M^1.1)*B^1.3.

IF D < 71.12 THEN C = C +0.011*(0.75 - B) * (2.8 - Di)

9.2.2 Classical Venturi Tube C = 0.984

9.2.3 Toroidal Throat Venturi Nozzle C = 0.9558-0.196*B^4.5

9.2.4 Cylindrical Throat Venturi Nozzle C = 0.9558-0.196*B^4.5

9.2.5 ASME Long Radius Nozzle C = 0.9975-6.53*(B^0.5)*(1/Re)^0.5