EQUATIONS IN ANY CONSISTENT UNITS

Mass Flow rate, any consistent units:

$$A = \frac{W}{K}\frac{1}{\sqrt{2\,g_c\,P\,\rho}}.$$

Volumetric Flow rate, any consistent units:

$$A = \frac{Q}{K}\sqrt{\frac{\rho}{2\,g_c\,P}}.$$

For liquids that are more viscous than water, a correction factor can be applied that is found as follows. First calculate the uncorrected area. Then, using the area of the next larger standard disk size, calculate the Reynolds number:

$$N_{re} = \frac{2\,W}{\mu\sqrt{\pi A}}.$$

Find the correction factor from Figure A. Then divide the original uncor-rected area by this factor. If the liquid is so viscous that the Reynolds number is not on the graph, you may consult OSECO for evaluation. Please also note the limits on Reynolds Number shown in Figure A. A curve fitted equation for this correction is also presented in Figure A.

REACTION FORCE

Reaction force for mass flow rate, any consistent units:

$$F = P\,A + \frac{W^2}{g_c\,\rho\,A}.$$

If the flow rate is given in volumetric rather than mass units, the equa-tions above can be used by substituting (ρ x Q) for W. For the equations above, the following legend applies:

- A - disk area
- F - reaction force
- g_c - the gravitational constant
- K - discharge coefficient (ASME permits 0.62)
- μ - dynamic or absolute viscosity
- P - pressure drop across the disk
- ρ - fluid density
- Q - volumetric flow rate
- W - mass flow rate

EQUATIONS IN CONVENTIONAL U.S. UNITS

Mass flow rate, conventional U.S. units:

$$A = \frac{W}{1492} \frac{1}{\sqrt{P \rho}} .$$

Volumetric flow rate, conventional U.S. units:

$$A = \frac{Q}{186} \sqrt{\frac{\rho}{P}} .$$

For liquids that are more viscous than water (viscosity greater than 1 cp), a correction factor can be found using the procedure detailed under "EQUA-TIONS IN ANY CONSISTENT SET OF UNITS" above. The Reynolds number can be calculated from:

$$N_{re} = 5.6 \frac{W}{\mu \sqrt{A}} \quad or \quad N_{re} = 45 \frac{\rho Q}{\mu \sqrt{A}} .$$

Reaction force for mass flow rate, conventional U.S. units:

$$F = P A + 3.45 x 10^{-7} \frac{W^2}{\rho A} \quad or \quad F = P A + 2.22 x 10^{-5} \frac{\rho Q^2}{A} ,$$

For conventional U.S. units in the above equations, the following applies:

- A - square inches
- F - pounds
- K - 0.62 per the ASME Code (included in equation constant)
- W - pounds per hour
- Q - gallons per minute
- ρ - pounds per cubic foot
- μ - centipoise
- P - pounds per square inch

For discharge coefficients K other than 0.62, multiply A as calculated above by 0.62/K. To use specific gravity of the liquid rather than density, sub-stitute 62.37 x specific gravity for density ρ in either of the above equations.

EQUATIONS IN METRIC UNITS

Mass flow rate, metric units:

$$A = 1.002 \frac{W}{\sqrt{P \rho}}.$$

Volumetric flow rate, metric units:

$$A = 3607\, Q \sqrt{\rho/P}\,.$$

For liquids that are more viscous than water (viscosity greater than $1x10^{-3}$ Pa-sec), a correction factor can be found using the procedure detailed under "EQUATIONS IN ANY CONSISTENT SET OF UNITS" above. The Reynolds number can be calculated from:

$$N_{re} = 0.3134 \frac{W}{\mu \sqrt{A}} \quad or \quad N_{re} = 1128 \frac{\rho Q}{\mu \sqrt{A}}\,.$$

Reaction force for mass flow rate, metric units:

$$F = 0.1\, P A + 0.07716 \frac{W^2}{\rho A},$$

For metric units in the equations above, the following applies:

- A - square millimeters
- F - Newtons
- K - 0.62 per the ASME Code (included in equation constant)
- W - kilograms per hour
- Q - cubic meters per second
- ρ - kilograms per cubic meter
- µ - Pa-sec (kg/m-sec)
- P - bars

For discharge coefficients K other than 0.62, multiply A as calculated above by 0.62/K.

GASES AND VAPORS

Flow of a gas or vapor through a ruptured disk will be at sonic velocity if the ratio of outlet to inlet pressure is sufficiently low. As a rule of thumb, this will occur if the inlet pressure exceeds 15 psig and the relief device vents to atmosphere.

From an analytical standpoint, sonic flow will occur when the ratio of out-let to inlet absolute pressures P_2/P_1 is less than or equal to the critical pressure ratio r_c, defined by:

$$r_c = \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}},$$

For this equation:
k - ratio of specific heat at constant pressure to specific heat at constant volume (C_p/C_v)

Subsonic flow will occur when P_2/P_1 is greater than r_c.

The equations for gas or vapor flow shown below are the same for either so-nic or subsonic flow except for the evaluation of the gas flow constant C included in the equations. Definition of this constant is shown below.

EQUATIONS IN ANY CONSISTENT SET OF UNITS

Mass flow rate, any consistent units:

$$A = \frac{W}{K\,C\,P_1}\sqrt{\frac{Z\,T}{M}}.$$

Volumetric flow rate, actual conditions, any consistent units:Volumetric flow rate, standard conditions, any consistent units:

$$A = \frac{V_S}{R^*\,K\,C\,P_1}\,\frac{P_S}{Z_S\,T_S}\sqrt{M\,Z\,T}.$$

For sonic flow ($P_2/P_1 < r_c$), the gas flow constant C is given by

$$C = \sqrt{\frac{k\,g_c}{R^*}\left[\frac{2}{k+1}\right]^{\frac{k+1}{k-1}}}.$$

$$C = \sqrt{\frac{2k}{k-1}\,\frac{g_c}{R^*}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}}\right]}.$$

For subsonic flow ($P_2/P_1 > r_c$),Reaction force for sonic flow, any consistent units:

$$F = P\,A\,(1 + k)\,.$$

If flow is subsonic, the reaction force will be less than the value given by this equation.

For the equations shown above, the following legend applies:

- A - disk area
- F - reaction force
- g_c - gravitational constant
- K - 0.62 per ASME Code
- k - ratio of specific heats
- M - molecular weight
- P - inlet pressure, gauge value
- P_1 - inlet pressure, absolute value
- P_2 - outlet pressure, absolute value
- R^* - Universal Gas Constant,
- T - temperature, absolute value
- V_A - volumetric flow rate, actual conditions
- V_S - volumetric flow rate, standard conditions
- W - mass flow rate
- Z - compressibility factor

EQUATIONS IN CONVENTIONAL U.S. UNITS

Mass flow rate, conventional U.S. units:

$$A = 1.613 \frac{W}{C P_1} \sqrt{\frac{Z T}{M}}.$$

Volumetric flow rate, actual conditions, conventional U.S. units:

$$A = 9.02 \frac{V_A}{C} \sqrt{\frac{M}{Z T}}.$$

Volumetric flow rate, standard conditions, conventional U.S. units:

$$A = \frac{V_S}{3.92\, C P_1} \sqrt{Z M T},$$

For the above equations, the following applies:

- A - square inches
- W - pounds per hour
- V_A - actual cubic feet per minute
- V_S - standard cubic feet per minute (14.7 psia at 60°F)
- K - 0.62 per the ASME Code (included in equation constant)
- P_1 - pounds per square inch absolute
- T - °R (degrees Rankine)

If the compressibility factor Z is not known, Figure B can be utilized to determine this factor. Using Z = 1.0 is frequently done when there is insufficient data to determine the value of Z. If the specific gravity of the gas (relative to air at standard conditions) is known but the molecular weight is not known, substitute 28.964 x specific gravity for M in the equation for standard conditions.

For sonic flow ($P_2/P_1 < r_c$), the gas flow constant C changes to the equation below :

$$C = 520 \sqrt{k \left[\frac{2}{k + 1}\right]^{\frac{k+1}{k-1}}}.$$

For subsonic flow, ($P_2/P_1 > r_c$), changes to the equation below:

$$C = 735 \sqrt{\frac{k}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}}\right]}$$

Reaction force for sonic flow, conventional U.S. units:

$$F = P A (1 + k),$$

In the equation immediately above:

F - pound_f

If flow is subsonic, the value given by this equation will be an upper limit of the reaction force.

EQUATIONS IN METRIC UNITS

Mass flow rate, metric units:

$$A = 1.613 \frac{W}{C P_1} \sqrt{\frac{Z T}{M}}.$$

Volumetric flow rate, actual conditions, metric units:

$$A = 69{,}840 \frac{V_A}{C} \sqrt{\frac{M}{Z T}}.$$

Volumetric flow rate, standard conditions, metric units:

$$A = 242.4 \frac{V_S}{C P_1} \sqrt{M Z T},$$

For the above equations, the following legend applies:

A - square millimeters
W - kilograms per hour
V_A - actual cubic meters per second
V_S - standard cubic meters per second (1 bar absolute at 15°C)
K - 0.62 per the ASME Code (included in equation constant)
P_1 - bars absolute
T - °K (degrees Kelvin)

For sonic flow ($P_2/P_1 < r_c$), the gas flow constant C is given by:

$$C = 3.948 \sqrt{k \left[\frac{2}{k+1} \right]^{\frac{k+1}{k-1}}}.$$

For subsonic flow ($P_2/P_1 > r_c$), C changes to the equation below:

$$C = 5.583 \sqrt{\frac{k}{k-1} \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1} \right)^{\frac{k+1}{k}} \right]}.$$

Reaction force for sonic flow, metric units:

$$F = 0.1\, P A\, (1 + k),$$

In the equation immediately above:
F - Newtons

If flow is subsonic, the value given by this equation will be an upper limit to the reaction force.

STEAM

EQUATIONS IN CONVENTIONAL U.S. UNITS
(Sonic flow, P_2/P_1 less than 0.55.)

Superheated steam (Napier's empirical equation):

$$A = \frac{W (1 + 0.00065\, \Delta T)}{51.5\, K P_1}.$$

Dry saturated steam, pressures up to 1500 psig:

$$A = \frac{W}{51.5\, K P_1}.$$

Dry saturated steam, pressures between 1500 and 3200 psig:

$$A = \frac{W}{51.5\, K P_1 \left(\frac{0.1906\, P_1 - 1000}{0.2292\, P_1 - 1061} \right)}.$$

Wet steam:

$$A = \frac{W(1 - 0.012\,\Delta X)}{51.5\,K P_1}\,.$$

For the above equations, the following applies:

- A - square inches
- W - pounds per hour
- ΔT - degrees of superheat - °F (degrees Fahrenheit)
- K - 0.62 per the ASME Code
- P_1 - inlet pressure - psia
- ΔX - (100 - % steam quality)

The reaction force for steam discharge can be found by using the equation for gases and vapors with k = 1.33 .

EQUATIONS IN METRIC UNITS
(Sonic flow, P_2/P_1 less than 0.55.)

Superheated steam (Napier's empirical equation):

$$A = 1.904\,\frac{W(1 + 0.00117\,\Delta T)}{K P_1}\,.$$

Dry saturated steam, pressures up to 102 bar:

$$A = \frac{1.904\,W}{K P_1}\,.$$

Dry saturated steam, pressures between 102 and 220 bar:

$$A = \frac{1.904\,W}{K P_1 \left(\dfrac{2.764\,P_1 - 1000}{3.324\,P_1 - 1061}\right)}\,.$$

Wet steam:

$$A = 1.904\,\frac{W(1 - 0.012\,\Delta X)}{K P_1}\,,$$

For the above equations, the following applies:

A - square millimeters
W - kilograms per hour
ΔT - degrees of superheat in °C (degrees Celsius or Centigrade)
K - 0.62 per ASME Code
P_1 - inlet pressure - bar absolute
ΔX - (100 - % steam quality)

EXAMPLE 1, LIQUIDS

Determine the rupture disk size required for relieving the following conditions:

Vessel MAWP	45 psig
Flow Requirement	1500 gallons per minute
Back Pressure	5 psig
Specific Gravity	0.85
Application	Primary Relief

Use 10% over-pressure as permitted by ASME code. Volumetric flow rate, conventional U.S. units:

$$A = \frac{Q}{186}\sqrt{\frac{\rho}{P}} = \frac{1500}{186}\sqrt{\frac{(.85)(62.37)}{(1.1)(45-5)}} = 8.80\ sq.\ inch.$$

Using discharge areas in Table B, the required nominal disk size is 4 inch for a STD or CO type rupture disk and a 3 inch FAS or PCR type rupture disk.

EXAMPLE 2, GASES

Determine the rupture disk size required for relieving the following conditions:

Vessel MAWP	150 psig
Flow Requirement	5000 actual cubic feet per minute
Back Pressure	20 psig
Flow Temperature	250°F (degrees Fahrenheit)
Flow Media	Air (M = 29, k = 1.4, use Z = 1)
Application	Primary Relief

Use 10% over-pressure as permitted by ASME code. Flow pressure ratio:

$$\frac{P_2}{P_1} = \frac{20 + 14.7}{(1.1)(150) + 14.7} = 0.193.$$

Critical pressure ratio:

$$r_c = \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}} = \left[\frac{2}{1.4+1}\right]^{\frac{1.4}{1.4-1}} = 0.528.$$

P_2/P_1 is less than r_c, therefore the flow will be sonic. For conventional U.S. units:

$$C = 520\sqrt{k\left[\frac{2}{k+1}\right]^{\frac{k+1}{k-1}}} = 520\sqrt{1.4\left[\frac{2}{1.4+1}\right]^{\frac{1.4+1}{1.4-1}}} = 356.$$

Given the required flow in actual cubic feet per minute:

$$A = 9.02\,\frac{V_A}{C}\sqrt{\frac{M}{ZT}} = 9.02\,\frac{5000}{356}\sqrt{\frac{29}{(1)(250+460)}} = 25.6\ sq\ inch.$$

Using discharge areas in Table B, the required nominal disk size is 8 inch for a STD or CO type rupture disk and a 6 inch FAS or PCR type rupture disk.

EXAMPLE 3, GASES

Determine the rupture disk size required for relieving the following conditions:

Vessel MAWP	15 psig
Flow Requirement	2000 standard CFM
Back Pressure	5 psig
Flow Temperature	-40°F (degrees Fahrenheit)
Media Specific Gravity	0.72
Specific Heat Ratio	1.26
Compressibility Factor	0.95
Application	Primary Relief

In this case 10% of gauge pressure is less than 3 psi, therefore 3 psi over-pressure is permitted by ASME code. Flow pressure ratio:

$$\frac{P_2}{P_1} = \frac{5+14.7}{3+15+14.7} = 0.602.$$

Critical pressure ratio:

$$r_c = \left[\frac{2}{k + 1}\right]^{\frac{k}{k - 1}} = \left[\frac{2}{1.26 + 1}\right]^{\frac{1.26}{1.26 - 1}} = 0.553.$$

P_2/P_1 is greater than r_c, therefore the flow will be subsonic. For conventional U.S. units:

$$C = 735\sqrt{\frac{k}{k + 1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k + 1}{k}}\right]} = 735\sqrt{\frac{1.26}{1.26 + 1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{1.26}} - \left(\frac{P_2}{P_1}\right)^{\frac{1.26 + 1}{1.26}}\right]} = 341.$$

Given the required flow in standard cubic feet per minute:

$$A = \frac{V_S\sqrt{ZMT}}{3.92\,C\,P_1} = \frac{2000\sqrt{(.95)(29)(.72)(460 - 40)}}{(3.92)(341)(3 + 15 + 14.7)} = 4.18\ sq.\ inch.$$

Using discharge areas in Table B, the required nominal disk size is 3 inch for a STD or CO type rupture disk and a 2 inch FAS or PCR type rupture disk.