

Pipe Flow Expert Software

Compressible Gas Flow Equations

Isothermal Flow Equations:

- General Fundamental Flow Equation
- Complete Isothermal Flow Equation (Crane)
- AGA Flow Equation
- Weymouth Flow Equation
- Panhandle A Flow Equation
- Panhandle B Flow Equation
- IGT Flow Equation

General Fundamental Isothermal Flow Equation

The General Fundamental Isothermal Flow Equation is the basic equation for relating pressure drop with flow rate for compressible gases.

$$Q = 1.1494\ x\ 10^{-3} \left(\frac{T_b}{P_b}\right)\left(\frac{{P_1}^2 - {P_2}^2}{GT_f LZf}\right)^{0.5} D^{2.5}$$

Where:

Q = gas flow rate, measured at standard conditions, m^3/day (SCMD)
f = friction factor, dimensionless
P_b = base pressure, kPa absolute
T_b = base temperature, K (273.15 + °C)
P_1 = upstream pressure, kPa absolute
P_2 = downstream pressure, kPa absolute
G = gas gravity (Air = 1.00)
T_f = average gas flowing temperature, K (273.15 + °C)
L = pipe segment length, km
Z = gas compressibility factor at the flowing temperature, dimensionless
D = pipe inside diameter, mm

Sometimes this equation is referred to as just the General Flow equation or Fundamental Flow equation.

The gas flow rate depends upon several factors including the gas gravity and the compressibility factor Z. If the gas gravity is increased (heavier gas) the flow rate will decrease. Similarly if the compressibility factor Z increases, the flow rate will decrease. Also if the flowing temperature T was increased the flow rate will decrease, thus the hotter the gas, the lower the flow rate.

The above equation does not include any terms that account for change in elevation in the pipe. Pipe Flow Expert accounts for the effects of elevation change by calculating an average gas density within the pipe, to work out a loss or gain in fluid head. For compressible systems the average gas pressure within a section of pipe is given by the following equation:

$$Pavg = \frac{2}{3}(P1 + P2 - \frac{P1\ P2}{P1 + P2})$$

While a number of slightly simplified and different variations of the General Flow equation have been used to calculate gas flow for specific situations such as the Weymouth equation, the Panhandle A equation, the Panhandle B equation, the AGA equation, the IGT equation, and the Complete Isothermal equation (from Crane TP 410), with the increased capability of computer software calculations, this general equation perhaps now represents the most universal approach to performing compressible isothermal flow calculations.

Crane Complete Isothermal Flow Equation

The flow of gases in long pipe lines closely approximates isothermal conditions. The pressure drop in such lines is often large relative to the inlet pressure.

$$w = 316.23 \sqrt{\frac{A^2}{\bar{V}_1 \left(\frac{fL}{D} + 2 \ln \frac{\acute{p}_1}{\acute{p}_2} \right)} \left(\frac{\acute{p}_1{}^2 - \acute{p}_2{}^2}{\acute{p}_1} \right)}$$

Where:

w = rate of flow, in kilograms per second
A = cross sectional area of pipe or orifice, in square metres
$\bar{V}_1$ = specific volume of fluid, in cubic metres per kilogram ($1/density\ at\ \acute{p}_1$)
f = friction factor
L = length of pipe, in metres
D = internal diameter of pipe, in metres
$\acute{p}$ = pressure, in bar absolute

This formula was developed and published based on these assumptions:

1. Isothermal Flow.
2. No mechanical work is done on or by the system.
3. Steady flow and discharge is unchanged with time.
4. The gas obeys the perfect gas laws.
5. The velocity of gas may be represented by the average velocity at a cross section.
6. The friction factor is constant along the pipe.
7. The pipe is straight and horizontal between end points.

Pipe Flow Expert accounts for the effects of elevation change by calculating an average gas density within the pipe, to work out a loss or gain in fluid head, which is then used in addition to the above equation.

American Gas Association (AGA) Equation (AGA NB-13 method)

The AGA equation is used to calculate a transmission factor that is used with the General Fundamental Isothermal Flow Equation.

For fully turbulent flow, the following equation is recommended:

$$F = 4log_{10}\left(\frac{3.7D}{e}\right)$$

Where:
F = transmission factor for use with the General Fundamental Isothermal Equation
D = pipe diameter, mm
e = pipe roughness, mm

For the partially turbulent zone, F is calculated from the following equations:

$$F = 4D_f log_{10}\left(\frac{Re}{1.4125\ F_t}\right) \quad and \quad F_t = 4log_{10}\left(\frac{Re}{F_t}\right) - 0.6$$

Where:
F_t = Von Karman smooth pipe transmission factor
D_f = pipe drag factor that depends on the Bend Index (BI) of the pipe

Pipe Flow Expert calculates a transmission factor for each of the turbulent zone and the partially turbulent zone, and uses the transmission factor, F, with the lowest value, to calculate the friction factor that is then used in the General Flow equation.

The friction factor is calculated from the transmission factor based on the following equation:

$$\frac{2}{\sqrt{f}} = F$$

Where:
F = transmission factor
f = friction factor

The AGA equation is generally used for calculations with natural gas where the gas gravity is around 0.6.

Weymouth Isothermal Flow Equation

The Weymouth equation is generally used for high pressure, high flow rate and large diameter gas gathering systems.

$$Q = 3.7435\ x\ 10^{-3} E \left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s\ P_2^2}{G T_f L_e Z}\right)^{0.5} D^{2.667}$$

Where:

Q = volume flow rate, standard condition m^3/day (SCMD)
E = pipeline efficiency, a decimal value less than or equal to 1.0
P_b = base pressure, kPa absolute
T_b = base temperature, K (273.15 + °C)
P_1 = upstream pressure, kPa absolute
P_2 = downstream pressure, kPa absolute
G = gas gravity
T_f = average gas flowing temperature, K (273.15 + °C)
L_e = equivalent length of pipe segment length, km
Z = gas compressibility factor, dimensionless
D = pipe inside diameter, mm
s = elevation adjustment parameter, dimensionless, defined as:

$$s = 0.0684\ G \left(\frac{H_2 - H_1}{T_f Z}\right)$$

Where:
H_1 = upstream elevation, m
H_2 = downstream elevation, m

$$L_e = L\frac{(e^s - 1)}{s}$$

Where:
L = Length of pipe, m
s = elevation adjustment value as calculated above

The above equation includes terms that account for change in elevation in the pipe. Pipe Flow Expert uses the above equation without the elevation change parameters and then accounts for the effects of elevation change by calculating an average gas density within the pipe, to work out a loss or gain in fluid head. This method gives a similar and comparable result. Losses and gains due to changes in elevation are normally relatively small for gas systems unless there is a significant elevation difference between the start and end of the pipe.

Panhandle A Isothermal Flow Equation

The Panhandle A equation was developed for use in natural gas pipelines incorporating an efficiency factor, for Reynolds numbers between 5 million and 11 million.

$$Q = 4.5965\ x\ 10^{-3} E \left(\frac{T_b}{P_b}\right)^{1.0788} \left(\frac{P_1^2 - e^s\ P_2^2}{G^{0.8539} T_f L_e Z}\right)^{0.5394} D^{2.6182}$$

Where:
Q = volume flow rate, standard condition m^3/day (SCMD)
E = pipeline efficiency, a decimal value less than or equal to 1.0
P_b = base pressure, kPa absolute
T_b = base temperature, K (273.15 + °C)
P_1 = upstream pressure, kPa absolute
P_2 = downstream pressure, kPa absolute
G = gas gravity
T_f = average gas flowing temperature, K (273.15 + °C)
L_e = equivalent length of pipe segment length, km
Z = gas compressibility factor, dimensionless
D = pipe inside diameter, mm
s = elevation adjustment parameter, dimensionless, defined as:

$$s = 0.0684\ G \left(\frac{H_2 - H_1}{T_f Z}\right)$$

Where:
H_1 = upstream elevation, m
H_2 = downstream elevation, m

$$L_e = L \frac{(e^s - 1)}{s}$$

Where:
L = Length of pipe, m
s = elevation adjustment value as calculated above

The above equation includes terms that account for change in elevation in the pipe. Pipe Flow Expert uses the above equation without the elevation change parameters and then accounts for the effects of elevation change by calculating an average gas density within the pipe, to work out a loss or gain in fluid head. This method gives a similar and comparable result. Losses and gains due to changes in elevation are normally relatively small for gas systems unless there is a significant elevation difference between the start and end of the pipe.

Panhandle B Isothermal Flow Equation

The Panhandle B equation is used in large diameter, high pressure transmission lines. In fully turbulent flow it is found to be accurate for Reynolds numbers between 4 million and 40 million.

$$Q = 1.002\ x\ 10^{-2} E \left(\frac{T_b}{P_b}\right)^{1.02} \left(\frac{P_1^2 - e^s\ P_2^2}{G^{0.961} T_f L_e Z}\right)^{0.51} D^{2.53}$$

Where:

Q = volume flow rate, standard condition m^3/day (SCMD)
E = pipeline efficiency, a decimal value less than or equal to 1.0
P_b = base pressure, kPa absolute
T_b = base temperature, K (273.15 + °C)
P_1 = upstream pressure, kPa absolute
P_2 = downstream pressure, kPa absolute
G = gas gravity
T_f = average gas flowing temperature, K (273.15 + °C)
L_e = equivalent length of pipe segment length, km
Z = gas compressibility factor, dimensionless
D = pipe inside diameter, mm
s = elevation adjustment parameter, dimensionless, defined as:

$$s = 0.0684\ G \left(\frac{H_2 - H_1}{T_f Z}\right)$$

Where:
H_1 = upstream elevation, m
H_2 = downstream elevation, m

$$L_e = L \frac{(e^s - 1)}{s}$$

Where:
L = Length of pipe, m
s = elevation adjustment value as calculated above

The above equation includes terms that account for change in elevation in the pipe. Pipe Flow Expert uses the above equation without the elevation change parameters and then accounts for the effects of elevation change by calculating an average gas density within the pipe, to work out a loss or gain in fluid head. This method gives a similar and comparable result. Losses and gains due to changes in elevation are normally relatively small for gas systems unless there is a significant elevation difference between the start and end of the pipe.

Institute of Gas Technology (IGT) Equation

The IGT equation is proposed by the Institute of Gas Technology and is also known as the IGT distribution equation[2]. It is applicable to natural gas distribution pipelines.

$$Q = 1.2822\ x\ 10^{-3} E \left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s\ P_2^2}{G^{0.8} T_f L_e \mu^{0.2}}\right)^{0.555} D^{2.667}$$

Where:

Q = volume flow rate, standard condition m^3/day (SCMD)
E = pipeline efficiency, a decimal value less than 1.0
P_b = base pressure, kPa absolute
T_b = base temperature, K (273.15 + °C)
P_1 = upstream pressure, kPa absolute
P_2 = downstream pressure, kPa absolute
G = gas gravity
T_f = average gas flowing temperature, K (273.15 + °C)
L_e = equivalent length of pipe segment length, km
D = pipe inside diameter, mm
μ = gas viscosity, Poise
s = elevation adjustment parameter, dimensionless, defined as:

$$s = 0.0684\ G \left(\frac{H_2 - H_1}{T_f Z}\right)$$

Where:
H_1 = upstream elevation, m
H_2 = downstream elevation, m

$$L_e = L\frac{(e^s - 1)}{s}$$

Where:
L = Length of pipe, m
s = elevation adjustment value as calculated above

The above equation includes terms that account for change in elevation in the pipe. Pipe Flow Expert uses the above equation without the elevation change parameters and then accounts for the effects of elevation change by calculating an average gas density within the pipe, to work out a loss or gain in fluid head. This method gives a similar and comparable result. Losses and gains due to changes in elevation are normally relatively small for gas systems unless there is a significant elevation difference between the start and end of the pipe.

REFERENCES

1. Flow of Fluids through Valves, Fittings and Pipe Metric Edition – SI Units, Crane Technical Paper 410M, Crane Ltd.

2. Gas Pipeline Hydraulics, 2005, CRC Press
   E. Shashi Menon