pipeFLOW®

taking the pressure out of fluid flow calculations

Gas Flow Rate

Verification of Calculation Results
For Compressible Flow

www.pipeflow.com

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Introduction

Pipe Flow Gas Flow Rate is a software application that calculates the flow rate in a pipe that occurs for a given pressure difference between the start of the pipe and the end of the pipe (the available pressure difference) using Compressible Isothermal Flow equations. The software considers the size of the internal pipe diameter, the internal roughness of the pipe material, the length of pipe, the friction loss in the pipe for the calculated flow velocity, and the friction loss through pipe fittings and bends.

The gas flow rate calculations produced by the Pipe Flow Gas Flow Rate software can be verified by comparison against published results data for compressible gas systems. The information in this document provides a general description of a published problem, the **Reference Source**, the **Published Results Data**, the **App Results Data** and a commentary on the results obtained for pressure drops, flow rates, diameter sizes and pipe lengths.

For each of the calculation problems detailed in this document, the results data produced by the **Pipe Flow Gas Flow Rate software compares well with the published results data.**

Calculations

Fluid Properties for the pressure condition at the start of each pipe are calculated from the user defined fluid data using the **Ideal Gas Law** plus any specified **Compressibility Factor Z** to establish the density of the gas.

Ideal Gases are considered to be perfectly elastic. Ideal gases follow Boyle's Law & Charles's Law thus the gas density at various points in the system can be calculated using these equations.

Real Gases behave according to a modified version of the ideal gas law. The modifying factor is known as the **Gas Compressibility Factor Z.** Where natural gas pressures are higher than 115 psi.a (800 kPa.a) the gas compressibility factor may not be close to 1.00, so it can be advisable to use a gas compressibility factor based on the pressure in the pipe.

There are different methods that can be used to calculate a gas compressibility factor for a specific pressure condition. The California Natural Gas Association (CNGA) method provides such a calculation for natural gas. The Pipe Flow Gas Flow Rate software includes the option to automatically use the CNGA method to determine the natural gas compressibility for the average conditions in each pipe. The CNGA factor is then applied when calculating the gas flow rate using a specific Isothermal Flow Equation that allows for gas compressibility. The CNGA compressibility factor is only applicable to natural gas and is not applicable to other gases such as air etc.

The General Fundamental Isothermal Flow Equation (sometimes known as just the **General Flow equation** or the **Fundamental Flow equation**) provides perhaps the most universal method for calculating isothermal flow rates, however it relies on the inclusion of an accurate friction factor. The Pipe Flow Gas Flow Rate software calculates an accurate friction factor using the Colebrook-White equation.

In addition to the **General Flow Equation**, Pipe Flow Gas Flow Rate provides the functionality to allow calculations based on alternative equations such as:

The **Complete Isothermal Flow Equation (as defined in Crane Technical Paper 410)**,

The **AGA Isothermal Flow Equation,**

The **Weymouth Isothermal Flow Equation**,

The **Panhandle A Isothermal Flow Equation,**

The **Panhandle B Isothermal Flow Equation.**

The **IGT Isothermal Flow Equation.**

Each of these equations can be used to calculate isothermal flow rates in pipes. Most of these equations use a Pipeline Efficiency factor (instead of a friction factor) and a Compressibility Factor. The software allows the user to specify the factors that are used in the calculations.

Software Releases

The Pipe Flow Gas Flow Rate App is currently available only on iOS (Apple Mobile Devices).

Pipe Flow Software produces a range of different software applications for calculating flow rates and pressure losses in pipe systems, including our premier Pipe Flow Expert software for Windows, which is used to design energy efficient piping and pumping systems.

Pipe Flow Software programs are used by engineers in over 100 countries worldwide.

We have clients in a variety of industries including aerospace, chemical processing, education, food and beverage, general engineering, mining, petrochemical, pharmaceutical, power generation, water distribution, and wastewater processing.

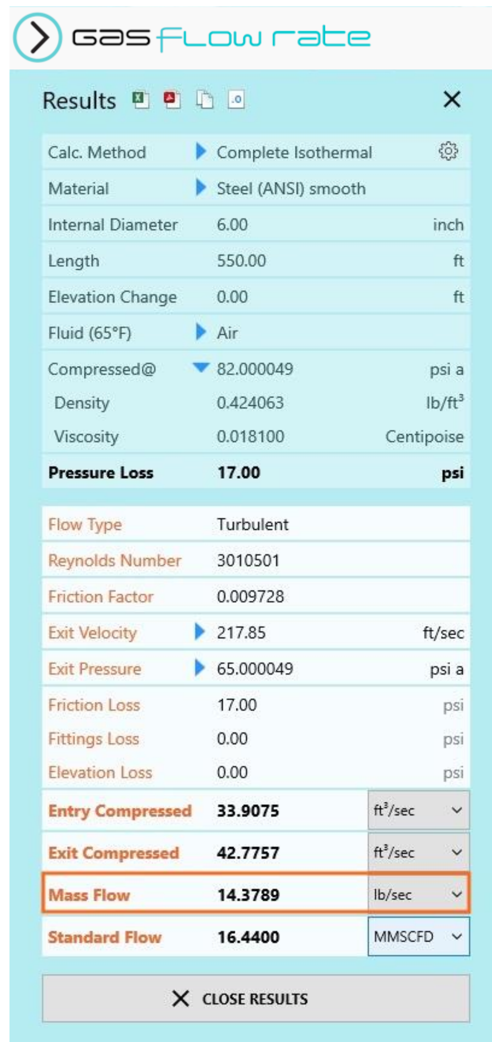
Case 01: Mass Flow of Air

Reference: Fluid Mechanics and Hydraulics, 3rd Ed, 1994,
McGraw-Hill; R. V. Giles, J. B. Evett PhD, C. Liu page 237, Example 11.1

Gas Flow Rate App: Find _Flow_Case_01_Mass_Flow_Air.pfwf

Calculation Problem:

Find the mass flow rate of air flowing isothermally through a 6-inch diameter pipe, at 65 °F, where the inlet pressure is 82 psi absolute, and at a distance of 550 feet downstream of the inlet, the pressure is 65 psi absolute.



The pipe surface is smooth (the problem specifies an assumed friction factor of 0.0095) and the calculation method used for the published data was the Complete Isothermal Flow equation.

Pipe Flow Gas Flow Rate Software Calculation Data:

Fluid Ref: Air at 65 °F, 0.0 psi.g, Viscosity 0.0181 centipoise
Fluid Data: Software calculates compressed gas properties.
Pipe Data: Roughness 0.000001 inches
Friction factor = 0.00973

Calculation Method: Complete Isothermal Flow equation.
Standard Atmospheric Conditions: 68°F, 14.696 psi.a
Gas Model: Ideal Gas Law.

Commentary:

See the Results Comparison Table below.

The published data and the calculated results compare well.

The published data used several rounded numbers in the calculation.

In the Pipe Flow Wizard software calculation, the pipe's internal roughness value was set to a very small value (much lower than the usual internal roughness for any of the common pipe materials). This was done to simulate the very "smooth" pipe that was used in the published literature (friction factor of 0.0095).

Results Comparison:

Data Item	Published Data	App
Mass Flow (lb/sec)	14.5	14.379

Case 02: Gas Pipeline Flow Rate

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 2, page 62 Example 13

Gas Flow Rate App: Find_Flow_Case_02_Natural_Gas_Pipeline_Flow_Rate.pfwf

Calculation Problem:

Calculate the flow rate in a gas pipeline system, 15 miles long, with a 12.25 inch internal pipe diameter.

The upstream pressure is 1200 psi absolute and the delivery pressure required at the end of the pipe is 750 psi absolute. The pipe internal roughness is 700 micro-inches. Use a compressibility factor of 0.94 and a pipeline efficiency of 0.95.

The calculation methods used in the published data are:

i) Weymouth equation
ii) General Flow equation

Pipe Flow Gas Flow Rate Software Calculation Data:

Fluid Ref: Gas specific gravity 0.59 (0.044 lb/ft³)
75 °F, 0.0 bar.g, Viscosity 0.0119 centipoise.
Fluid Data: Software calculates compressed gas properties.
Pipe Data: Roughness 700 micro-inches

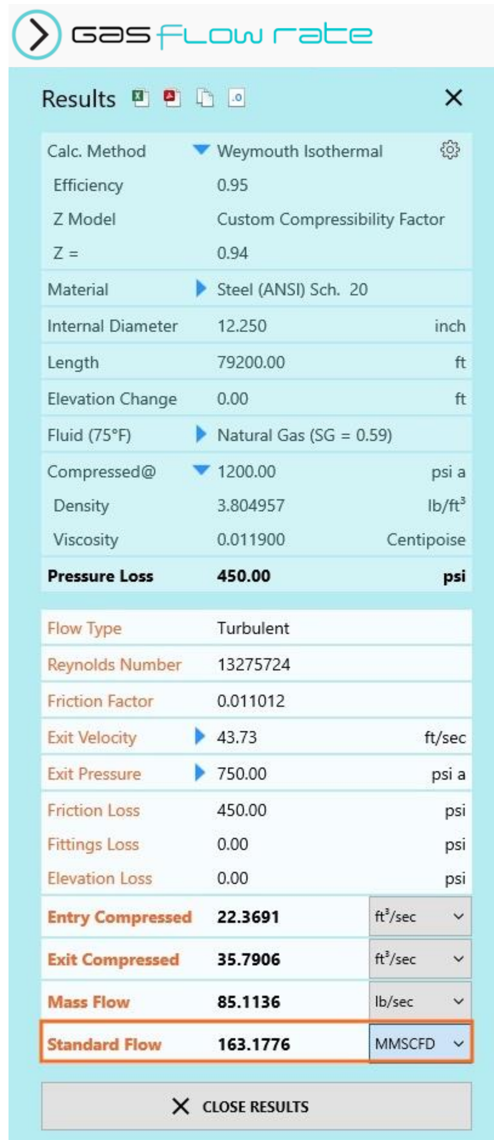
Calculation Method: Weymouth equation (Efficiency = 0.95)
General Flow equation
Standard Atmospheric Conditions: 60°F, 14.696 psi.a
Gas Model: Real Gas (Ideal Gas Law, compressibility Z=0.94)

Commentary:

See the Results Comparison Table below.

The published data and the calculated results compare well.

Comparing the result from the General Flow equation against the result from the Weymouth equation shows that the result from the Weymouth equation is quite conservative.



Results Comparison:

Data Item	Published Data	App
Gas Flow Rate, Weymouth equation, MMSCFD	163.26	163.178
Gas Flow Rate, General Flow equation, MMSCFD	192.98	192.984

Case 03: IGT (Institute of Gas Technology) Equation Flow Rate

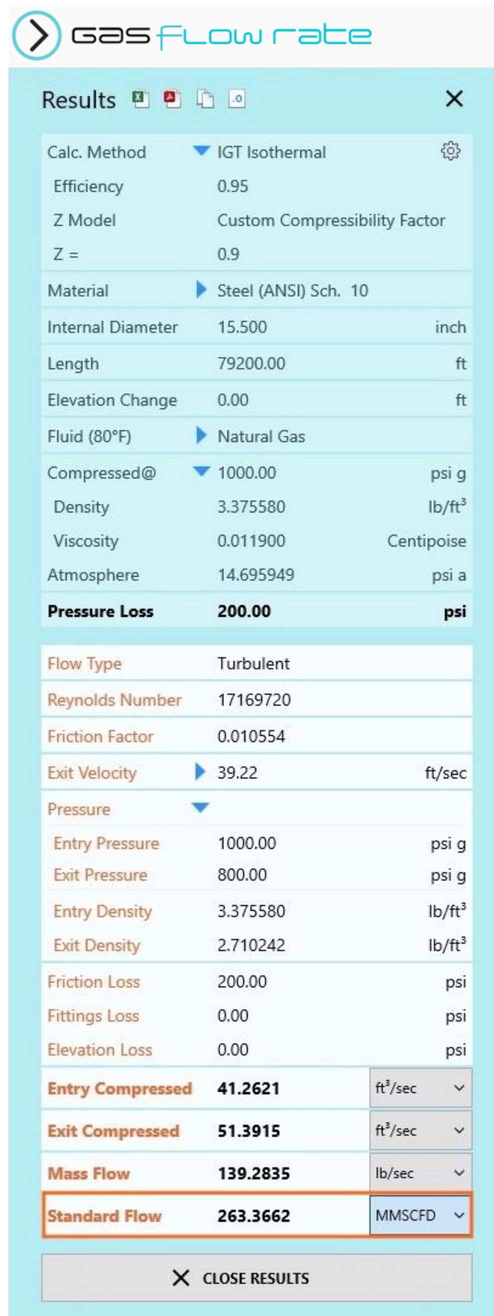
Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon, Chapter 2, page 71 Example 19

Gas Flow Rate App: Find_Flow_Case_03_IGT_Equation.pfwf

Calculation Problem:

Find the flow rate in a natural gas pipeline 15 miles long.
The pipe is NPS 16 with a 0.250 inch wall thickness.
The inlet & outlet pressures are 1000 psi.g and 800 psi.g, respectively. The pipeline efficiency is 0.95.
Average gas temperature is 80 °F.
Gas Specific Gravity = 0.6, Viscosity = 0.000008 lb/ft-sec.
The compressibility factor Z = 0.90

Use the IGT (Institute of Gas Technology) equation to calculate the flow rate in the pipe.



Pipe Flow Wizard Software Calculation Data:

Fluid Ref: Gas with specific gravity 0.6 (0.044 lb/ft³), 80 °F, 0.00 psi.g, Viscosity 0.0119 centipoise.
Fluid Data: Software calculates compressed gas properties.
Pipe Data: Roughness 700 micro-inches.

Calculation Method: IGT Isothermal Flow equation.
Standard Atmospheric Conditions: 60°F, 14.696 psi.a
Gas Model: Real Gas (Ideal Gas Law with compressibility Z=0.9)

Commentary:

See the Results Comparison Table below.

The published data and the calculated results compare well.

Results Comparison:

Data Item	Published Data	App
Flow Rate MMSCFD	263.1	263.366

Case 04: Flow Rate of Natural Gas Through Pipeline

Reference: Gas Pipeline Hydraulics, 2013, CRC Press, E. Shashi Menon, Chapter 2, page 97 Example 2.20

Gas Flow Rate App: Find_Flow_Case_04_Natural_Gas_Flow_Rate.pfwf

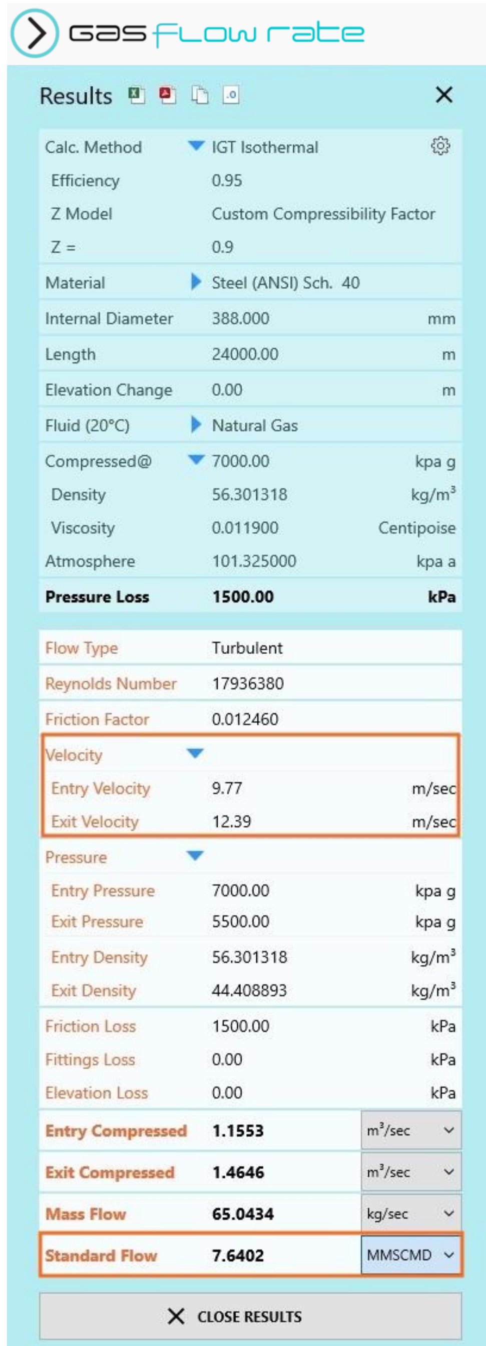
Calculation Problem:

A Natural gas pipeline, 24km long, is used to transport gas at an inlet pressure of 7000 kPa.g and an outlet pressure of 5500 kPa.g.

Calculate the flow rate using the IGT equation.
(IGT is Institute of Gas Technology)

Assume a pipeline efficiency of 0.95
and a compressibility factor Z of 0.9

Calculate the gas velocity at the inlet and outlet of the pipe.



Pipe Flow Wizard Software Calculation Data:

Fluid Ref: Natural Gas at 20 °C, 0.0 bar.g
Gas with specific gravity of 0.6
Viscosity 0.00119 centipoise
Fluid Data: Software calculates compressed gas properties.
Pipe Data: DN 400 with 6mm wall thickness.

Calculation Method: IGT Isothermal Flow equation (Effic=0.95)
Standard Atmospheric Conditions: 15°C, 101.325 kPa.a
Gas Model: Real Gas (Ideal Gas Law with compressibility Z=0.9)

Commentary:

See the Results Comparison Table below.

The published data and the calculated results compare well.

Results Comparison:

Data Item	Published Data	App
Flow Rate MMSCMD	7.67	7.640
Inlet Velocity (m/s)	9.78	9.771
Outlet Velocity (m/s)	12.4	12.387

Case 05: Pumping Hydrogen Gas from a Reservoir

Reference: Chemical Engineering Volume 1, 6th Ed, 1999, Elsevier, J M Coulson, J F Richardson, page 375 Example 8.10

Gas Flow Rate App: Find_Flow_Case_05_Hydrogen_Reservoir_Pump.pfwf

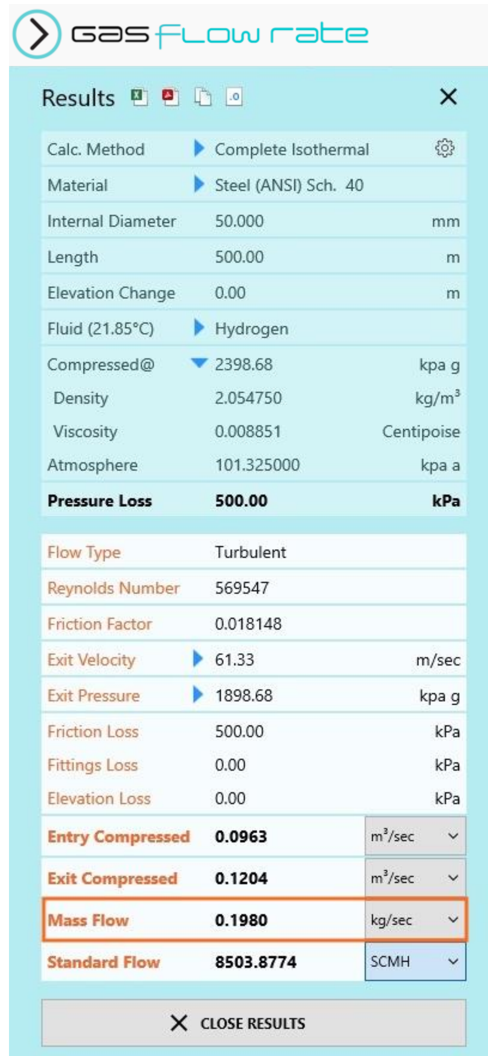
Calculation Problem:

Hydrogen is pumped from a reservoir at 2 MN/m^2 through a clean horizontal mild steel pipe 50 mm in diameter and 500 m long. The pressure of the gas is raised to 2.5 MN/m^2 by a pump at the start of the pipe. The downstream pressure at the end of the pipe is 2 MN/m^2.

The conditions of flow are isothermal, and the temperature of the gas is 295 K.

What is the flow rate of hydrogen?

The calculation method used for the published data was the Complete Isothermal equation with Ideal Gas Law.



Pipe Flow Wizard Software Calculation Data:

Fluid Ref: Hydrogen at 21.85 °C, 0.0 bar.g
Density 0.083279 kg/m^3, Viscosity 0.008851 cP.
Fluid Data: Software calculates compressed gas properties.
Pipe Data: Internal diameter 50 mm, roughness 0.05 mm.

Calculation Method: Complete Isothermal Flow equation.
Standard Atmospheric Conditions: 20°C, 1.01325 bar absolute.
Gas Model: Ideal Gas Law

Commentary:

See the Results Comparison Table below.

The published data and the calculated results compare well.

Results Comparison:

Data Item	Published Data	App
Flow Rate (kg/second)	0.200	0.198

Case 06: Carbon Dioxide – Flow Through a Pipe

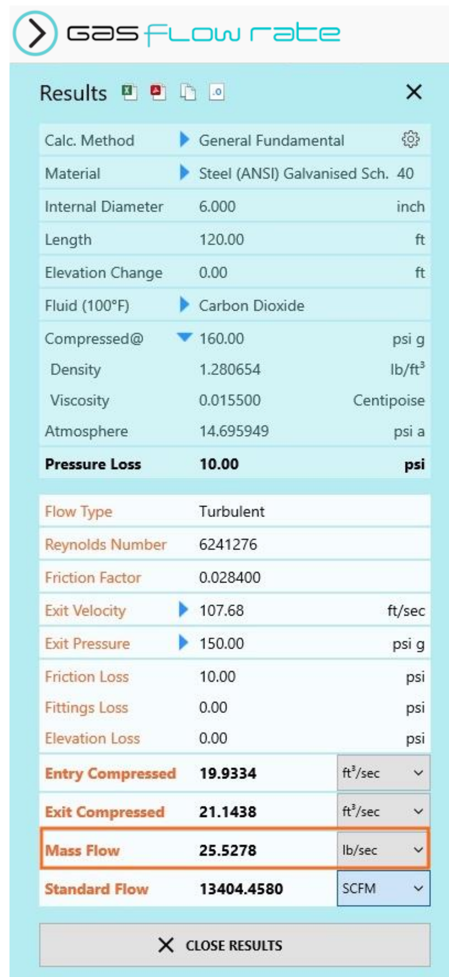
Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 483, Example problem 16.78

Gas Flow Rate App: Find_Flow_Case_06_Carbon_Dioxide_Flow_Through_A_Pipe.pfwf

Calculation Problem:

Carbon Dioxide at temperature of 100°F flows through a pipe with 6" internal diameter. The pipe internal roughness is 0.002 ft (0.024 inch). The flow is isothermal. The pressure at the start of a 120 ft long horizontal pipe section is 160 psi.g and the pressure at the end of the section is 150 psi.g.

Calculate the weight of flow (mass flow rate) of the air.



Pipe Flow Wizard Software Calculation Data:

Fluid Ref: Carbon Dioxide at 155 psi gauge and 100 °F
Density 1.244000 lb/ft³, Viscosity 0.015500 centipoise.
The reference fluid properties can be been defined for any pressure condition, however they must always be defined at the required temperature condition.

Fluid Data: The Pipe Flow Wizard software automatically calculates the compressed gas properties.

Pipe Data: Internal diameter 6 inch. Roughness 0.0024 inches.

Calculation Method: General Isothermal Flow equation.
Standard Atmospheric Conditions: 68 °F, 14.696 psi absolute
Gas Model: Ideal Gas Law

Commentary:

The published data and the calculated results compare well.

The published text assumes an initial Reynolds Number greater than 1000000 and a friction factor of 0.0285 to estimate the weight of flow as 25.3 lb/sec. The weight of flow is then used to recalculate the Reynolds Number as 5000000 and this is taken as confirmation of the previously calculated weight of flow.

The Pipe Flow Wizard software uses the Colebrook-White equation to calculate friction factors and these are generally considered to be more accurate than a value read from a Moody Chart.

Results Comparison:

Data Item	Published Data	App
Weight of Flow (lb/sec)	25.3	25.528
Reynolds Number	5000000	6241276
Friction Factor	0.0285	0.0284

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