



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

GAS flow rate

Results

Calc. Method	Complete Isothermal	
Material	Steel (ANSI) smooth	
Internal Diameter	6.00	inch
Length	550.00	ft
Elevation Change	0.00	ft
Fluid (65°F)	Air	
Compressed@	82.000049	psi a
Density	0.424063	lb/ft³
Viscosity	0.018100	Centipoise
Pressure Loss	17.00	psi
Flow Type	Turbulent	
Reynolds Number	3010501	
Friction Factor	0.009728	
Exit Velocity	217.85	ft/sec
Exit Pressure	65.000049	psi a
Friction Loss	17.00	psi
Fittings Loss	0.00	psi
Elevation Loss	0.00	psi
Entry Compressed	33.9075	ft³/sec
Exit Compressed	42.7757	ft³/sec
Mass Flow	14.3789	lb/sec
Standard Flow	16.4400	MMSCFD

CLOSE RESULTS

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.

GAS flow rate

Results

Calc. Method: Weymouth Isothermal
 Efficiency: 0.95
 Z Model: Custom Compressibility Factor
 Z = 0.94
 Material: Steel (ANSI) Sch. 20
 Internal Diameter: 12.250 inch
 Length: 79200.00 ft
 Elevation Change: 0.00 ft
 Fluid (75°F): Natural Gas (SG = 0.59)
 Compressed@: 1200.00 psi a
 Density: 3.804957 lb/ft³
 Viscosity: 0.011900 Centipoise
Pressure Loss: 450.00 psi

Flow Type: Turbulent
 Reynolds Number: 13275724
 Friction Factor: 0.011012
 Exit Velocity: 43.73 ft/sec
 Exit Pressure: 750.00 psi a
 Friction Loss: 450.00 psi
 Fittings Loss: 0.00 psi
 Elevation Loss: 0.00 psi

Entry Compressed: 22.3691 ft³/sec
Exit Compressed: 35.7906 ft³/sec
Mass Flow: 85.1136 lb/sec
Standard Flow: 163.1776 MMSCFD

CLOSE RESULTS

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

GAS flow rate

Results

Calc. Method	IGT Isothermal	
Efficiency	0.95	
Z Model	Custom Compressibility Factor	
Z =	0.9	
Material	Steel (ANSI) Sch. 10	
Internal Diameter	15.500	inch
Length	79200.00	ft
Elevation Change	0.00	ft
Fluid (80°F)	Natural Gas	
Compressed@	1000.00	psi g
Density	3.375580	lb/ft ³
Viscosity	0.011900	Centipoise
Atmosphere	14.695949	psi a
Pressure Loss	200.00	psi

Flow Type	Turbulent
Reynolds Number	17169720
Friction Factor	0.010554
Exit Velocity	39.22 ft/sec
Pressure	
Entry Pressure	1000.00 psi g
Exit Pressure	800.00 psi g
Entry Density	3.375580 lb/ft ³
Exit Density	2.710242 lb/ft ³
Friction Loss	200.00 psi
Fittings Loss	0.00 psi
Elevation Loss	0.00 psi
Entry Compressed	41.2621 ft ³ /sec
Exit Compressed	51.3915 ft ³ /sec
Mass Flow	139.2835 lb/sec
Standard Flow	263.3662 MMSCFD

CLOSE RESULTS

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

GAS flow rate

Results

Calc. Method: IGT Isothermal
 Efficiency: 0.95
 Z Model: Custom Compressibility Factor
 Z: 0.9
 Material: Steel (ANSI) Sch. 40
 Internal Diameter: 388.000 mm
 Length: 24000.00 m
 Elevation Change: 0.00 m
 Fluid (20°C): Natural Gas
 Compressed@: 7000.00 kPa g
 Density: 56.301318 kg/m³
 Viscosity: 0.011900 Centipoise
 Atmosphere: 101.325000 kPa a
 Pressure Loss: 1500.00 kPa

Flow Type: Turbulent
 Reynolds Number: 17936380
 Friction Factor: 0.012460

Velocity:
 Entry Velocity: 9.77 m/sec
 Exit Velocity: 12.39 m/sec

Pressure:
 Entry Pressure: 7000.00 kPa g
 Exit Pressure: 5500.00 kPa g
 Entry Density: 56.301318 kg/m³
 Exit Density: 44.408893 kg/m³
 Friction Loss: 1500.00 kPa
 Fittings Loss: 0.00 kPa
 Elevation Loss: 0.00 kPa

Entry Compressed: 1.1553 m³/sec
 Exit Compressed: 1.4646 m³/sec
 Mass Flow: 65.0434 kg/sec
 Standard Flow: 7.6402 MMSCMD

CLOSE RESULTS

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/m² 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/m² by a pump at the start of the pipe. The downstream pressure at the end of the pipe is 2 MN/m².

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/m³, 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		
Calc. Method	Complete Isothermal	
Material	Steel (ANSI) Sch. 40	
Internal Diameter	50.000	mm
Length	500.00	m
Elevation Change	0.00	m
Fluid (21.85°C)	Hydrogen	
Compressed@	2398.68	kpa g
Density	2.054750	kg/m ³
Viscosity	0.008851	Centipoise
Atmosphere	101.325000	kpa a
Pressure Loss	500.00	kPa
Flow Type	Turbulent	
Reynolds Number	569547	
Friction Factor	0.018148	
Exit Velocity	61.33	m/sec
Exit Pressure	1898.68	kpa g
Friction Loss	500.00	kPa
Fittings Loss	0.00	kPa
Elevation Loss	0.00	kPa
Entry Compressed	0.0963	m ³ /sec
Exit Compressed	0.1204	m ³ /sec
Mass Flow	0.1980	kg/sec
Standard Flow	8503.8774	SCMH

CLOSE RESULTS

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 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

The screenshot shows the 'Results' window of the 'Gas Flow Rate' software. The interface is light blue with a white header. The title bar says 'Gas Flow Rate'. Below the title bar, there are icons for file operations and a close button. The main area is divided into two sections: 'Calc. Method' and 'Results'. The 'Calc. Method' section shows 'General Fundamental' selected. The 'Results' section displays various parameters and their values. The 'Fluid' section shows 'Carbon Dioxide' at 100°F. The 'Compressed' section shows a pressure of 160.00 psi.g. The 'Density' is 1.280654 lb/ft³ and 'Viscosity' is 0.015500 Centipoise. The 'Atmosphere' is 14.695949 psi.a. The 'Pressure Loss' is 10.00 psi. The 'Flow Type' is 'Turbulent'. The 'Reynolds Number' is 6241276. The 'Friction Factor' is 0.028400. The 'Exit Velocity' is 107.68 ft/sec. The 'Exit Pressure' is 150.00 psi.g. The 'Friction Loss' is 10.00 psi, 'Fittings Loss' is 0.00 psi, and 'Elevation Loss' is 0.00 psi. The 'Entry Compressed' flow is 19.9334 ft³/sec, 'Exit Compressed' is 21.1438 ft³/sec, 'Mass Flow' is 25.5278 lb/sec, and 'Standard Flow' is 13404.4580 SCFM. A 'CLOSE RESULTS' button is at the bottom.

Calc. Method	General Fundamental
Material	Steel (ANSI) Galvanised Sch. 40
Internal Diameter	6.000 inch
Length	120.00 ft
Elevation Change	0.00 ft
Fluid (100°F)	Carbon Dioxide
Compressed@	160.00 psi.g
Density	1.280654 lb/ft³
Viscosity	0.015500 Centipoise
Atmosphere	14.695949 psi.a
Pressure Loss	10.00 psi
Flow Type	Turbulent
Reynolds Number	6241276
Friction Factor	0.028400
Exit Velocity	107.68 ft/sec
Exit Pressure	150.00 psi.g
Friction Loss	10.00 psi
Fittings Loss	0.00 psi
Elevation Loss	0.00 psi
Entry Compressed	19.9334 ft³/sec
Exit Compressed	21.1438 ft³/sec
Mass Flow	25.5278 lb/sec
Standard Flow	13404.4580 SCFM

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