Pipe Flow Expert

Fluid Flow and Pressure Loss Calculations Software

http://www.pipeflow.com

Verification of Calculation Results For Compressible Isothermal Flow

Table of Contents – Results Data: Systems Solved by Pipe Flow Expert

Introduction

Pipe Flow Expert is a software application for designing and analyzing complex pipe networks where the flows and pressures must be balanced to solve the system. It can handle both non-compressible and compressible fluid flow.

This document relates to verification of the Pipe Flow Expert software for calculating flow rates and pressure drops for compressible gas systems.

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 Expert 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 Expert software provides such a friction factor by calculating this using the Colebrook-White equation. For complex interconnected pipe systems this equation provides perhaps the best overall calculation result, however this approach is only made possible by the advanced software algorithms and the power of computer calculation.

In addition to this general flow equation, Pipe Flow Expert 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 these factors and these are then used in the calculations.

Flow and Pressure Loss Calculations produced by the Pipe Flow Expert software can be verified by comparison against published results from a number of well-known sources. The information in this document provides a general description of a **Published Problem**, the **Reference Source**, the **Published Results Data**, the **Pipe Flow Expert Results Data** and a commentary on the results obtained.

The Pipe Flow Expert Results Data compares very well with the published results data for each of the cases that are listed.

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

Pipe Flow Expert is currently used by engineers in over 75 countries worldwide.

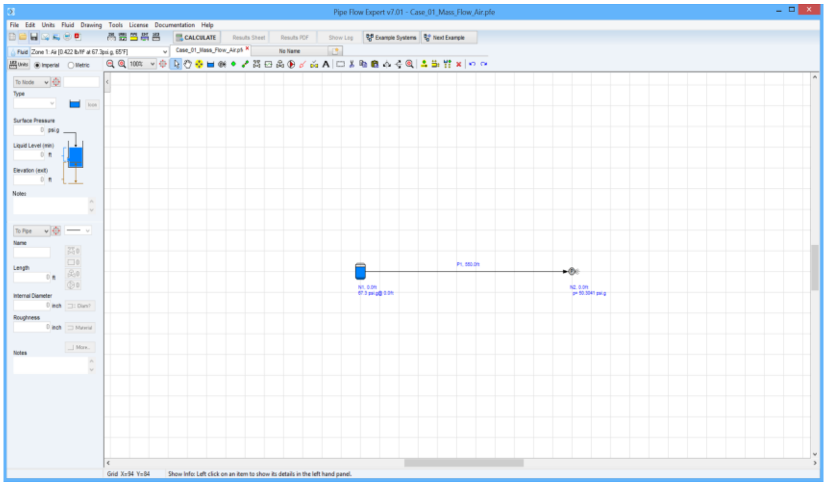
Case 01: Mass Flow of Air

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

Pipe Flow Expert File: Case_01_Mass_Flow_Air.pfe

Problem description:
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 the pressure at a distance of 550 feet downstream is 65 psi absolute. The pipe surface is smooth (the problem specifies an assumed friction factor of 0.0095).

The calculation method used for the published data was the Complete Isothermal Flow equation.



Pipe Flow Expert Parameters:

Fluid data: Air at 65 °F, 0.0 psi.g, viscosity 0.0181 centipoise.
Pipe data: Roughness 0.000001 inches (friction factor = 0.00973).
Calculation method: Complete Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 68°F, 14.696 psi.
Gas physical model: Ideal Gas Law.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Mass Flow (lb/sec)	14.5	14.38

Commentary:

The published data and the calculated results compare well.

The published data may have used some rounded numbers in the calculation. The pipe roughness value set in Pipe Flow Expert is very low (much lower than any of the common pipe materials), which is intended to simulate the "smooth" pipe that was used in the published literature (friction factor of 0.0095).

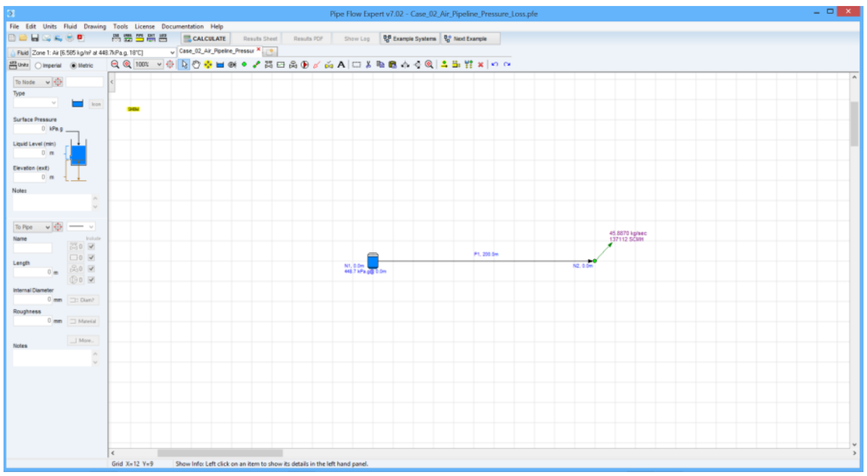
Case 02: Air Pipeline Pressure Loss

Reference: Fluid Mechanics and Hydraulics, 3rd Ed, 1994, McGraw-Hill; R. V. Giles, J. B. Evett PhD, C. Liu page 238, Example 11.2

Pipe Flow Expert File: Case_02_Air_Pipeline_Pressure_Loss.pfe

Problem description:
Air at 18 °C flows isothermally through a 300 mm diameter pipe at a flow rate of 0.450 kN/s (equivalent to 45.887 kg/s). The pipe is smooth (friction factor = 0.0080). If the pressure at the entry point is 550 kPa, find the pressure at a point 200 m downstream.

The calculation method used for the published data was the Complete Isothermal equation.



Pipe Flow Expert Parameters:

Fluid data: Air at 18 °C, 0.0 kPa.g, viscosity 0.0181 centipoise.
Pipe data: Used roughness 0.000001 mm (to give friction factor = 0.00802).
Flow rate: 45.887 kg/s (equivalent to 0.450 kN/s).
Calculation method: Complete Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 20°C, 101.325 kPa.
Gas physical model: Ideal Gas Law.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure 200m downstream (kPa.a)	233	231.3

Commentary:

The published data and the calculated results compare well.

The published literature states the flow rate as a weight of flow in kN/s rather than as a gas flow at standard conditions. Kg/s = (kN/s) x (1000/g) (where g is acceleration due to gravity, normally 9.80665 m/s²). Hence a mass flow rate of 45.877 kg/s has been used in the calculation.

Case 03: Gas Pipeline Flow Rate

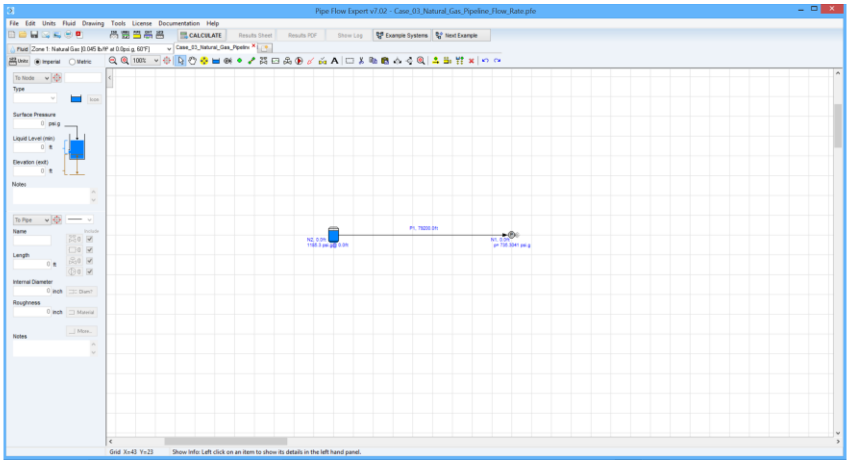
Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 2, page 62 Example 13

Pipe Flow Expert File: Case_03_Natural_Gas_Pipeline_Flow_Rate.pfe

Problem description:
Calculate the flow rate in a gas pipeline system, 15 miles long, with a 12.25 inch internal pipe diameter. Upstream pressure is 1200 psi absolute and the delivery pressure required at the end of the pipe is 750 psi absolute. Pipe roughness is 700 micro-inches. Use a compressibility factor of 0.94 and a pipeline efficiency of 0.95.

The calculation methods used for the published data were:

i) Weymouth equation
ii) General Flow equation



Pipe Flow Expert Parameters:

Fluid data: Gas specific gravity 0.59 (0.044 lb/ft³) at 75 °F, 0.0 bar.g, viscosity 0.0119 centipoise.
Pipe data: Roughness 700 micro-inches.
Calculation method: Weymouth equation, General Flow Equation, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi.
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.94).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Gas flow rate (Weymouth equation, MMSCFD)	163.26	163.18
Gas flow rate (General Flow equation, MMSCFD)	192.98	192.98

Commentary:

The published data and the calculated results compare well. It can be seen that the results from the Weymouth equation are quite conservative.

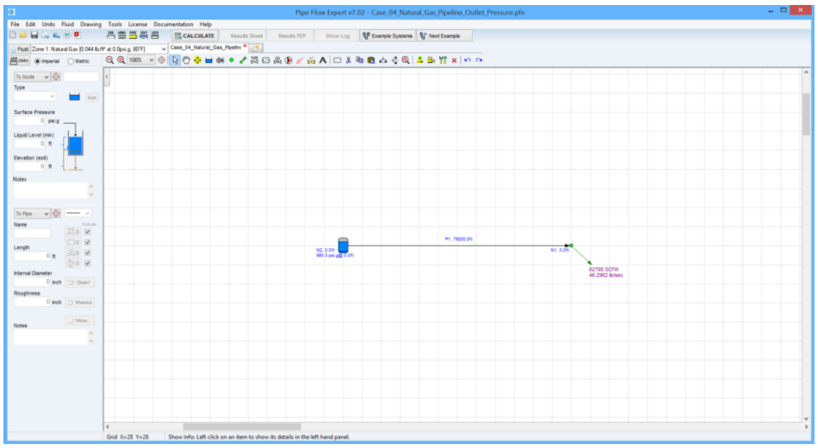
Case 04: Gas Pipeline Outlet Pressure

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 2, page 65 Example 15

Pipe Flow Expert File: Case_04_Natural_Gas_Pipeline_Outlet_Pressure.pfe

Problem description:
Calculate the outlet pressure in a 15 mile natural gas pipeline, with internal diameter 15.5 inches. The gas flow rate is 100 MMSCFD and the inlet pressure is 1000 psi absolute. The pipeline efficiency value is 0.92. Average gas temperature is 80 °F. Gas gravity = 0.6, viscosity = 0.000008 lb/ft-sec. Use the CNGA method to calculate gas compressibility factor Z.

The calculation method used for the published data was the Panhandle A equation.



Pipe Flow Expert Parameters:

Fluid data: Gas specific gravity 0.6 (0.045 lb/ft^3), 80 °F, 0.00 psi.g, viscosity 0.0119 centipoise (equivalent to 0.000008 lb/ft-sec).
Pipe data: Pipeline efficiency = 0.92.
Calculation method: Panhandle A Isothermal equation, Node Adjust Method.
Standard atmospheric model: 60 °F, 14.696 psi.a
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor calculated using CNGA method).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Outlet pressure (psi absolute)	968.35	968.19

Commentary:

The published data and the calculated results compare well.

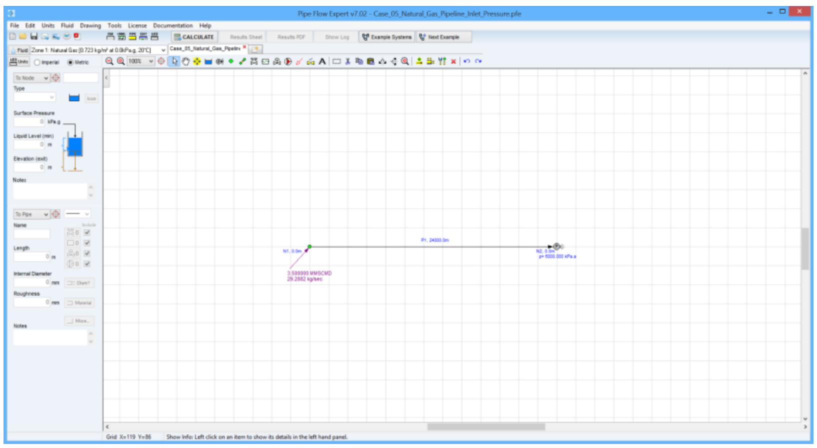
Case 05: Gas Pipeline Inlet Pressure

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 2, page 67 Example 16

Pipe Flow Expert File: Case_05_Natural_Gas_Pipeline_Inlet_Pressure.pfe

Problem description:
Calculate the inlet pressure in a 24 km natural gas pipeline, with internal diameter 288 mm. The gas flow rate is 3.5 Mm^3/day and the delivery pressure is 6000 kPa absolute. The average gas temperature is 20 °C, the pipeline efficiency is 0.92 and the gas compressibility factor is 0.90.

The calculation method used for the published data was the Panhandle A equation.



Pipe Flow Expert Parameters:

Fluid data: Gas specific gravity 0.6 (0.723 kg/m^3), 20 °C, 0.00 kPa.g, viscosity 0.0119 centipoise.
Pipe data: Pipeline efficiency = 0.92.
Flow Rate: 3.5 MMSCMD.
Calculation method: Panhandle A Isothermal equation, Node Adjust Method.
Standard atmospheric model: 15 °C, 101.325 kPa.
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.9).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Inlet pressure (psi absolute)	7471	7480

Commentary:

The published data and the calculated results compare well.

The publication states the gas flow rate is 3.5 Mm^3/day. Here, the ‘M’ stands for ‘one million’, which is not the same as the ‘M’ in “standard condition” units i.e. MSCMD. In “standard condition” units a single ‘M’ stands for ‘one thousand’, and ‘MM’ stands for one million.

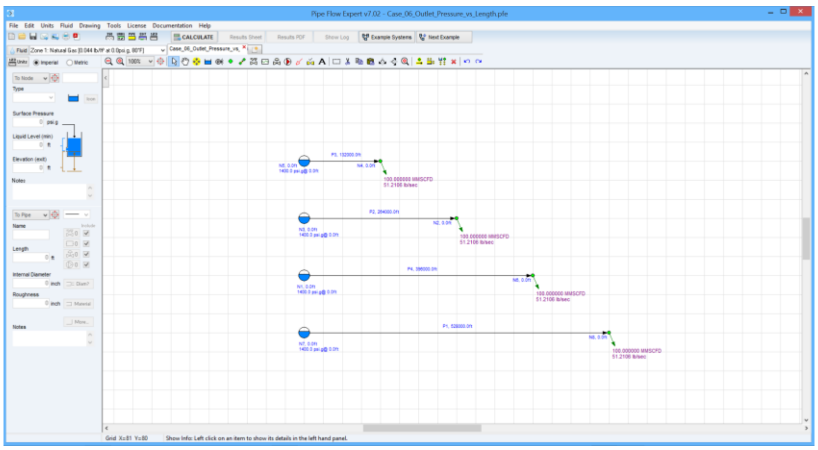
Case 06: Gas Pipeline Outlet Pressure vs Length

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 2, page 80

Pipe Flow Expert File: Case_06_Outlet_Pressure_vs_Length.pfe

Problem description:
For a 100 mile long gas pipeline, 15.5 inch internal diameter, use different flow equations to compare the outlet pressure at points 25 miles, 50 miles, 75 miles and 100 miles downstream from the start of the pipe for a gas flow rate of 100 MMSCFD. The gas temperature is 80 °F, and the upstream pressure at the start of the pipe is fixed at 1400 psi.g.

The published data uses 5 different calculation methods for comparison: Panhandle A, Panhandle B, General with Colebrook-White, AGA and Weymouth. For details of pipeline efficiency and gas compressibility see comments in results table.



Pipe Flow Expert Parameters:

Fluid data: Gas specific gravity 0.6 (0.044 lb/ft^3), 80 °F, 0.00 psi.g, viscosity 0.0119 centipoise.
Pipe data: Roughness 700 micro-inches
Calculation method: Various Isothermal flow equations, Node Adjust Method.
Standard atmospheric model: 60 °F, 14.696 psi.a
Gas physical model: Real Gas Model (Ideal Gas Law with CNGA compressibility factor).

A pipeline efficiency value of 0.95 was used in the Panhandle and Weymouth equations.
The General Fundamental Isothermal Flow equation used Colebrook-White friction factors.
The CNGA compressibility factor was used with all isothermal flow equations except for the AGA Ideal Gas Case.

Result Comparison:

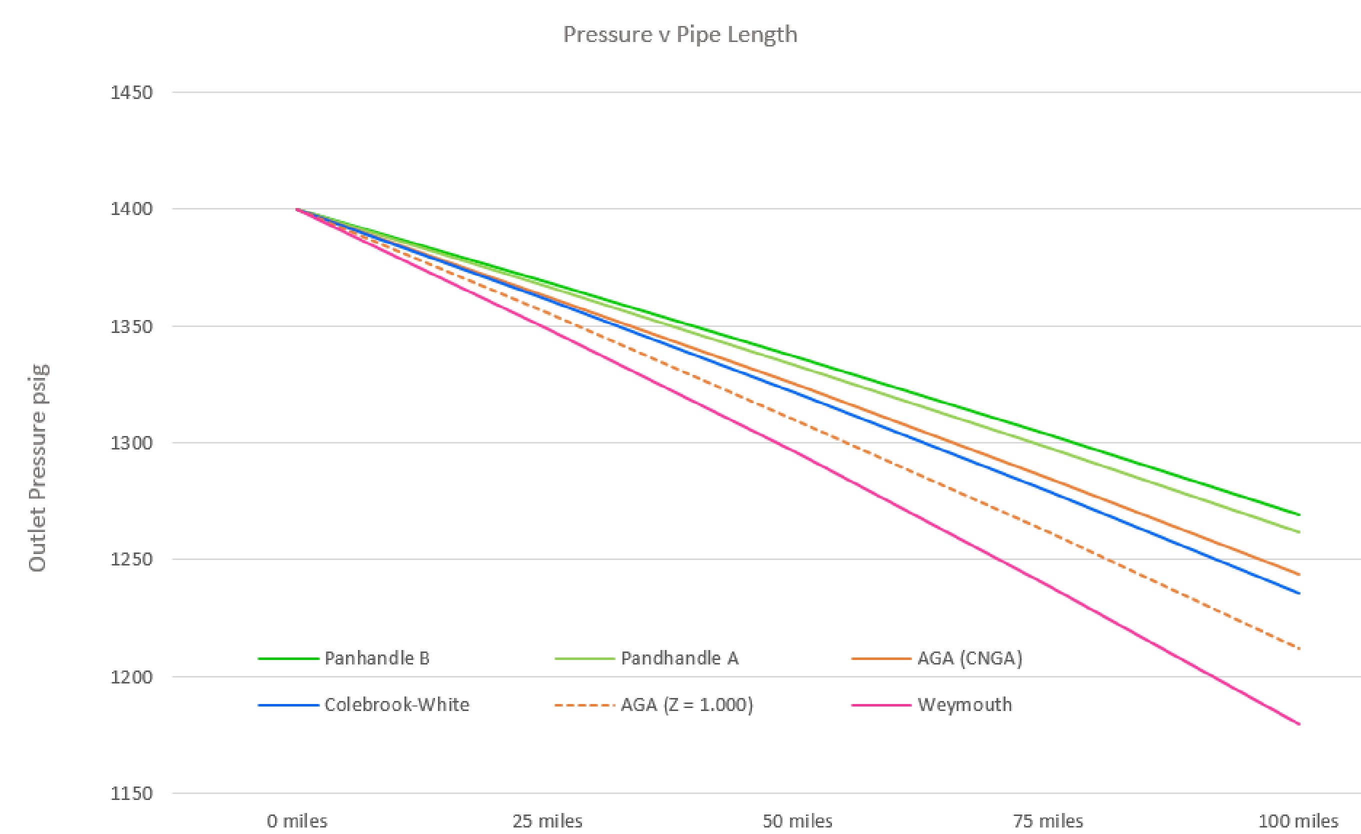
Published Graph Readings of Outlet Pressures (Psi.g):

Formula	**Panhandle B**	**Panhandle A**	**General** Colebrook-White	**AGA**	**AGA Ideal Gas**	**Weymouth**
Friction	Effic. = 0.95	Effic. = 0.95	IR =0.0007in	IR =0.0007in	IR =0.0007in	Effic. = 0.95
Assumed Compressibility	CNGA factor	CNGA factor	CNGA factor	CNGA factor	Ideal gas Z = 1.000	CNGA factor
25 miles	1368	1365	1359	Not available	1353	1345
50 miles	1335	1330	1318	Not available	1305	1289
75 miles	1303	1295	1276	Not available	1258	1234
100 miles	1270	1260	1235	Not available	1210	1178

Pipe Flow Expert Calculated Results of Outlet Pressures (Psi.g):

Formula	**Panhandle B**	**Panhandle A**	**General** Colebrook-White	**AGA**	**AGA Ideal Gas**	**Weymouth**
Friction	Effic. = 0.95	Effic. = 0.95	IR =0.0007in	IR =0.0007in	IR =0.0007in	Effic. = 0.95
Compressibility	CNGA factor	CNGA factor	CNGA factor	CNGA factor	Ideal gas Z = 1.000	CNGA factor
25 miles	1368.7	1366.9	1361	1362.8	1355.4	1348.7
50 miles	1336.5	1332.9	1320.7	1324.4	1309.2	1295.1
75 miles	1303.4	1297.9	1278.9	1284.7	1261.4	1238.8
100 miles	1269.3	1261.7	1235.5	1243.5	1211.7	1179.4

Graphical Comparison of Formula:



Commentary:

The published results specified a pipe roughness (700 μ inches) for use in both the AGA & General Flow equations (with Colebrook-White friction factors) and a pipeline efficiency of 0.95 for used in the Panhandle & Weymouth equations. Reference to IR=0.0007in in the above tables means an internal roughness of 700 μ inches.

The published data did not specify if a compressibility factor had been used in the calculations, however most of the other example calculations in the published work included a compressibility factor. In the Pipe Flow Expert software, the CNGA (Californian Natural Gas Association) method for automatic calculation of the compressibility factor was selected. The calculated results compare well with the published graph readings, indicating that a compressibility factor was used in the calculation of the published data for all equations except the published AGA results, which appear to have been based on assumption of the Ideal Gas Law with no compressibility.

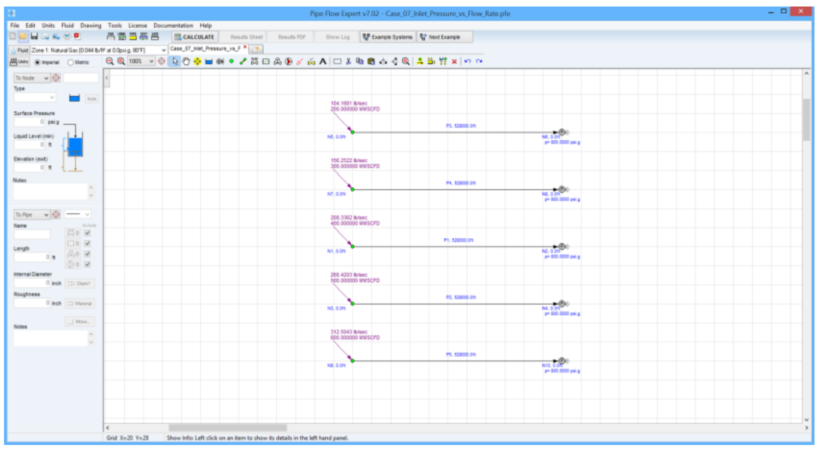
Case 07: Gas Pipeline Inlet Pressure vs Flow Rate

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 2, page 81

Pipe Flow Expert File: Case_07_Inlet_Pressure_vs_Flow_Rate.pfe

Problem description:
For a 100 mile long gas pipeline, 29.0 inch internal diameter, use different flow equations to compare the inlet pressure for gas flow rates of 200, 300, 400, 500 and 600 MMSCFD. The gas temperature is 80 °F, and the delivery pressure at the end of the pipe is fixed at 800 psi.g.

The published data used 5 different calculation methods for comparison: Panhandle A, Panhandle B, General with Colebrook-White, AGA and Weymouth. For details of pipeline efficiency and gas compression see comments in results table.



Pipe Flow Expert Parameters:

Fluid data: Gas specific gravity 0.6 (0.044 lb/ft³), 80 °F, 0.00 psi.g, viscosity 0.0119 centipoise.
Pipe data: Roughness 700 micro-inches.
Calculation method: Various Isothermal flow equations, Node Adjust Method.
Standard atmospheric model: 60 °F, 14.696 psi.a
Gas physical model: Real Gas Model (Ideal Gas Law with CNGA compressibility factor).

A pipeline efficiency value of 0.95 was used in the Panhandle and Weymouth equations.
The General Fundamental Flow equation used Colebrook-White friction factors.
The CNGA compressibility factor was used with all isothermal flow equations except for the AGA Ideal Gas case.

Result Comparison:

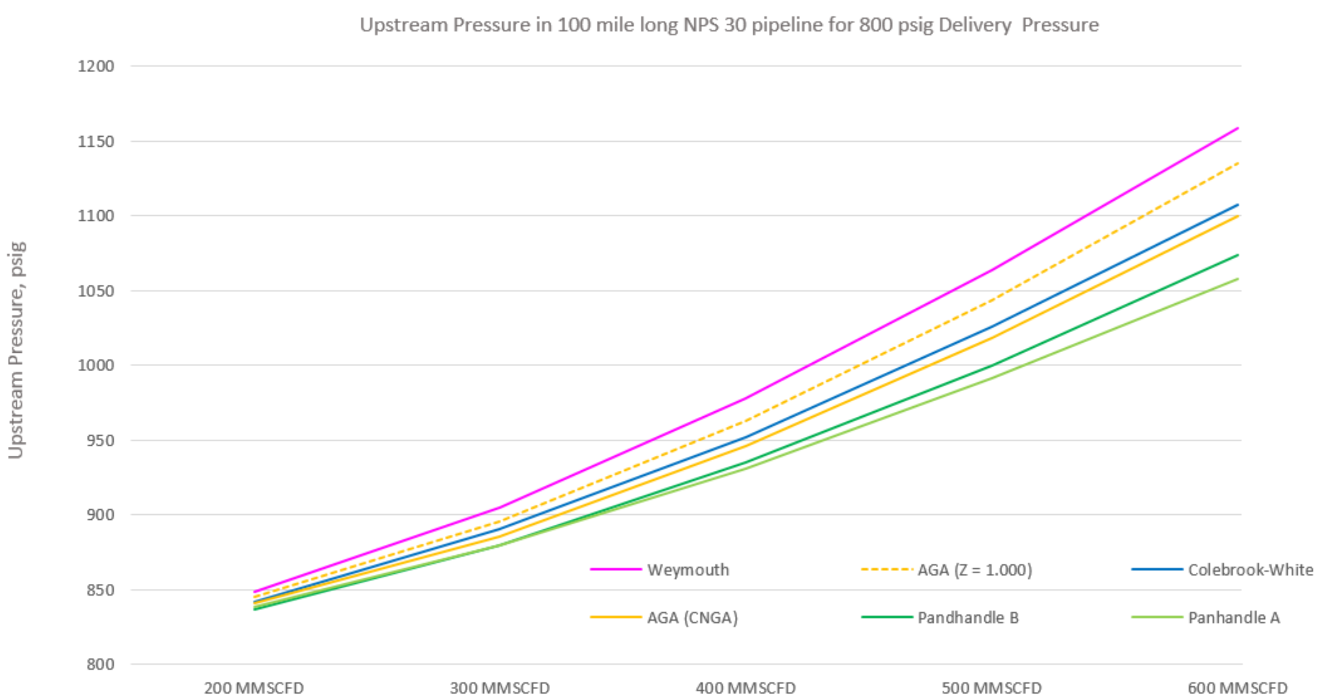
Published Graph Readings of Inlet Pressures (Psi.g):

Formula	**Panhandle A**	**Panhandle B**	**General** Colebrook-White	**AGA**	**AGA Ideal Gas**	**Weymouth**
Friction	Effic.=0.95	Effic.=0.95	IR=0.0007in	IR=0.0007in	IR=0.0007in	Effic.=0.95
Assumed Compressibility	CNGA factor	CNGA factor	CNGA factor	CNGA factor	Ideal gas Z = 1.000	CNGA factor
200 MMSCFD	837	837	844	Not available	846	850
300 MMSCFD	882	882	894	Not available	900	909
400 MMSCFD	942	947	960	Not available	977	987
500 MMSCFD	1010	1020	1040	Not available	1060	1080
600 MMSCFD	1074	1093	1132	Not available	1156	1172

Pipe Flow Expert Calculated Results of Inlet Pressures (Psi.g):

Formula	**Panhandle A**	**Panhandle B**	**General** Colebrook-White	**AGA**	**AGA Ideal Gas**	**Weymouth**
Friction	Effic. = 0.95	Effic. = 0.95	IR =0.0007in	IR =0.0007in	IR =0.0007in	Effic. = 0.95
Compressibility	CNGA factor	CNGA factor	CNGA factor	CNGA factor	Ideal gas Z = 1.000	CNGA factor
200 MMSCFD	838.5	836.8	842.2	840.8	845.5	848.2
300 MMSCFD	879.5	879.3	890.1	885.5	895.3	904.6
400 MMSCFD	931.1	934.6	952.1	946.3	963.0	977.6
500 MMSCFD	991.0	1000.1	1025.4	1018.5	1043.7	1063.4
600 MMSCFD	1057.3	1073.6	1107.4	1099.8	1134.7	1158.8

Graphical Comparison of Formula:



Commentary:

The published results specified a pipe roughness (700 μ inches) for use in both the AGA & General Flow equations (with Colebrook-White friction factors) and a pipeline efficiency of 0.95 for used in the Panhandle & Weymouth equations. Reference to IR=0.0007in in the above tables means an internal roughness of 700 μ inches was used.

The published data did not specify if a compressibility factor had been used in the calculations, however most of the other example calculations in the published work included a compressibility factor. In the Pipe Flow Expert software, the CNGA (Californian Natural Gas Association) method for automatic calculation of the compressibility factor was selected. The calculated results compare well with the published graph readings, indicating that a compressibility factor was used in the calculation of the published data for all equations except the published AGA results, which appear to have been based on assumption of the Ideal Gas Law with no compressibility.

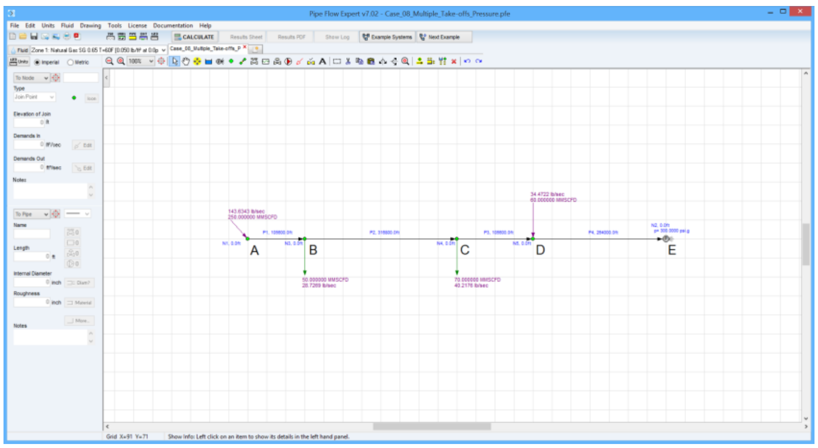
Case 08: Natural Gas Pipeline Outlet Pressures with Multiple Take-Offs

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 3, page 94 Example 2a

Pipe Flow Expert File: Case_08_Multiple_Take-offs_Pressure.pfe

Problem description:
A 150 mile pipeline carrying methane consists of several injections and deliveries. The pipe internal diameter is 19 inches and at point A has an inlet volume of 250 MMSCFD. At points b (20 miles downstream of the inlet) 50 MMSCFD is delivered and at point C (80 miles downstream of the inlet) 70 MMSCFD is delivered. At point D, 100 miles downstream of the inlet, gas enters the pipeline at 60 MMSCFD. Point E represents the end of the pipeline, 150 miles downstream of the inlet. Calculate the pressures at points A, B, C and D for a minimum delivery pressure of 300 psi.g at point E. Use a drag factor of 0.96 and a compressibility factor of 0.85 throughout.

The calculation method used for the published data was the American Gas Association (AGA) equation.



Pipe Flow Expert Parameters:

Fluid data: Gas with gravity 0.65 (0.04964 lb/ft^3), 60 °F at 0.00 psi.g, viscosity 0.0119 centipoise.
Pipe data: Roughness 150 micro-inches.
Calculation method: AGA Isothermal Flow equation with 0.96 drag factor, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi.
Gas physical model: Real Gas Model (Ideal Gas Law with custom compressibility factor Z=0.85).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Inlet pressure A (psi.g)	927.34	924.18
Outlet pressure B (psi.g)	832.25	832.58
Outlet pressure C (psi.g)	610.36	612.59
Outlet pressure D (psi.g)	572.41	572.52

Commentary:

The published data and the calculated results compare well.

The calculations used for the published results used an approximation by re-using the AGA transmission factor from the first pipe section (D – E) for all of the other pipe sections, whereas Pipe Flow Expert calculated the AGA transmission factor separately for each pipe section (which is more accurate).

Case 09: Natural Gas Pipeline Outlet Pipe Diameter with Multiple Take-Offs

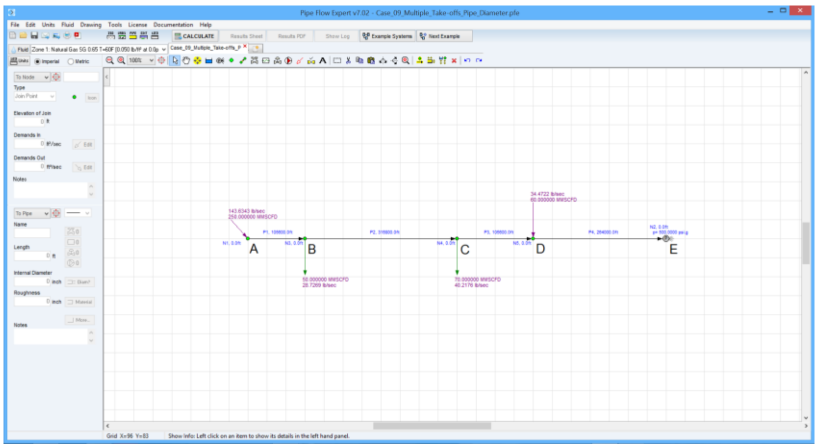
Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 3, page 94 Example 2b

Pipe Flow Expert File: Case_09_Multiple_Take-offs_Pipe_Diameter.pfe

Problem description:
A 150 mile pipeline carrying methane consists of several injections and deliveries, as shown in the screen image. The pipe internal diameter is 19 inches and at point A has an inlet volume of 250 MMSCFD. At points b (20 miles downstream of the inlet) 50 MMSCFD is delivered and at point C (80 miles downstream of the inlet) 70 MMSCFD is delivered. At point D, 100 miles downstream of the inlet, gas enters the pipeline at 60 MMSCFD. Point E represents the end of the pipeline, 150 miles downstream of the inlet.

Calculate the pipe diameter that will be required for section DE if the required delivery pressure at E is increased to 500 psi.g and the inlet pressure at A is the value that was calculated in Case 08. Assume a drag factor of 0.96 and a compressibility factor of 0.85 throughout.

The calculation method used for the published data was the American Gas Association (AGA) equation.



Pipe Flow Expert Parameters:

Fluid data: Gas with gravity 0.65 (0.04964 lb/ft^{3}), 60 °F at 0.00 psi.g, viscosity 0.0119 centipoise.
Pipe data: Roughness 150 micro-inches.
Calculation method: AGA Isothermal Flow equation, with 0.96 drag factor, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi.
Gas physical model: Real Gas Model (Ideal Gas Law with custom compressibility factor Z=0.85).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pipe Diameter of DE section (inches)	23.79	23.95

Commentary:

The published data and the calculated results compare well.
The pipe diameter calculated was that needed to produce an inlet pressure of 924.18 psi.g (which corresponds with the Pipe Flow Expert result in the previous example). The calculations for the published results used an approximation by re-using the AGA transmission factor from the previous example for all of the other pipe sections, whereas Pipe Flow Expert correctly calculates the AGA transmission factor separately for each pipe section.

Case 10: Inlet Pressure of Natural Gas Pipeline with Reducing Pipe Diameter

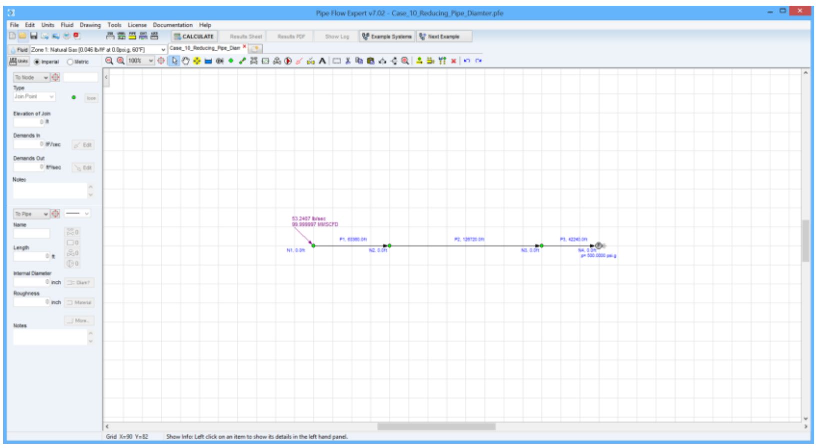
Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon Chapter 3, page 107 Example 5

Pipe Flow Expert File: Case_10_Reducing_Pipe_Diameter.pfe

Problem description:
A series piping system consists of 12 miles of pipe, internal diameter 15.25 inches, connected to a length of pipe 24 miles long with internal diameter 13.5 inches, which in turn is connected to an 8 mile section of pipe of internal diameter 12.25 inches. Use a compressibility factor of 0.9.

The gas flow rate is 100 MMSCFD and the delivery pressure is 500 psi.g. Calculate the inlet pressure.

The calculation method used for the published data was the General Flow equation.



Pipe Flow Expert Parameters:

Fluid data: Gas with specific gravity 0.6 (0.046 lb/ft³), 60 °F, 0.00 psi.g, viscosity 0.0119 centipoise.
Pipe data: Roughness 0.0145 inches, all pipes.
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi.
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.9)

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Inlet pressure (psi.g)	980.1	982.7

Commentary:

The published data and the calculated results compare well.

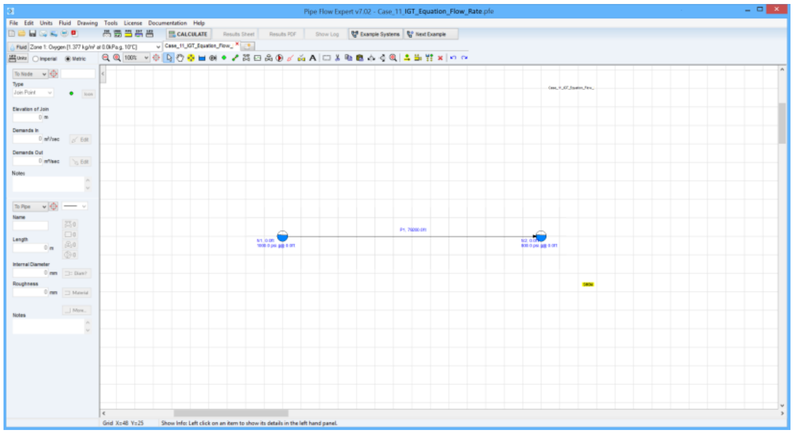
The published literature states that a friction factor of 0.02 was used for all pipes, whereas Pipe Flow Expert calculates the friction factor for each pipe separately. In order to achieve an average friction factor of approximately 0.02 for the system, a large pipe roughness of 0.0145 inches was used.

Case 11: IGT (Institute of Gas Technology) Equation Flow Rate

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

Pipe Flow Expert File: Case_11_IGT_Equation.pfe

Problem description:
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 & 800 psi.g, respectively. The pipeline efficiency is 0.95. Average gas temperature is 80 °F. Gas gravity = 0.6, viscosity = 0.000008 lb/ft-sec. The compressibility factor Z = 0.90.
Use the IGT equation to calculate the flow rate.



Pipe Flow Expert Parameters:

Fluid data: Gas with specific gravity 0.6 (0.044 lb/ft^3), 80 °F, 0.00 psi.g, viscosity 0.0119 centipoise.
Pipe data: Roughness 700 micro-inches.
Calculation method: IGT (Institute of Gas Technology) Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi.
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.9)

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow rate MMSCFD	263.1	263.37

Commentary:

The published data and the calculated results compare well.

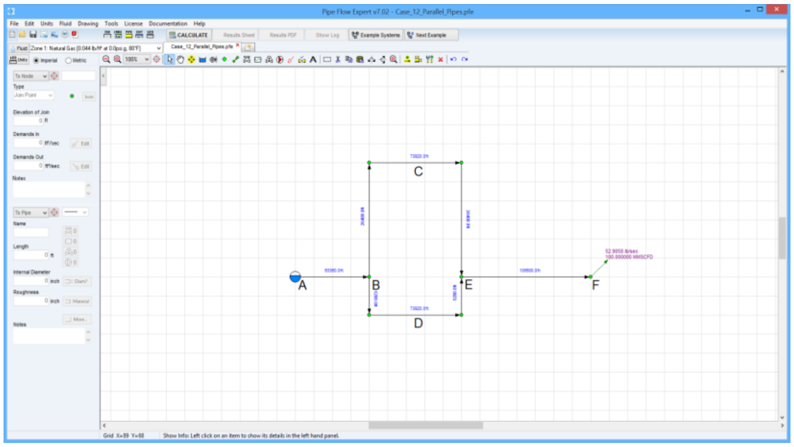
Case 12: Parallel Pipes: Pressures at Nodes

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon, Chapter 3, page 116 Example 7

Pipe Flow Expert File: Case_12_Parallel_Pipes.pfe

Problem description:
A gas pipeline consists of two parallel pipes, as shown in the screen image below, designed to operate at a flow rate of 100 MMSCFD. Pipe segment AB is 12 miles long, consisting of a pipe with an internal diameter of 15.5 inches. The loop BCE is 24 miles long with pipes of 13.5 inches internal diameter. The loop BDE is 16 miles long with pipes of 12.25 inches internal diameter. The pipe segment EF is 20 miles long, consisting of a pipe with internal diameter 15.5 inches. Assuming a gas gravity of 0.6, calculate the outlet pressure at F and the pressures at the beginning and end of the pipe loops and the flow rates through them.

The inlet pressure at A is 1200 psi.g, and the gas flowing temperature is 80 °F. Use a compressibility factor of 0.92. The calculation method used for the published data was the General Flow equation.



Pipe Flow Expert Parameters:

Fluid data: Gas with specific gravity 0.6 (0.044 lb/ft³), 80 °F, 0.00 psi.g, viscosity 0.0119 centipoise.
Pipe data: Roughness 0.004 inches for all pipes.
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 60 °F, 101.325 kPa.
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.92).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow rate BCE (MMSCFD)	51.0	51.2
Flow rate BDE (MMSCFD)	49.0	48.8
Pressure at B (psi.g)	1166.6	1167.6
Pressure at E (psi.g)	1130.9	1131.5
Pressure at F (psi.g)	1071.12	1073.6

Commentary:

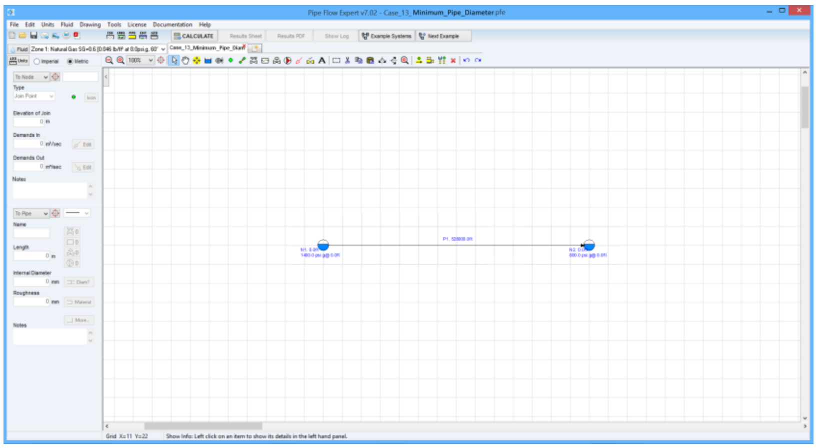
The published data and the calculated results compare well. The roughness value used of 0.004 gave a friction factor of around 0.015 for all pipes, as per the published results.

Case 13: Minimum Pipe Diameter

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon, Chapter 3, page 97 Example 3

Pipe Flow Expert File: Case_13_Minumum_Pipe_Diameter.pfe

Problem description:
A pipeline 100 miles long transports natural gas, at a constant temperature of 60°F. The inlet pressure is 1400 psi.g and the delivery pressure required is 800 psi.g. The required flowrate is 100 MMSCFD. Find the minimum pipe diameter needed using the AGA, General with Colebrook-white, Panhandle B and Weymouth equations. Use a compressibility factor of 0.9 and a 95% pipeline efficiency where appropriate. The pipe roughness is 700 micro inches.



Pipe Flow Expert Parameters:

Fluid data: Gas with specific gravity 0.6 (0.0458 lb/ft^3), 60 °F, 0.00 psi.g, viscosity 0.0119 centipoise.
Pipe data: Pipe roughness 0.000700 inches.
Calculation method: AGA, General Flow, Panhandle B and Weymouth equations, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi.a
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.90).

Result Comparison:

Data Item	Published data	Equation	Pipe Flow Expert	Pipe Flow Expert Flow Rate
Pipe diameter	12.47 inches	AGA	12.463 inches	100.043 MMSCFD
Pipe diameter	12.55 inches	General	12.538 inches	100.044 MMSCFD
Pipe diameter	11.93 inches	Panhandle B	11.931 inches	100.034 MMSCFD
Pipe diameter	13.30 inches	Weymouth	13.305 inches	100.012 MMSCFD

Commentary:

The published data and the calculated results compare well.
Colebrook-white refers to the method used to calculate friction factors in the General Isothermal Flow equation.
The pipe diameter was amended in the Pipe Flow Expert model for each of the equations selected, until the flow rate obtained was just in excess of 100 MMSCFD. The pipe diameter iteration took only 2 or 3 adjustments to obtain the results above.

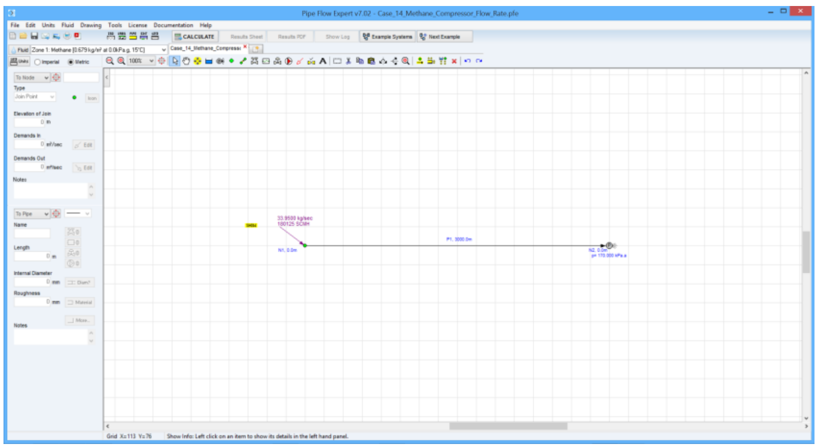
Case 14: Methane Compressor to Processing Unit

Reference: Chemical Engineering Volume 1, 6th Ed, 1999, Elsevier, J M Coulson, J F Richardson, page 168 Example 4.3

Pipe Flow Expert File: Case_14_Methane_Compressor_Flow_Rate.pfe

Problem description:
A flow of 50 m^3/s methane at 288 K and 101.3 kN/m^2 has to be delivered along a 0.6 m diameter line, 3.0 km long with a relative roughness of 0.0001, linking a compressor and a processing unit. The delivery pressure is to be 170 kN/m^2 and the delivery temperature 288 K. The methane leaves the compressor at 297 K. What pressure is needed at the compressor to achieve this flow rate?

The calculation method used for the published data was the Complete Isothermal equation.



Fluid data: Methane at 293 K average, 0.00 kPa.g, density 0.667218 kg/m^3, viscosity 0.0108 centipoise.
Pipe data: Absolute roughness 0.06 mm.
Calculation method: Complete Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 15°C, 101.325 kPa
Gas physical model: Ideal Gas Law

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Compressor pressure (N/m^2)	405000	408198

Commentary:

The calculation method used was the Complete Isothermal equation.
The published data and the calculated results compare well.

Case 15: Natural Gas Looped Pipeline Inlet Pressure

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon, Chapter 3, page 118 Example 8

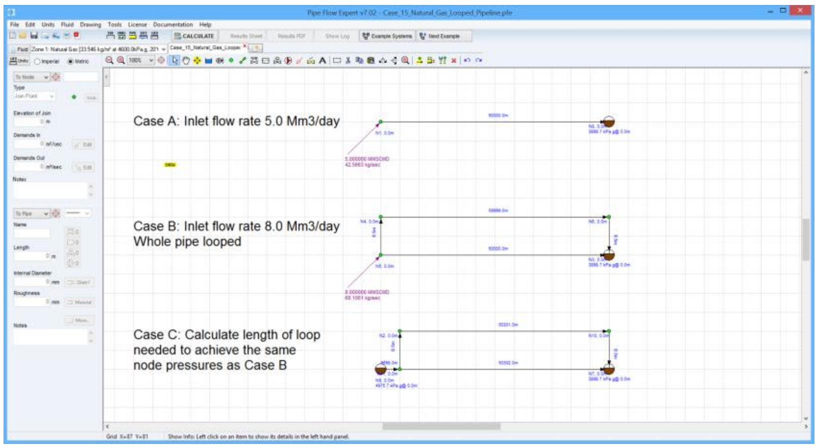
Pipe Flow Expert File: Case_15_Natural_Gas_Looped_Pipeline.pfe

Problem description:
A natural gas pipeline, internal diameter 476 mm, is 60 km long. The gas flow rate is 5.0 Mm^3/day at 15 °C. Calculate the inlet pressure required to achieve a delivery pressure of 4 MPa.a. The pipe roughness is 0.015 mm. Gas gravity is 0.65 and the compressibility factor is 0.88.

In order to increase the flow rate through the pipeline, the entire line is looped with pipe of internal diameter 476 mm. Assuming the same delivery pressure, calculate the inlet pressure at the new flow rate of 8 Mm^3/day.

If the inlet and outlet pressures are held the same as before, what length of the pipe should be looped to achieve the increased flow?

The calculation method used for the published data was the General Flow equation.



Fluid data: Natural Gas with specific gravity 0.65 (0.783 kg/m^3), 15 °C, 0.0 bar.g, viscosity 0.0119 centipoise.
Pipe data: Absolute roughness 0.015 mm.
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 15°C, 101.325 kPa.
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.88).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Inlet pressure (MPa absolute) flow rate = 5.0 Mm^3/day	5.077	5.077
Inlet pressure (MPa absolute) flow rate = 8.0 Mm^3/day	4.724	4.724
Length of pipe loop (km)	48.66	48.66

Commentary:
The published data and the calculated results compare well. The target flow rate for the looped 48.66 km pipeline was 8 Mm^3/day. The Pipe Flow Expert flow results for this looped model was 7.9978 MMSCMD (with an inlet pressure 5.077 MPa absolute, same as the 5.0 Mm^3/day flow arrangement).

Case 16: Natural Gas Pipeline Pressure Regulator

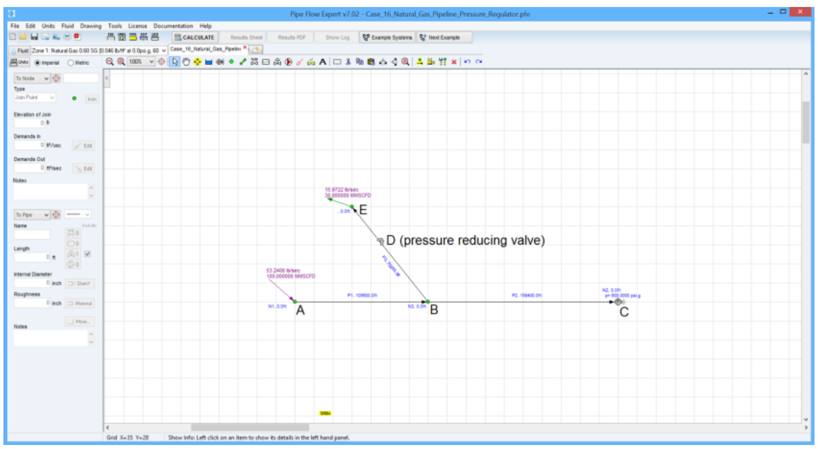
Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon, Chapter 3, page 127 Example 9

Pipe Flow Expert File: Case_16_Natural_Gas_Pipeline_Pressure_Regulator.pfe

Problem description:
A natural gas pipeline with internal diameter 15.5 inches, 50 miles long, with a branch pipe as shown in the screen image below, is used to transport 100 MMSCFD gas from A to B. At B, 20 miles downstream of A, a delivery of 30 MMSCFD occurs into the branch pipe BE which has internal diameter of 8.125 inches, length 15 miles. The delivery pressure at E must be maintained at 300 psi.g. The remaining volume of 70 MMSCFD is shipped to the terminus C at a delivery pressure of 600 psi.g. The gas is at 60 °F, with a specific gravity of 0.6 and a viscosity of 0.0119 centipoise. Compressibility factor is 0.88 and pipeline efficiency is 0.95.

Calculate the inlet pressure required at A. Is a pressure regulator required at E?
If the inlet flow at A drops to 60 MMSCFD, what is the impact in the branch pipeline BE if the flow rate of 30 MMSCFD is maintained?

The calculation method used for the published data was the Panhandle A equation.



Fluid data: Natural Gas with specific gravity 0.60 (0.046 lb/ft³), 60 °F, 0.00 kPa.g, viscosity 0.0119 centipoise.
Pipe data: Absolute roughness 0.001811 inch.
Calculation method: Panhandle A Isothermal equation, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.88).

Result Comparison:

Data Item	Published data	Pipe Flow Expert	Pipe Flow Expert
Inlet pressure at A (psi.g) for 100 MMSCFD flow	700.38 psi.g	700.74	700.74
Pressure at E (psi.g) (regulator requirement for 100 MMSCFD flow)	530.2 psi.g; Regulator is needed	529.90 psi.g; Regulator is needed to maintain 300 psi.g	Regulate at 300 psi.g PRV Loss calculated is 229.901 psi
Pressure at B (psi.g) for 60 MMSCFD total flow	609.77 psi.g	609.81	609.81
Pressure at E (psi.g) (regulator requirement for (60 MMSCFD flow)	486.06 psi.g; Regulator is needed	485.57 psi.g; Regulator is needed to maintain 300 psi.g	Regulate at 300 psi.g PRV Loss calculated is 185.57 psi

Commentary:
The published data and the calculated results compare well.

Case 17: Natural Gas Distribution Pipeline Looping

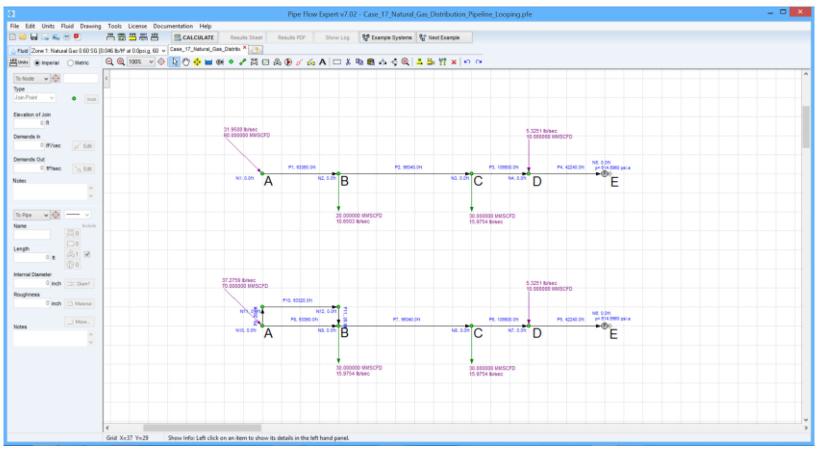
Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon, Chapter 5, page 194 Example 3

Pipe Flow Expert File: Case_17_Natural_Gas_Distribution_Pipeline_Looping.pfe

Problem description:
In a gas distribution pipeline, 60 MMSCFD enters the pipeline at A, as shown in the screen image below. If the delivery at B is increased from 20 MMSCFD to 30 MMSCFD by increasing the inlet flow at A, keeping all downstream flow rates the same, calculate the diameter of looping pipe necessary for section AB to ensure pressures are not changed throughout the pipeline. Assume the entire section AB is looped.

Pipe AB is 12 miles long with 13.5 inch internal diameter, BC is 18 miles long with 12.25 inch internal diameter, pipe CD is 20 miles long with 10.25 inch internal diameter and DE is 8 miles long with 12.25 inch internal diameter. The delivery pressure at E is fixed at 600 psi.g. The gas gravity is 0.6 and the flow temperature is 60 °F. Compressibility factor is 0.85.

The calculation method used for the published data was the General Flow Equation.



Fluid data: Natural Gas with specific gravity 0.6, 60 °F (0.046 lb/ft^3), viscosity 0.0119 centipoise.
Pipe data: Absolute roughness 0.000250 inches.
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.85).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure at A (psi abs) for initial flow rate	677.45	680.64
Pressure at B (psi abs) for initial flow rate	651.90	654.85
Internal diameter of looped pipe (inches)	6.6	6.8

Commentary:
The published data and the calculated results compare well.

The published data used a transmission factor of 20 instead of a roughness value for the pipe. We have used a roughness value of 0.00025 inches which gives friction factors around 0.01, which is equivalent to a transmission factor of 20.

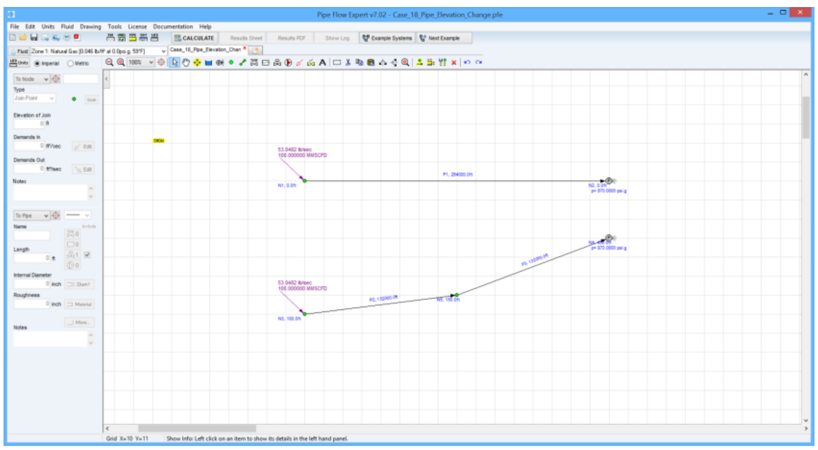
Case 18: Elevated Pipeline Inlet Pressure

Reference: Gas Pipeline Hydraulics, 2005, CRC Press, E. Shashi Menon, Chapter 3, page 87 Example 1

Pipe Flow Expert File: Case_18_Pipe_Elevation_Change.pfe

Problem description:
A gas pipeline, 15.5 inch internal diameter, 50 miles long, transports natural gas (SG = 0.6 and viscosity = 0.0119 centipoise) at a flow rate of 100 MMSCFD at an inlet temperature of 60 °F. Assuming isothermal flow, calculate the inlet pressure required if the required delivery pressure at the pipeline terminus is 870 psi.g.

Case A: No elevation change along the pipeline length.
Case B: Elevation changes as follows: inlet elevation of 100 ft, delivery point elevation of 450 ft, with midpoint elevation of 250 ft.
The calculation method used for the published data was the General Flow equation.



Fluid data: Natural Gas with specific gravity 0.6, 60 °F, 14.696 psi.g (0.04582 lb/ft³), viscosity 0.01191 centipoise.
Pipe data: Absolute roughness 0.0007 inches.
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 60 °F, 14.696 psi
Gas physical model: Real Gas Model (Ideal Gas Law with CNGA-calculated compressibility factor).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Inlet pressure (psi.g) for Case A	985.66	985.62
Inlet pressure (psi.g) for Case B	993.64	992.78

Commentary:
The published data and the calculated results compare well.

The published data was calculated using a compressibility factor of 0.8666, which was derived using the CNGA formula as applied to the first arrangement of the system. For simplification the published data then used the same compressibility factor for each pipe in the second arrangement of the system.
Pipe Flow Expert calculated an independent compressibility factor for each pipe (0.8662, 0.8617, 0.8693) using the CNGA formula.

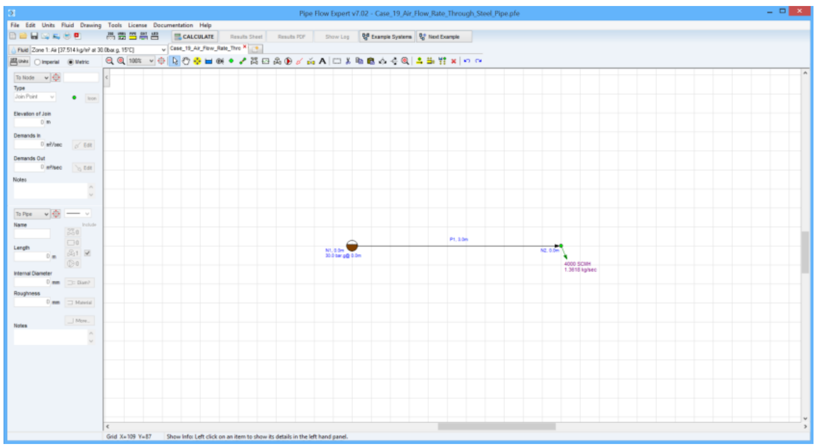
Case 19: Flow Rate of Air through Steel Pipe

Reference: Flow of Fluids through Valves, Fittings and Pipe Metric Edition – SI Units, Crane Technical Paper 410M, page 3-16 Example 2

Pipe Flow Expert File: Case_19_Air_Flow_Rate_Through_Steel_Pipe.pfe

Problem description:
Air at 30 bar.g and 15° C flows through a steel pipe with a 40.3 mm inside diameter, at a rate of 4000 standard cubic metres per hour at metric standard conditions (1.01325 bar and 15°C). Find the flow rate in kilograms per hour and the velocity in metres per minute.

The calculation method used for the published data was Darcy's equation.



Fluid data: Air at 15 °C, 0 bar.g, density 1.226 kg/m^3, viscosity 0.01795 centipoise.
Pipe data: Roughness 0.046 mm (pipe material Steel (ANSI) schedule 40).
Calculation method: General Isomthermal equation, Node Adjust Method.
Standard atmospheric model: 15°C, 0.0 bar.g
Gas physical model: Ideal Gas Law

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Mass Flow (kg/hour)	4900	4904
Velocity (m/min)	1700	1708 (entry velocity) (28.459 m/s) 1712 (exit velocity) (28.530 m/s)

Commentary:

The published data and the calculated results compare well.

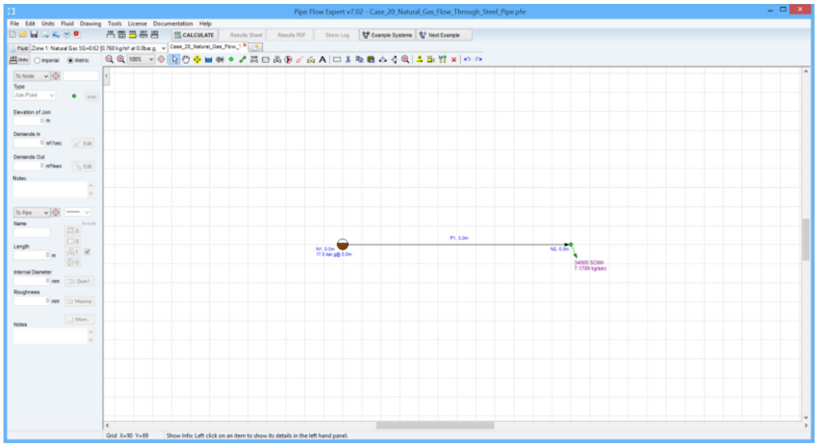
Case 20: Flow of Natural Gas through Steel Pipe

Reference: Flow of Fluids through Valves, Fittings and Pipe Metric Edition – SI Units, Crane Technical Paper 410M, page 3-18 Example 1

Pipe Flow Expert File: Case_20_Natural_Gas_Flow_Through_Steel_Pipe.pfe

Problem description:
Natural Gas at 17 bar gauge and 15° C with a specific gravity of 0.62, flows through a steel pipe 200 mm inside diameter at a rate of 34 000 standard cubic metres per hour. Find the flow rate in kilograms per hour, the Reynolds number and the friction factor.

The calculation method used for the published data was the Darcy-Weisbach equation.



Fluid data: Natural Gas at 15 °C, specific gravity 0.62, 0.0 bar.g, density 0.760 kg/m^3, viscosity 0.0120 centipoise.
Pipe data: Roughness 0.046 mm (pipe material Steel (ANSI) schedule 40).
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 15°C, 0.0 bar.g
Gas physical model: Ideal Gas Law

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Mass Flow (kg/hour)	26000	25844
Reynolds Number	4000000	3808530
Friction Factor	0.014	0.014369

Commentary:

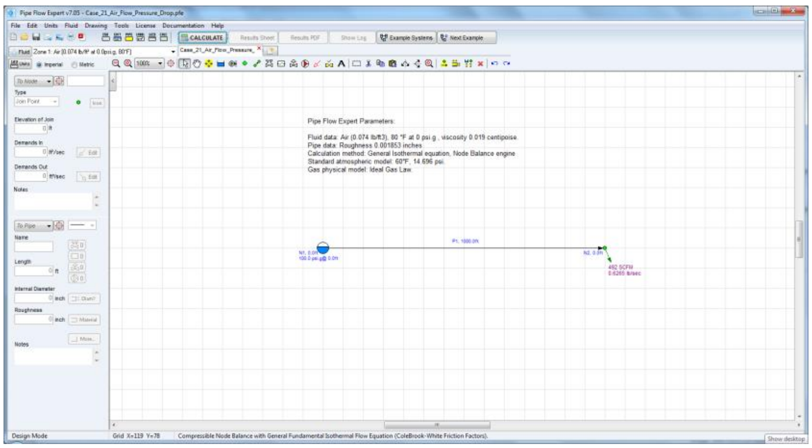
The published data and the calculated results compare well.
Pipe Flow Expert calculated the friction factor more accurately and displayed it to six decimal places.
Using a more accurate friction factor produces a slightly difference result, as shown above.

Case 21: Air Pressure Drop in Steel Pipe

Reference: Piping Calculations Manual, 2005, McGraw-Hill, E. Shashi Menon, Chapter 5, page 265 Example 5.8

Pipe Flow Expert File: Case_21_Air_Flow_Pressure_Drop.pfe

Problem description:
Air flows at 50 ft/s in a 2" inside diameter pipe at 80°F, at an initial pressure of 100 psi.g.
If the pipe is horizontal and 1000 ft long, calculate the pressure drop if the flow is isothermal. Use a friction factor of 0.02. The calculation method used for the published data was the General Isothermal Flow Equation.



Fluid data: Air at 80 °F, 0.0 bar.g, density 0.736 lb/ft^3, viscosity 0.0185 centipoise.
Pipe Flow Expert will automatically calculate for compression of the gas to the 100 psi.g condition.
The fluid data must however be defined at the required temperature.
Pipe data: Roughness 0.001853 inches (pipe material Steel (ANSI) schedule 40).
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi.a
Gas physical model: Ideal gas Law.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Outlet Pressure (psi.a)	94.18	94.1782
Pressure drop (psi)	20.52	20.5178

Commentary:

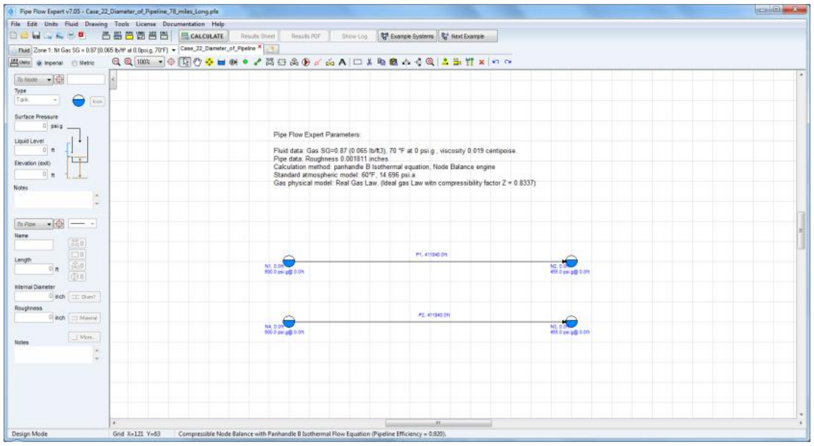
The published data and the calculated results compare well.
The normal pipe roughness for mild steel pipe is 0.001811 inches, however this was adjusted to 0.001853 inches to give a friction factor of 0.02 as assumed in the published text.
Although the fluid data is defined for 80°F and 0.0 bar.g, Pipe Flow Expert's compressible flow engine automatically accounts for and calculates for compression of the air down to the 100 psi.g starting condition.

Case 22: Natural Gas Flow Rate vs Pressure Drop In Steel Pipe

Reference: Fluid Flow Handbook, 2002, McGraw-Hill, Jamal M. Saleh, Ph D., PE, Chapter 9, page 9.14 Ex. 9.5.1

Pipe Flow Expert File: Case_22_Diameter_of_Pipeline_78_miles_long.pfe

Problem description:
Find the inside diameter of a steel pipe used to transport natural gas (SG = 0.87) a distance of 78 miles when the following requirements are specified.
The inlet pressure is 600 psi.g and the maximum allowable pressure drop is 145 psi.g.
Assume isothermal flow and a pipeline efficiency of 0.92
The compressibility factor Z = 0.8337 (calculated from Papay's correlation)
The calculation method used for the published data was the Panhandle B equation.



Fluid data: Natural Gas at 70 °f, 0.0 psi.g, density 0.650 lb/ft³, viscosity 0.0119 centipoise
Pipe data: Internal diameter 18.812 inches (nominal 20" diameter), roughness 0.001811 inches (pipe material Steel (ANSI) schedule 40).
Calculation method: Panhandle B Isothermal equation, Node Adjust Method.
Standard atmospheric model: 60°F, 14.696 psi.a
Gas physical model: Real Gas Model (Ideal Gas Law with compressibility factor Z=0.8337).

Result Comparison:

Data Item	Published data	Pipe Flow Expert	Pipe Flow Expert; Flow Rate
Inner diameter	18.80 inches	18.800 inches	100.049 MMSCFD
20" nominal diameter	N/A	18.812 inches	100.211 MMSCFD

Commentary:

The published data and the calculated results compare well.
A supplementary calculation using a nominal 20 inch Steel pipe (schedule 40) with an 18.812 inch inner diameter confirms a similar flow rate within the allowed 145 psi.g pressure drop.

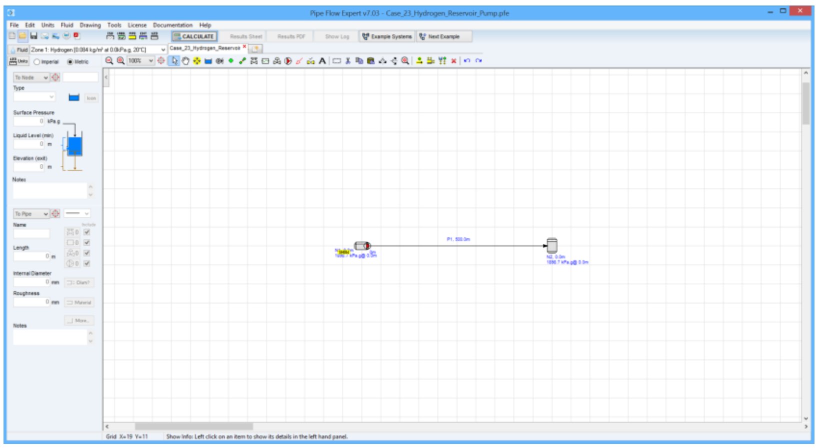
Case 23: Pumping Hydrogen Gas from a Reservoir

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

Pipe Flow Expert File: Case_23_Hydrogen_Reservoir_Pump.pfe

Problem description:
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 flowrate of hydrogen?

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



Fluid data: Hydrogen at 21.85 °C, 0.0 bar.g, density 0.084 kg/m^3, viscosity 0.009 centipoise.
Pipe data: Internal diameter 50 mm, roughness 0.05 mm.
Calculation method: Complete Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 20°C, 1.01325 bar absolute.
Gas physical model: Ideal Gas Law

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow Rate (kg/second)	0.200	0.199

Commentary:

The published data and the calculated results compare well.

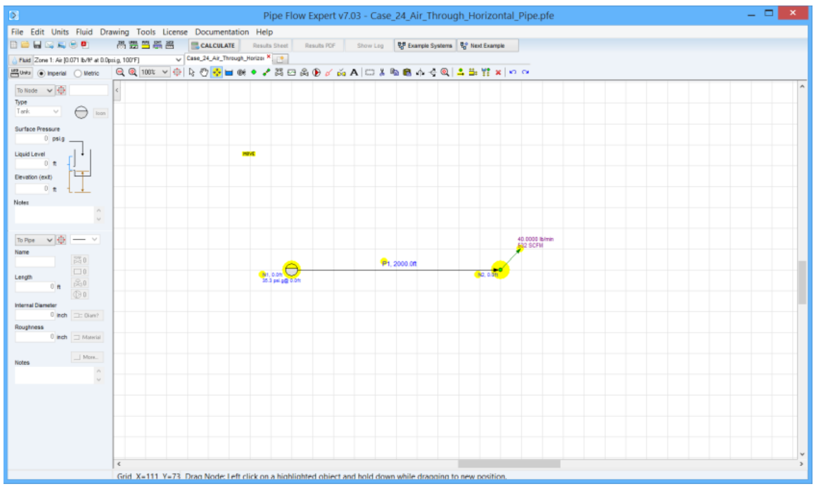
Case 24: Air Flowing through Horizontal Pipe

Reference: Elementary Fluid Mechanics, 1940, John Wiley & Sons, Inc., John K. Vennard, page 163 "Illustrative Problem"

Pipe Flow Expert File: Case_24_Air_Through_Horizontal_Pipe.pfe

Problem description:
Air is pumped from a reservoir at 50 psi.a through a clean horizontal smooth pipe 3" in diameter and 2000 ft long. The conditions of flow are isothermal and the temperature of the gas is 100 degrees F. With a flow rate of 40 lb/min what is the pressure 2000 ft downstream?

The calculation method used for the published data was the Simplified version of the Complete Isothermal Equation, which neglects the term 2**ln*(V2/V1) since this is normally small compared to f*(L/D).



Fluid data: Air at 100 °F, 0.0 bar.g, density 0.071 lb/ft^3, viscosity 0.0191 centipoise.
Pipe data: Internal diameter 3 inches, roughness 0.000001 inches.
Calculation method: Complete Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 68 °F, 14.696 psi absolute.
Gas physical model: Ideal Gas Law

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure 2000 feet downstream	39.3 psi.a	38.96 psi.a
Friction factor	0.0145	0.014818

Commentary:

The published data and the calculated results compare well.

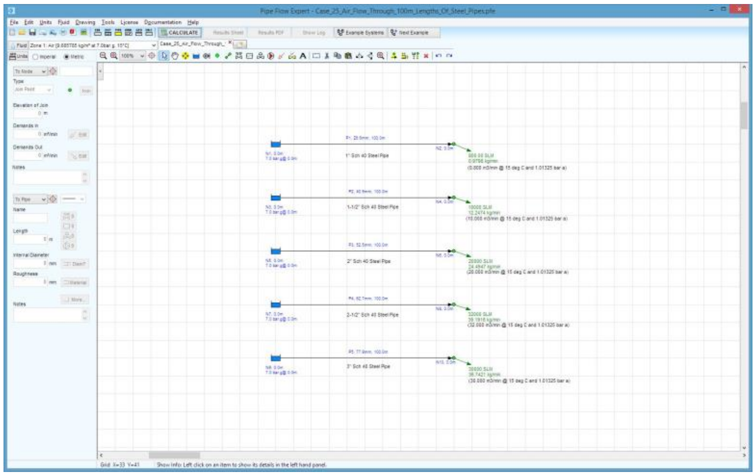
The published result was calculated using a friction factor of 0.0145 (which was read from a plot).
Pipe Flow Expert used a pipe roughness of 0.000001 inches, calculating a friction factor of 0.0148.

Case 25: Air – Flow Through 100m Lengths of Steel Pipes

Reference: Flow of Fluids – Technical Paper No 410M, 1999, Crane Co. Appendix B-14.

Pipe Flow Expert File: Case_25_Air_Flow_Through_100m_Lengths_Of_Steel_Pipes.pfe

Problem description:
Compressed air at 7 bar gauge and 15°C flows through 100 meter long schedule 40 steel pipes.
Find the pressure drop in each of the pipes.



Fluid data: Air at 15 °C, 7.0 bar.g, density 9.685785 kg/m³, viscosity 0.018069 centipoise.
Pipe data: Internal diameters of standard Schedule 40 Steel pipe, various sizes. Roughness 0.046 mm.
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 15 °C, 101.325 kPa absolute
Gas physical model: Ideal Gas Law

Result Comparison:

Pipe Details	Free Air m³/min	Compressed Flow m³/min	Published Pressure Drop (Bar)	Pipe Flow Expert Pressure Drop (Bar)
1.0” Diameter Schedule 40 Steel Pipe, 100 m long	0.800	0.101	0.044	0.0438
1-1/2” Diameter Schedule 40 Steel Pipe, 100 m long	10.000	1.264	0.640	0.6673
2.0” Diameter Schedule 40 Steel Pipe, 100 m long	20.000	2.528	0.685	0.7180
2-1/2” Diameter Schedule 40 Steel Pipe, 100 m long	32.000	4.046	0.682	0.7226
3.0” Diameter Schedule 40 Steel Pipe, 100 m long	30.000	3.793	0.197	0.2004

Commentary:

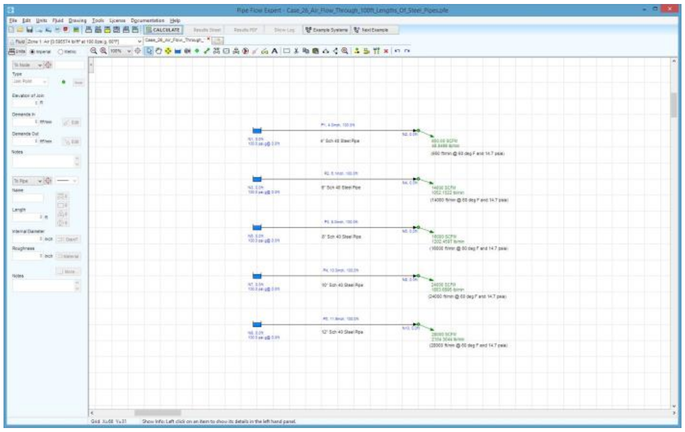
The published data and the calculated results compare well but differ slightly, with pressure drop comparisons varying by up to 0.04 bar (or about 5.5% of the total pressure drop). The published data was read from tabulated results, for various pipe sizes and flow rates, which we believe were calculated using the Darcy-Weisbach equation, since Pipe Flow Expert results produced with its non-compressible calculation engine generate almost exactly the same figures as the published data, whereas these Pipe Flow Expert results were generated using the General Fundamental Isothermal flow equation for compressible flow (which is better suited for air flow calculations).

Case 26: Air – Flow Through 100ft Lengths of Steel Pipes

Reference: Flow of Fluids – Technical Paper No 410, 1988, Crane Co. Appendix B-15.

Pipe Flow Expert File: Case_38_Air_Flow_Through_100ft_Lengths_Of_Steel_Pipes.pfe

Problem description:
Compressed air at 100 psi gauge and 60°F flows through 100 feet long schedule 40 steel pipes.
Find the pressure drop in each of the pipes.



Fluid data: Air at 100 psi gauge and 60°F, density 0.595574 lb/ft^3, viscosity 0.018095 centipoise.
Pipe data: Internal diameters of standard Schedule 40 Steel pipe, various sizes. Roughness 0.001811 inches.
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 60 °F, 14.696 psi absolute
Gas physical model: Ideal Gas Law

Result Comparison:

Pipe Details	Free Air ft³/min	Compressed Flow ft³/min	Published Pressure Drop (psi)	Pipe Flow Expert Pressure Drop (psi)
4.0" Diameter Schedule 40 Steel Pipe, 100 ft long	650	83.3	0.086	0.0832
6.0" Diameter Schedule 40 Steel Pipe, 100 ft long	14000	1794	4.21	4.2228
8.0" Diameter Schedule 40 Steel Pipe, 100 ft long	16000	2051	1.33	1.3121
10.0" Diameter Schedule 40 Steel Pipe, 100 ft long	24000	3076	0.918	0.9029
12.0" Diameter Schedule 40 Steel Pipe, 100 ft long	28000	3588	0.505	0.4957

Commentary:

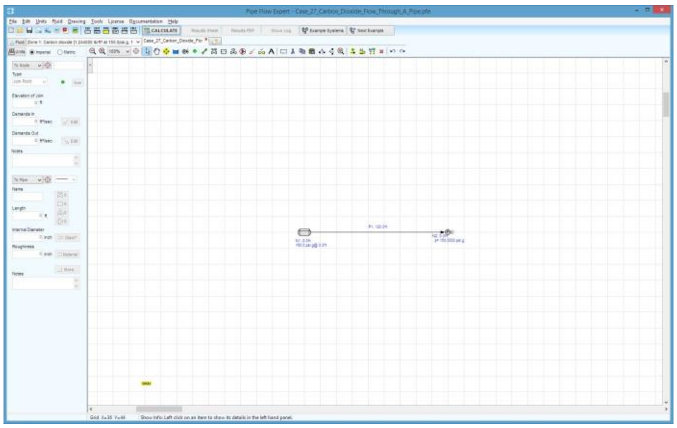
The published data and the calculated results compare well. The density of Air at 100 psi.g and 60°F used in the calculation of the published results was not specified, and the results were based on a non-compressible calculation since the pressure drop was small. Pipe Flow Expert's gas helper calculated the density of the Air at 0.595574 lb/ft^3 and used a compressible flow equation to calculate the results.

Case 27: 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

Pipe Flow Expert File: Case_41_Carbon_Dioxide_Flow_Through_A_Pipe.pfe

Problem description:
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"). The flow is isothermal. The pressure at the start of a 120 ft long horizontal pipe section is 160 psig the pressure at the end of the section is 150 psig.
Calculate the weight flow rate of the air.



Fluid data: Carbon Dioxide at 155 psi gauge and 100°F, density 1.244000 lb/ft^3, viscosity 0.015500 centipoise. Pipe Flow Expert will automatically calculate for compression of the gas. The fluid could have been defined at any pressure, although here it was defined at the average pressure condition of 155 psi.g. The fluid data must however be defined at the required temperature.
Pipe data: Internal diameters of 6 inches. Roughness 0.0024 inches.
Calculation method: General Isothermal Flow equation, Node Adjust Method.
Standard atmospheric model: 68 °F, 14.696 psi absolute
Gas physical model: Ideal Gas Law

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Weight of Flow (lb/sec)	25.3	25.5278
Reynolds Number	5000000	6241277
Friction Factor	0.0285	0.0284

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 which is used 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. The new Reynolds Number is greater than the initial assumption of the Reynolds Number and is taken as confirmation of the previously calculated weight of flow.

The Pipe Flow Expert program uses the Colebrook-White equation to determine friction factors that are used in the General Isothermal Flow equation. The Colebrook-White equation is usually considered to be more accurate than a value read from a Moody Chart.

References

1. Fluid Mechanics and Hydraulics, 3rd Ed, 1994, McGraw-Hill
   R. V. Giles, J. B. Evett PhD, C. Liu

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

3. Introduction to Compressible Fluid Flow, 2nd Ed, 2014, CRC Press
   Patrick H. Oosthuizen, William E. Carscallen

4. Chemical Engineering Volume 1, 6th Ed, 1999, Elsevier
   J M Coulson, J F Richardson

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

6. Elementary Fluid Mechanics, 1940, John Wiley & Sons, Inc., John K. Vennard

7. Fluid Flow Handbook, 2002, McGraw-Hill
   Jamal M. Saleh, Ph D., PE

8. Piping Calculations Manual, 2005, McGraw-Hill
   E. Shashi Menon