http://www.pipeflow.com

Pipe Flow Expert

Fluid Flow and Pressure Loss Calculations Software

Verification of Calculation Results For Non-Compressible 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.

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.

For each of the 50 cases detailed in this document, the Pipe Flow Expert Results Data compares well with the published results data.

Notes:

Friction Factors are calculated using the **Colebrook-White** equation.

Friction Loss for non-compressible fluids is calculated using the **Darcy-Weisbach** method, which provides accurate results for most fluids, including general process fluids.

Gases: The ‘non-compressible’ Darcy-Weisbach equation also provides satisfactory results of reasonable accuracy for compressible fluids (gases) when the pressure drop in the system is less than 10% of the absolute pressure at the starting point. If the calculated pressure drop in the system is greater than 10% but less than 40% of the absolute pressure at the starting point then the Darcy-Weisbach equation will give reasonable accuracy provided that the calculations are repeated using the average density of the fluid (at the average pressure condition) in the pipeline.

Cases 37 to 41 in this document compare the Pipe Flow Expert results using its non-compressible calculation engine against published data for relatively low pressure loss gas systems, however **Pipe Flow Expert now contains a separate Compressible calculation engine** that allows for the solution of compressible systems with equations such as the General Fundamental Isothermal Flow equation, the Complete Isothermal equation, the AGA equation, the Panhandle A equation, the Panhandle B equation, and the IGT equation. There is a separate ‘Compressible Results Verification’ document that compares Pipe Flow Expert’s results using its compressible calculation engine against the published results of more than 25 compressible gas systems.

Pipe Flow Expert is currently used by engineers in over 75 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 and wastewater processing.

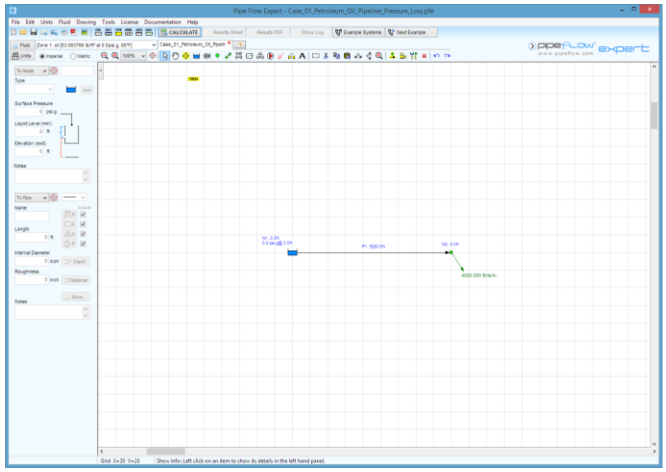
Case 01: Petroleum - Oil Pipeline Pressure Loss

Reference: Piping Calculations Manual, 2005, McGraw-Hill, E. Shashi Menon, P.E., Page 335, Example 6.16

Pipe Flow Expert File: Case_01_Petroleum_Oil_Pipeline_Pressure_Loss.pfe

Problem description:

Find head loss in one mile of NPS16 (0.250 inch wall thickness) pipeline at a flow rate of 4000 barrel/h.



Fluid data: Petroleum oil with a 0.85 specific gravity and 10 cSt viscosity.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Head Loss (ft. hd)	29.908	29.930
Reynolds Number	57129	57130
Fluid Velocity (ft/s)	4.76	4.761
Friction factor	0.0208	0.02078

Commentary:

The published data and the calculated results compare very well.
The rounding of the fluid velocity to 2 decimal places in the published data accounts for the slight differences with Pipe Flow Expert.

Case 02: Gasoline - Transport over 15 km

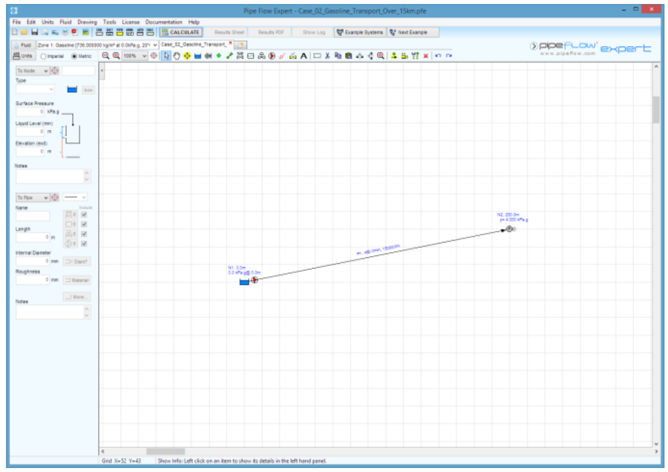
Reference: Piping Calculations Manual, 2005, McGraw-Hill, E. Shashi Menon, P.E., Page 337, Example 6.17

Pipe Flow Expert File: Case_02_Gasoline_Transport_Over_15km.pfe

Problem description:

A DN500 (10mm wall thickness) steel pipe is used to transport gasoline over a 15km distance. The delivery point is 200 m above the start of the pipeline.
A delivery pressure of 4 kPa has to be maintained at the delivery point.

Calculate the pump pressure needed to deliver a flow rate of 990 m³/h.



Fluid data: Gasoline with a 0.736 specific gravity and 0.6 cSt viscosity.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pump Pressure Required (kPa)	1792	1800.492
Reynolds Number	1215768	1215767
Fluid Velocity (m/s)	Not stated	1.520
Friction factor	0.013	0.01329

Commentary:

The published data and the calculated results compare well.
The published text uses a friction factor value of 0.013 read from the Moody diagram.
The Pipe Flow Expert program uses a friction factor calculated to more decimal places which accounts for the slight difference in the pump pressure required.

Case 03: Water - Pumping with Two Pumps in Parallel

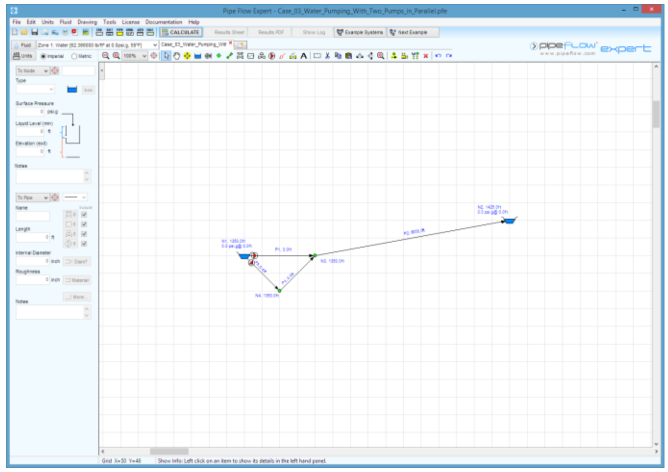
Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 24, Example problem 2.5

Pipe Flow Expert File: Case_03_Water_Pumping_With_Two_Pumps_in_Parallel.pfe

Problem description:

Water is transferred from a reservoir at 1350 ft elevation to a reservoir at 1425 ft elevation.
The pipeline is 6000 ft long is 18 inch diameter and has equivalent sand grain roughness *e* = 0.015 inch.
Two three stage Ingersoll-Dresser 15H277 pumps are used in parallel to pump the fluid.

Calculate the flow rate and pump head required.



Fluid data: Water at 59° F (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow rate gpm (US)	6680	6686.91
Pump Head Required (ft)	159.4	159.467
Friction factor	0.01917	0.01912

Commentary:

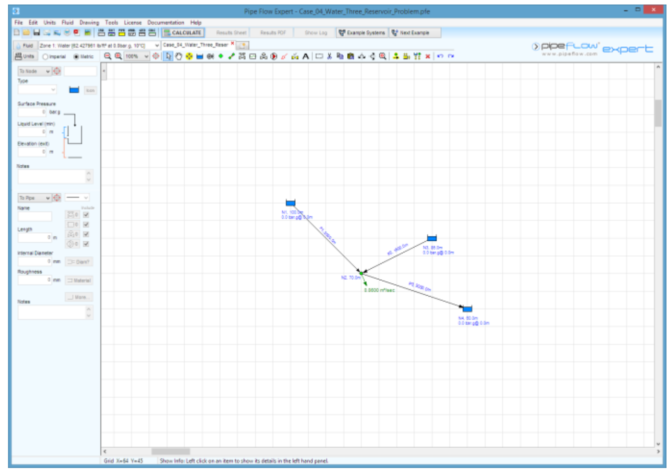
The published data and the calculated results compare well.

Case 04: Water - Three Reservoir Problem

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 26, Example problem 2.7

Pipe Flow Expert File: Case_04_Water_Three_Reservoir_Problem.pfe

Problem description:



Three water reservoirs are connected by three pipes.
The water surface elevations of the reservoirs are 100 m, 85 m and 60 m.
There is an external demand of 0.06 m^3/s at the common junction of the pipes.
The pipe from the high reservoir to the common junction is 2000 m long and has an internal diameter of 300 mm.
The pipe from the middle reservoir to the common junction is 1500 m long and has an internal diameter of 250 mm
The pipe from the common junction to the low reservoir is 3000 m long and has an internal diameter of 250 mm.
The elevation of the common junction is unspecified.
All pipes have an internal roughness of 0.5 mm.

Calculate the flow rate leaving or entering each reservoir.

Fluid data: Water at 10° C.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow rate leaving highest reservoir (m^3/s)	0.1023	0.1022
Flow rate leaving middle reservoir (m^3/s)	0.0200	0.0200
Outflow from Common Junction (m^3/s)	0.0600	0.0600
Flow rate entering lowest reservoir (m^3/s)	0.0622	0.0622

Commentary:

The published data and the calculated results compare well.

Case 05: Water - Flow Rate at 40 psi Outlet Point

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 218, Example problem 5.17

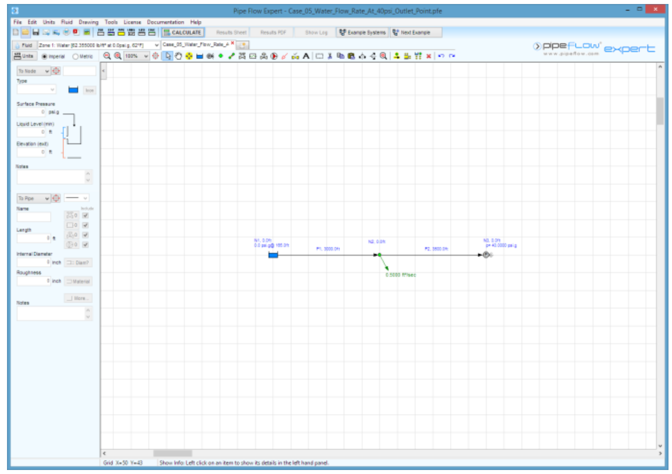
Pipe Flow Expert File: Case_05_Water_Flow_Rate_At_40psi_Outlet_Point.pfe

Problem description:

A pipeline consists of two cast iron asphalt lined pipes. One pipe is 8” diameter x 3000 ft long and the other pipe is 6” diameter x 3500 ft long.

The water source has a surface elevation of 165 ft.
An off-take at the joint between the two pipes removes 0.5 ft^3/s of water from the pipeline.
The pressure at the outlet from the 6” diameter pipe is 40 psi.

Calculate the flow rate in the 8” diameter pipe and the flow rate from the outlet of the 6” diameter pipe.



Fluid data: Water at 62° F.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow rate in 8” diameter pipe (ft^3/s)	1.438	1.4372
Flow rate leaving 6” diameter pipe (ft^3/s)	0.938	0.9372

Commentary:

The published data and the calculated results compare well.

Case 06: Water - Small Network with Loop

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 185, Example problem 5.5.2

Pipe Flow Expert File: Case_06_Water_Small_Network_With_Loop.pfe

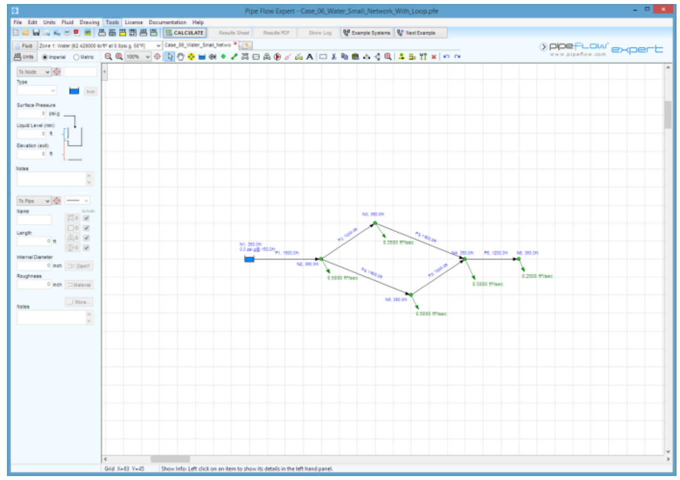
Problem description:

A small pipe network comprises 6 Cast Iron (Asphalt Dipped) pipes.

A water source has a surface elevation of 500 ft.

At each node in the pipe network water is removed from the system.

Calculate the flow rate and head loss in each pipe.
Calculate the pressure and Hydraulic Grade Line at each node.



Fluid data: Water at 50° F. (Assumed)

Result Comparison:

Pipe	Published Flow (ft^3/s)	Pipe Flow Expert (ft^3/s)
Pipe 1	2.100	2.1000
Pipe 2	0.824	0.8244
Pipe 3	0.474	0.4744
Pipe 4	0.776	0.7756
Pipe 5	0.276	0.2756
Pipe 6	0.249	0.2500

Pipe	Published Head Loss (ft)	Pipe Flow Expert Head Loss (ft)
Pipe 1	23.95	23.96
Pipe 2	11.39	11.40
Pipe 3	5.98	5.97
Pipe 4	15.21	15.21
Pipe 5	2.17	2.16
Pipe 6	10.94	10.94

Node	Published Press. (lb/in^2)	Pipe Flow Expert Press. (lb/in^2)
N1	n/a	n/a
N2	54.6	54.6424
N3	49.7	49.7020
N4	47.1	47.1120
N5	48.0	48.0499
N6	42.4	42.3693

Node	Published data HGL. (ft)	Pipe Flow Expert HGL. (ft)
N1	500.0	500.00
N2	476.0	476.04
N3	464.7	464.65
N4	458.7	458.67
N5	460.8	460.83
N6	447.7	447.73

Commentary:

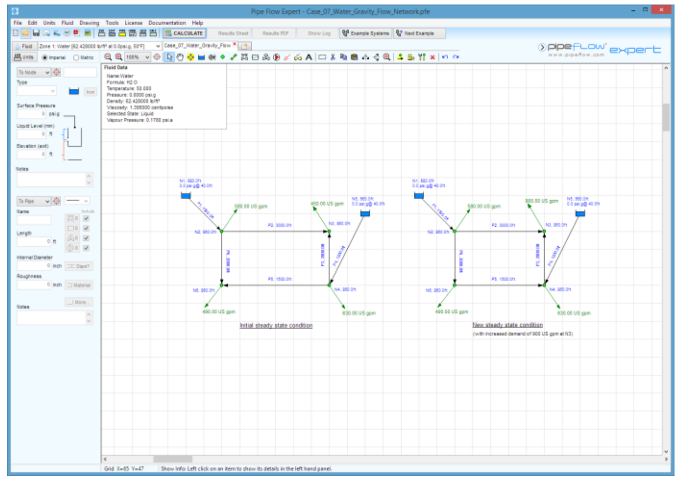
The published data and the calculated results compare very well.

Case 07: Water - Gravity Flow Network *- Initial and Increased Demands*

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 437, Example problem 12.4

Pipe Flow Expert File: Case_07_Water_Gravity_Flow_Network.pfe

Problem description:
Water is supplied from two elevated reservoirs to various outlet points in a pipe network. Initially the outflow demands of the network are 580 US gpm, 450 US gpm, 630 US gpm and 490 US gpm. A new situation arises where the demand at one outflow point must be increased from 450 US gpm to 900 US gpm to meet a need for fire suppression.



1. For the initial flow condition calculate the flow rate and head loss for each pipe, the pressure and HGL (Hydraulic grade line) at each node point.

2. When the additional flow is being supplied to meet the fire suppression requirement calculate the pressure at the node where the 900 US gpm leaves the network.

Fluid data: Water at 50° F (assumed).

Result Comparison:

Pipe	Published Flow (US gpm)	Pipe Flow Expert (US gpm)
Pipe 1	1447.0	1446.88
Pipe 2	389.0	388.82
Pipe 3	61.2	61.18
Pipe 4	703.0	703.12
Pipe 5	11.7	11.95
Pipe 6	478.0	478.05

Pipe	Published Head Loss (ft)	Pipe Flow Expert Head Loss (ft)
Pipe 1	15.61	15.61
Pipe 2	8.08	8.08
Pipe 3	0.19	0.19
Pipe 4	3.49	3.50
Pipe 5	0.02	0.01
Pipe 6	7.90	7.90

Node	Published Press. (lb/in²)	Pipe Flow Expert Press. (lb/in²)
N1	17.33	17.3411
N2	62.57	62.5911
N3	59.07	59.0947
N4	59.15	59.1776
N5	17.33	17.3411
N6	59.15	59.1740

Node	Published data HGL. (ft)	Pipe Flow Expert HGL. (ft)
N1	1020.0	1020.00
N2	1004.4	1004.39
N3	996.3	996.31
N4	996.5	996.50
N5	1000.0	1000.00
N6	996.5	996.49

Commentary:

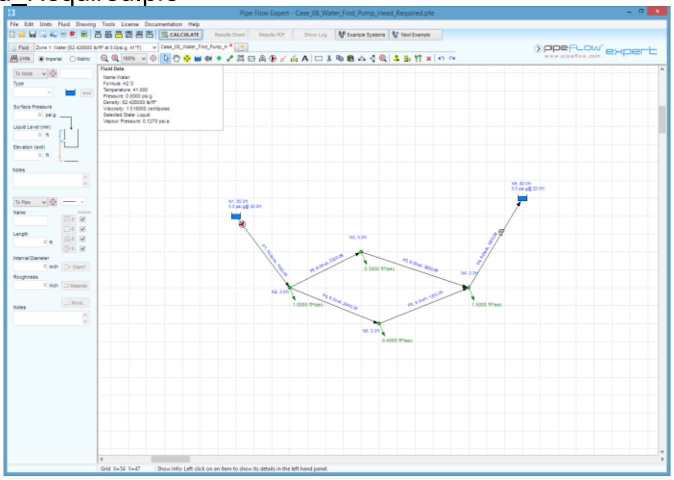
The published data and the calculated results compare very well.
The full analytical results for situation where the increased flow rate of 900 US gpm is delivered are not published, however the text notes that the new pressure head at the outlet point with this increased flow rate has fallen to 127.8 ft.

When the increased outlet flow is occurring, the flow direction in pipe P5 will be reversed due to the change in pressures at N4 and N6. Pipe Flow Expert reports the new pressure at N3 as 127.80 ft. This result agrees with the published text.

Case 08: Water - Find Pump Head Required

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 220, Example problem 5.30

Pipe Flow Expert File: Case_08_Water_Find_Pump_Head_Required.pfe



Problem description:

A small pipe network connects two reservoirs which have different water surface levels.

The main water source (lowest reservoir) has a surface elevation of 90 ft.
The highest reservoir has a surface elevation of 100 ft.

At each node in the pipe network water is removed from the system.

A pump supplies water from the lowest reservoir to the system.

When all out flow demands are being met calculate the pump head required to supply the network without any flow entering or leaving the highest reservoir.

Fluid data: Water at 41° F. (5° C Assumed)

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pump head required (ft)	51.0	50.631 (100.000 – 49.369)

Commentary:

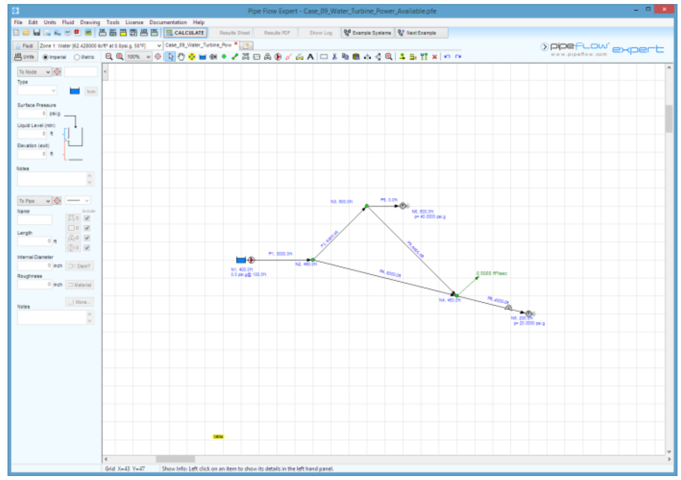
The published data and the calculated results compare very well.
To model this situation in Pipe Flow Expert a fixed head increase pump was used to add 100 ft hd to the system.
A flow control valve was placed on the pipe leading to the highest reservoir, to represent the requirement that zero flow should occur in this pipe the flow control flow rate was 0.0001 ft³/s (smallest allowable value).
The differential head introduced by the flow control valve was subtracted from the fixed 100 ft head added to the system to obtain the actual head that would be required from actual pump that would be installed in the system.

Case 09: Water - Turbine Power Available *- in 20 psi outlet leg*

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 222, Example problem 5.37

Pipe Flow Expert File: Case_09_Water_Turbine_Power_Available.pfe

Problem description:



Water is pumped from a reservoir with a 500 ft surface elevation to an outlet point at 600 ft elevation.
This outlet point must provide water at 40 psig pressure.
An outlet at 450 ft elevation provides 0.5 ft³/s of water at 0.0 psig.
A further outlet at 200 ft elevation provides 1.0 ft³/s of water at 20.0 psig.

1. Calculate the flow rate available from the 40 psig outlet point.

2. What head could be recovered by a turbine positioned in the 20 psig outlet leg, while the outlet flow and pressure demand are still being met?

Fluid data: Water at 50° F (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow rate from 40 psig outlet point (ft³/s)	0.976	0.9728
Head available to be recovered by a turbine (ft)	403.3	403.13

Commentary:

The published data and the calculated results compare well.

Case 10: Water - Eight Pipe Network with Pumps and Local Losses

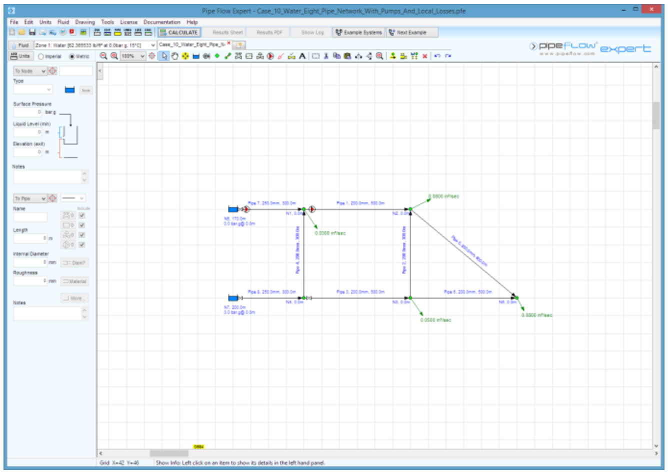
Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 100, Example problem 4.6

Pipe Flow Expert File: Case_10_Water_Eight_Pipe_Network_With_Pumps_And_Local_Losses.pfe

Problem description:

A network of 8 interconnected pipes delivers water from two reservoirs to outlet demands at various pipework junctions.
The network includes 2 pumps, two globe valves and a meter.
The network has two closed loops and one open loop.

Calculate the flow rate in each individual pipe.



Fluid data: Water at 15° C (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Q1 Flow rate (m³/s)	0.103	0.1032
Q2 Flow rate (m³/s)	0.014	0.0139
Q3 Flow rate (m³/s	0.107	0.1068
Q4 Flow rate (m³/s	0.078	0.0763
Q5 Flow rate (m³/s	0.037	0.0371
Q6 Flow rate (m³/s	0.043	0.0429
Q7 Flow rate (m³/s	0.055	0.0568
Q8 Flow rate (m³/s)	0.185	0.1832

Commentary:

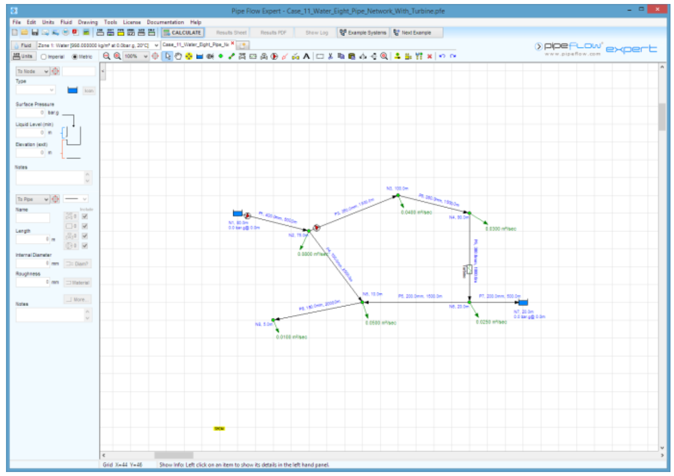
The published data and the calculated results compare well.

Case 11: Water - Eight Pipe Network with Two Pumps and a Turbine

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 115, Example problem 4.14

Pipe Flow Expert File: Case_11_Water_Eight_Pipe_Network_With_Turbine.pfe

Problem description:
Water is pumped from a single source around a network of 8 interconnected pipes. A booster pump is used get the water over hills which are at a higher elevation than the source.
A turbine is placed in the system to recovery the extra head after the water has been moved over the hill crest.
The network has one closed loops and one open loop.



1. Calculate the flow rate & head loss in each pipe.

2. Calculate the pressure and the hydraulic grade line at each node point.

Fluid data: Water at 20° C (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Q1 Flow rate (m³/s)	0.330	0.3309
Q2 Flow rate (m³/s)	0.217	0.2180
Q3 Flow rate (m³/s	0.177	0.1780
Q4 Flow rate (m³/s	0.033	0.0330
Q5 Flow rate (m³/s	0.027	0.0270
Q6 Flow rate (m³/s	0.147	0.1480
Q7 Flow rate (m³/s	0.095	0.0959
Q8 Flow rate (m³/s)	0.010	0.0100

Data Item	Published data	Pipe Flow Expert
Head Loss (m)	8.78	8.800
Head Loss (m)	23.02	23.128
Head Loss (m)	15.39	15.472
Head Loss (m)	76.55	76.346
Head Loss (m)	6.93	6.920
Head Loss (m)	15.87	15.984
Head Loss (m)	27.83	28.166
Head Loss (m)	5.89	5.865

Data Item	Published data	Pipe Flow Expert
N1 Pressure (kPa)	416.02	416.851
N2 Pressure (kPa)	90.10	90.810
N3 Pressure (kPa)	37.30	37.216
N4 Pressure (kPa)	303.00	305.807
N5 Pressure (kPa)	272.90	275.665
N6 Pressure (kPa)	294.30	297.342

Data Item	Published data	Pipe Flow Expert
HGL (m)	117.45	117.592
HGL (m)	109.19	109.279
HGL (m)	93.80	93.803
HGL (m)	40.9	41.246
HGL (m)	47.83	48.166
HGL (m)	35.83	35.381

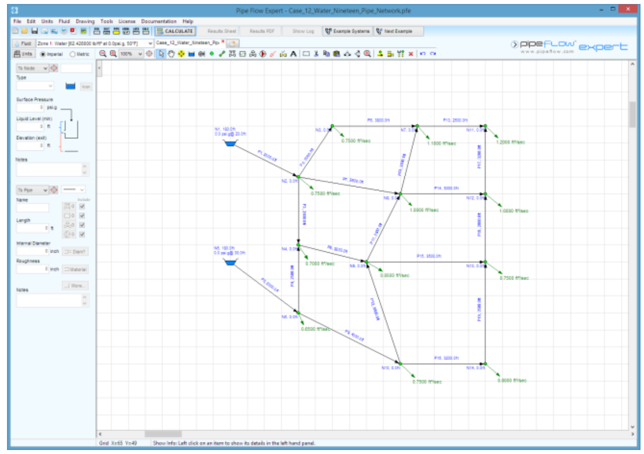
Commentary:

The published data and the calculated results compare well.
The reference contains a printing error on the network diagram:
The outflow from node 4 is shown as 0.025 m³/s the calculation input table shows a value of 0.050 m³/s.
The outflow from node 5 is shown as 0.050 m³/s the calculation input table shows a value of 0.025 m³/s.
The Pipe Flow Expert results are based on outflows from node 4 and node 5 as shown in the calculation input table.

Case 12: Water - Nineteen Pipe Network

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 423, Example problem 12.3.2

Pipe Flow Expert File:
Case_12_Water_Nineteen_Pipe_Network.pfe



Problem description:
Water is supplied from two reservoirs to a nineteen pipe network. The pipes are connected at twelve node points. Out flows from the network occur at each node point.

Find the flow rate and head loss for each pipe.
Find the pressure at each node point.

Fluid data: Water at 50° F (assumed).

Result Comparison:

Pipe	Published Flow (ft^3/s)	Pipe Flow Expert (ft^3/s)
P 1	5.30	5.2999
P 2	2.17	2.1717
P 3	0.41	0.4062
P 4	2.13	2.1287
P 5	5.00	5.0001
P 6	1.42	1.4217
P 7	1.97	1.9720
P 8	1.83	1.8349
P 9	2.22	2.2214
P 10	0.55	0.5450
P 11	0.50	0.5028
P 12	0.43	0.4291
P 13	0.87	0.8667
P 14	0.93	0.9298
P 15	0.91	0.9112
P 16	1.04	1.0423
P 17	0.33	0.3333
P 18	0.40	0.4035
P 19	0.24	0.2423

Pipe	Published Head Loss (ft)	Pipe Flow Expert Head Loss (ft)
P 1	24.26	24.28
P 2	10.96	10.96
P 3	0.60	0.60
P 4	13.19	13.19
P 5	21.67	21.68
P 6	9.29	9.29
P 7	15.95	15.95
P 8	12.70	12.71
P 9	22.89	22.90
P 10	4.30	4.30
P 11	2.65	2.65
P 12	3.00	3.00
P 13	7.34	7.34
P 14	10.06	10.06
P 15	11.29	11.30
P 16	13.32	13.33
P 17	1.59	1.59
P 18	1.41	1.41
P 19	0.97	0.97

Node	Published Press. (lb/in^2)	Pipe Flow Expert (lb/in^2)
N1	n/a	n/a
N2	76.15	76.1808
N3	71.40	71.4275
N4	75.89	75.9223
N5	81.61	81.6406
N6	n/a	n/a
N7	67.38	67.3985

Node	Published Press. (lb/in^2)	Pipe Flow Expert (lb/in^2)
N8	69.24	69.2468
N9	70.39	70.4121
N10	71.69	71.7123
N11	64.20	64.2159
N12	64.89	64.9034
N13	65.50	65.5142
N14	65.92	65.9343

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

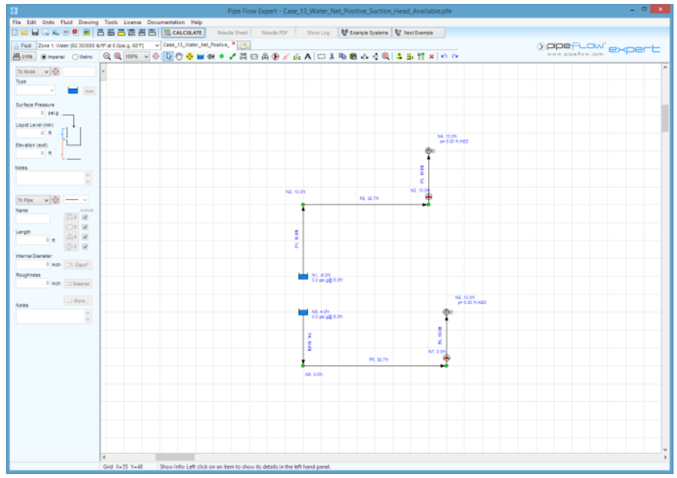
Case 13: Water - Net Positive Suction Head Available *- Example 1 & 2*

Reference: Cameron Hydraulic Data **,** 18th Edition, 1994, Ingersoll-Dresser Pumps. Page 1-13, Example No 1 and Example No 2

Pipe Flow Expert File: Case_13_Water_Net_Positive_Suction_Head_Available.pfe

Problem description:

A pump is used to deliver water to a distribution system. The friction loss through the suction line is assumed as 2.92 ft head in all cases.



Example No 1:
The water source is 10 ft below the pump.
The pressure on the surface of the fluid is atmospheric, 14.696 psia.

Find the NPSHa and the suction lift required.

Example No 2:
The water source is 10 ft above the pump.
The pressure on the surface of the fluid is atmospheric, 14.696 psia.

Find the NPSHa and the suction head available.

Fluid data: Water at 68°F at sea level.

Result Comparison:

Data Item Example 1	Published data	Pipe Flow Expert
NPSH available (ft. hd)	20.26	20.26
Suction Lift (ft. hd)	12.92	-12.90 HGL at pump

Data Item Example 2	Published data	Pipe Flow Expert
NPSH available (ft. hd)	40.26	40.26
Suction Head (ft. hd)	7.08 (positive)	7.07 HGL at pump

Commentary:

The published data and the calculated results compare well.
These are very simple examples where the friction loss through the pipes is assumed, not calculated.
To model these situations in Pipe Flow Expert a pipe diameter and flow rate was chosen and then the pipe length was varied until the frictional loss through the pipes of 2.92 ft hd was obtained.
The discharge pipework was modeled with a similar pipe size and a 10 ft lift on the discharge side of the pump.
This allows the HGL at the node where the pump has been located to be used for comparison with the published suction head available.

Case 14: Water - Net Positive Suction Head Available *- Example 2*

Reference: Cameron Hydraulic Data **,** 18th Edition, 1994, Ingersoll-Dresser Pumps. Page 1-14, Example No 3.

Pipe Flow Expert File: Case_14_Water_Net_Positive_Suction_Head_Available.pfe

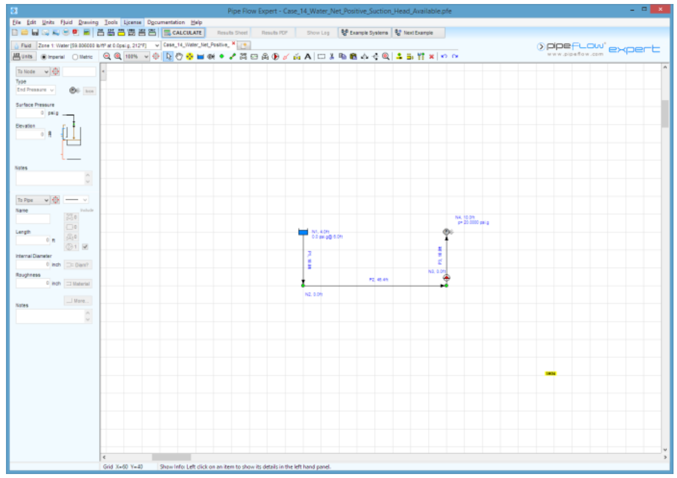
Problem description:

A pump is used to deliver water to a distribution system. The friction loss through the suction line is stated to be 2.92 ft head.

The water source is 10 ft above the pump.
The pressure on the surface of the fluid is atmospheric, 14.696 psi.a.

The fluid is boiling water at 212°F.

Find the NPSHa and the suction head available.



Fluid data: Water at 212°F at sea level.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
NPSH available (ft. hd)	7.08	7.08
Suction Head (ft. hd)	7.08 (positive)	7.08 HGL at pump

Commentary:

The published data and the calculated results compare well.
This is a very simple example where the friction loss through the pipes is stated.
To model this situation in Pipe Flow Expert, pipe diameters and pipe lengths have been set to give a total friction loss in the suction pipes of 2.92 ft hd, when the pump flow rate is set to 5 ft^3/sec.
The discharge pipework was modeled with a similar size pipe and a 10 ft lift on the discharge side of the pump. This allows the HGL at the node where the pump has been located to be used for comparison with the published suction head available.

Note: The vapor pressure of the boiling fluid is equal to the fluid surface pressure, so the pressure on the fluid surface does not add to the NPSHa.

Case 15: Water - Net Positive Suction Head Available *- Example 4*

Reference: Cameron Hydraulic Data **,** 18th Edition, 1994, Ingersoll-Dresser Pumps. Page 1-15, Example No 4.

Pipe Flow Expert File: Case_15_Water_Net_Positive_Suction_Head_Available.pfe

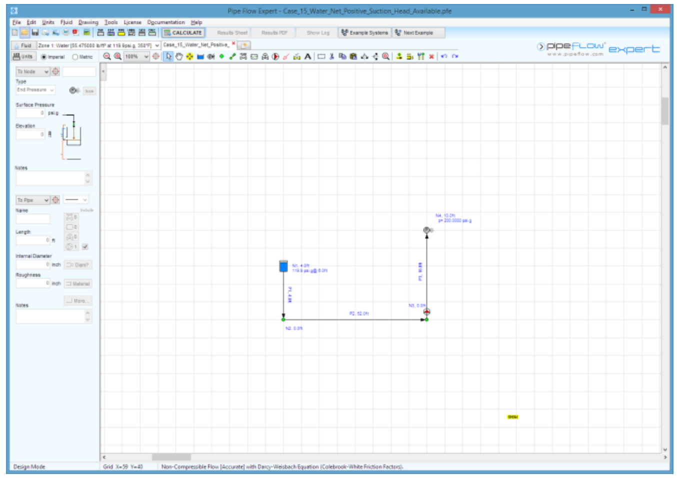
Problem description:

A pump is used to deliver water to a distribution system. The friction loss through the suction line is stated to be 2.92 ft head.

The water source is 10 ft above the pump.
The fluid is contained in a closed vessel which is under pressure.

The pressure on the surface of the fluid is 119.90 psig.

Find the NPSHa and the suction head available.



Fluid data: Water at 350°F, with specific gravity of 0.8904 and a vapor pressure of 134.60 psi.a.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
NPSH available (ft. hd)	7.08	7.07
Suction Head (ft. hd)	317.69 (positive)	318.31 HGL at pump

Commentary:

The published data and the calculated results compare well.
This is a very simple example where the friction loss through the pipes is stated.
To model this situation in Pipe Flow Expert pipe diameters and pipe lengths have been set to give a total friction loss in the suction pipes of 2.92 ft hd, when the pump flow rate is set to 5 ft³/sec.
The discharge pipework was modeled with a similar size pipe and a 10 ft lift on the discharge side of the pump to a required delivery pressure of 200 psi.g.
This allows the HGL at the node where the pump has been located to be used for comparison with the published suction head available.

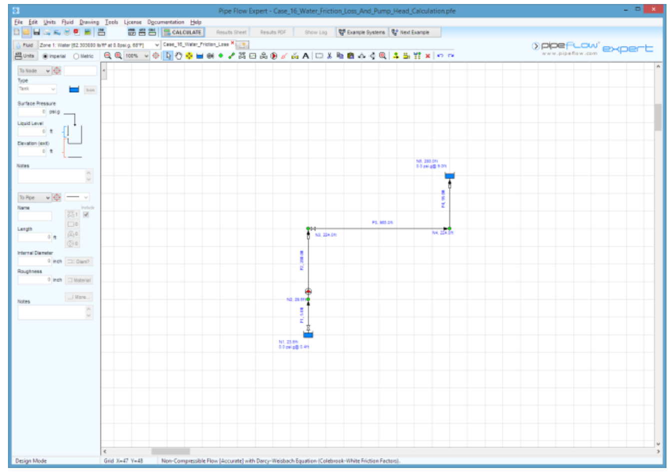
Case 16: Water - Friction Loss and Pump Head Calculation

Reference: Cameron Hydraulic Data **,** 18th Edition, 1994, Ingersoll-Dresser Pumps. Page 3-9, Friction – Head Loss – Sample Calculation.

Pipe Flow Expert File: Case_16_Water_Friction_Loss_And_Pump_Head_Calculation.pfe

Problem description:

A pump is used to deliver water through a 1250 ft long discharge pipe at a flow rate of 200 US gpm.



The water source is approximately 5 ft below the pump.
The pump is at 28.62 ft elevation.
The liquid level above the suction pipe is 0.38 ft.
The elevation of the water level in the discharge tank is 289 ft.

The pipeline friction calculation has to include for:
A foot valve and strainer,
Two long radius elbows,
A swing check valve,
A gate valve,
An exit condition to the discharge tank.

Find the total suction lift.
Find the head loss of the fittings on the discharge line.
Find the total pump head required.

Fluid data: Water at 68°F (Assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Suction Lift (ft. hd)	5.35	5.34
Discharge Fittings Loss (ft. hd)	1.52	1.54
Total Pump Head (ft. hd)	295.35	295.504

Commentary:

The published data and the calculated results compare well.

Case 17: Water - Large Diameter Cast Iron Pipe

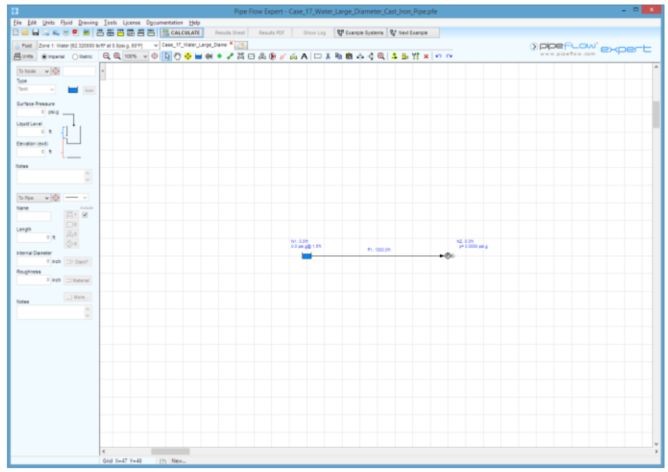
Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S. , Page 209, Example problem 9.64

Pipe Flow Expert File: Case_17_Water_Large_Diameter_Cast_Iron_Pipe.pfe

Problem description:

A 96” new cast iron pipe has a frictional pressure loss of 1.5 ft. hd per 1000 ft of length, when carrying water at 60°F.

Calculate the discharge capacity of the pipe.



Fluid data: Water at 60°F (v = 1.21 x 10^{-5} ft^{2}/s).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow capacity (ft^3/s)	397	395.5420
Pressure loss per 1000 ft. (ft. hd)	1.5	1.50
Friction factor	0.0124	0.01247

Commentary:

The published data and the calculated results compare well.

Case 18: SAE 10 Oil - Pressure Loss per Mile

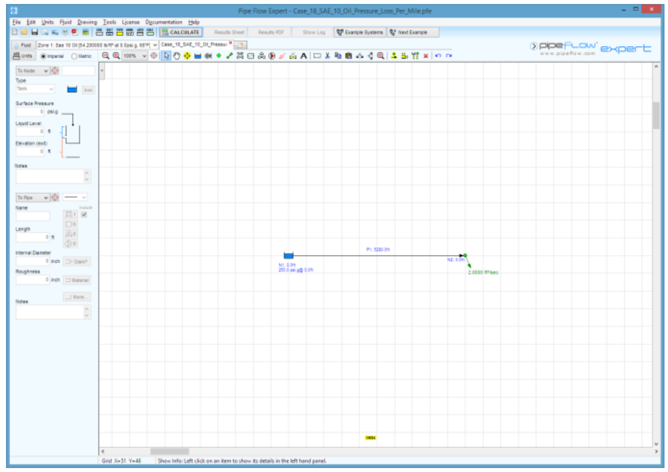
Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 211, Example problem 9.68

Pipe Flow Expert File: Case_18_SAE_10_Oil_Pressure_Loss_Per_Mile.pfe

Problem description:

A 6" wrought iron pipe carries SAE 10 oil at 68°F.

Calculate the pressure loss per mile of pipe.



Fluid data: SAE 10 at 68°F.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure loss per mile. (psi)	244	241.3314
Reynolds number	5035	5047
Friction factor	0.038	0.03766

Commentary:

The published data and the calculated results compare well.

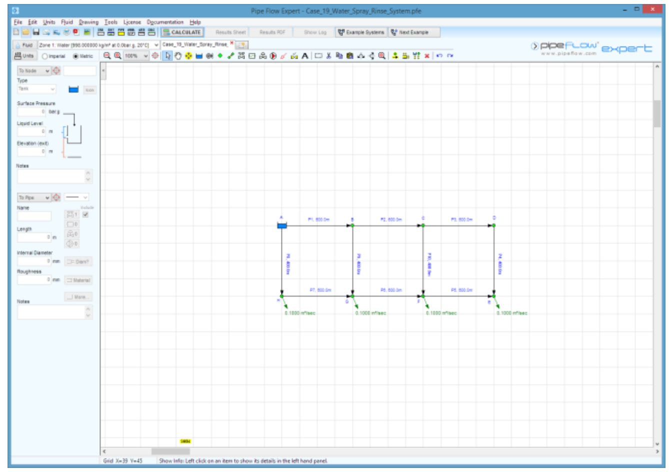
Case 19: Water - Spray Rinse System

Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 322, Example problem 13.5

Pipe Flow Expert File: Case_19_Water_Spray_Rinse_System.pfe

Problem description:

Water is pumped from a single source around a spray rinse pipe network.
Out flow demands are specified at 4 points of the network.



The published text is based on a solution using the empirical **Hazen-Williams** equation to calculate friction head losses.
Assume C = 120 for all pipes.

The published results are based on the **Hardy Cross** method which has been used to balance the flow around the loops.

Calculate the flow rate each individual pipe.

Fluid data: Water at 20° C (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
AB Flow rate (m³/s)	0.215	0.2182
BG Flow rate (m³/s)	0.095	0.0962
GH Flow rate (m³/s	0.085	0.0818
HA Flow rate (m³/s	0.185	0.1818
BC Flow rate (m³/s	0.120	0.1219
CF Flow rate (m³/s	0.064	0.0646
FG Flow rate (m³/s	0.080	0.0781
GB Flow rate (m³/s)	0.095	0.0962
CD Flow rate (m³/s)	0.056	0.0574
DE Flow rate (m³/s)	0.056	0.0574
EF Flow rate (m³/s)	0.044	0.0426
FC Flow rate (m³/s)	0.064	0.0646

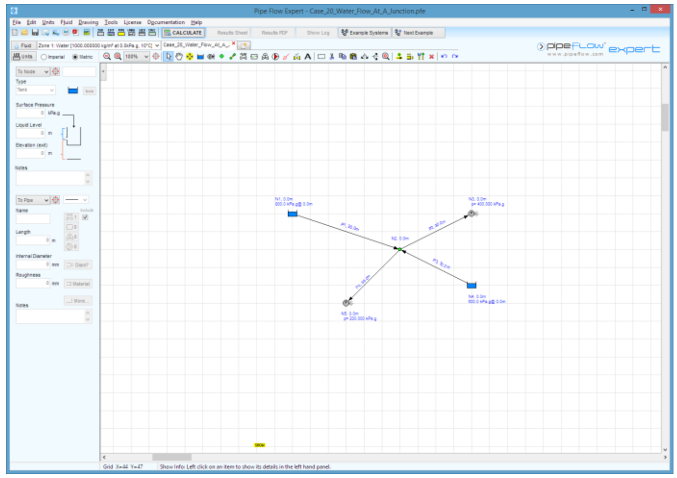
Commentary:

The published data and the calculated results compare well.
The Pipe Flow Expert results have been rounded to 3 decimal places for comparison purposes.
The Pipe Flow Expert results have been based on calculations using the Darcy-Weisbach equation, which provides more accurate results than those obtained by using the Hazen Williams equation.

Case 20: Water - Flow at a Junction

Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 339, Example problem 13.23

Pipe Flow Expert File: Case_20_Water_Flow_At_A_Junction.pfe



Problem description:

Four cast iron pipes connect at a junction.
The pressure at the end of each pipe which is not connected to the junctions are:
P1 = 800 kPa
P2 = 400 kPa
P3 = 600 kPa
P4 = 200 kPa

The internal roughness of the cast iron pipe has been set to 0.250 mm to simulate the friction factor of 0.0294 assumed in the published text.

Calculate the flow rate in each individual pipe.
Calculate the pressure at the junction.

Fluid data: Water at 10° C (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Q1 Flow rate (m^3/s)	+0.0181	+0.0182
Q2 Flow rate (m^3/s)	-0.0104	-0.0104
Q3 Flow rate (m^3/s)	+0.0104	+0.0104
Q4 Flow rate (m^3/s)	-0.0181	-0.0182
Pressure at Junction (kPa)	500	500.0000

Commentary:

The published data and the calculated results compare well.
Flow to the junction has been indicated by a positive flow rate value.
Flow away from the junction has been indicated by a negative flow rate value.

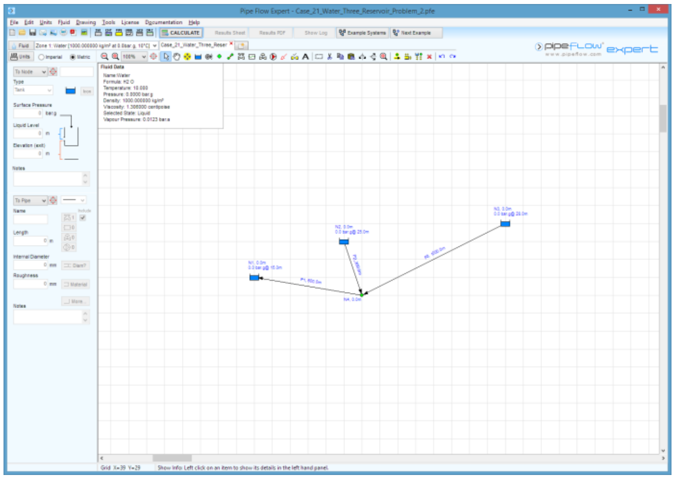
Note: The flow balance to and away from the junction is maintained.

Case 21: Water - Three Reservoir Problem 2

Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 309, Example problem 12.11

Pipe Flow Expert File: Case_21_Water_Three_Reservoir_Problem_2.pfe

Problem description:



Three reservoirs with fluid surface elevations of 15 m, 25 m and 28 m are connected by 3 pipes

Pipe 1 connected to the lowest reservoir is 300 mm diameter x 600 m long.
The internal pipe roughness is 3.0 mm.

Pipe 2 connected to the middle reservoir is 200 mm diameter x 300 m long.
The internal pipe roughness is 1.0 mm.

Pipe 3 connected to the highest reservoir is 200 mm diameter x 1000 m long.
The internal pipe roughness is 1.0 mm.

Calculate the flow rate in each individual pipe.
Calculate the HGL at the pipe junction.

Fluid data: Water at 10° C (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pipe 1 Flow rate (l/s)	-77.8	-78.671
Pipe 2 Flow rate (l/s)	+46.2	+46.662
Pipe 3 Flow rate (l/s)	+31.7	+32.009
HGL at Junction (m hd)	19.7	19.811

Commentary:

The published data and the calculated results compare well.
Flow to the junction has been indicated by a positive flow rate value.
Flow away from the junction has been indicated by a negative flow rate value.

The method of solution proposed in the text is to assume an elevation for the pipe junction, then calculate the three flow rates. If the flow rates are not balanced the elevation of the pipe junction is adjusted and the calculation is repeated.
Only three iterations of the node elevation are used in the text 19.0 m, 20.0 m and 19.7 m, the calculation is halted at this point.

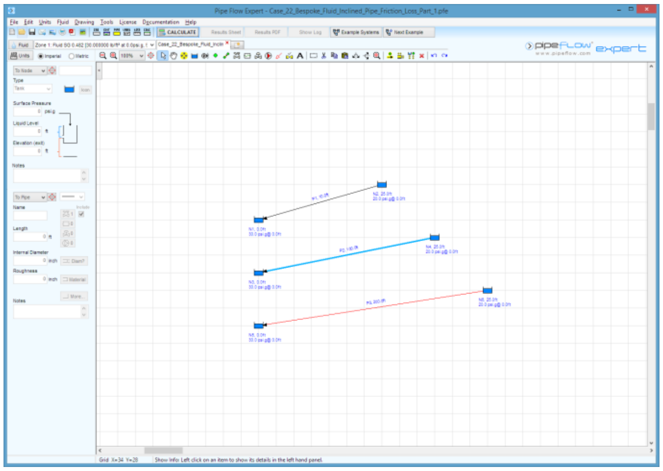
Note: The flow balance to and away from the junction is maintained.

Case 22: Bespoke Fluid - Inclined Pipe Friction Loss

Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 190, Example problem 8.125

Pipe Flow Expert Files:
Case_22_Bespoke_Fluid_Inclined_Pipe_Friction_Loss_Part_1.pfe
Case_22_Bespoke_Fluid_Inclined_Pipe_Friction_Loss_Part_2.pfe

Problem description:



An inclined pipe connects two points at which the fluid pressure is 20 psi and 30 psi.
The elevation of the 20 psi point is 25 ft above the elevation of the 30 psi pressure.
Assume flow direction from the upper point to the lower point.

The length, diameter and internal roughness of the pipe are unspecified.

1. If the fluid density is 30 lbs/ft³ calculate the friction loss in the pipe. Check the direction of the flow.

2. If the fluid density is 100 lbs/ft³ calculate the friction loss in the pipe. Check the direction of the flow.

Fluid data: Fluid density as stated above.

Result Comparison:

Fluid density	Data Item	Published data	Flow Direction	Pipe Flow Expert	Pipe Flow Expert
30 lbs/ft³	Pipe Friction head (ft)	-23.0	From lower point to upper point	-23.0	Correctly reversed flow direction of the pipes

Fluid density	Data Item	Published data	Flow Direction	Pipe Flow Expert	Pipe Flow Expert
100 lbs/ft³	Pipe Friction head (ft)	10.6	From upper point to lower point	10.6	Confirmed flow direction of the pipes

Commentary:

The published data and the calculated results compare well.
The length, diameter and internal roughness of the pipe have no effect on the Pipe Friction Head in this example.
The pipe friction head is dependant on the pressure difference, the difference in elevations and the density of the fluid in the pipe.
The flow rate in a particular pipe must produce a frictional loss equal to the pressure difference between the two points, therefore if the pipe characteristics are changed the flow rate in the pipe will change.

Several different pipe diameters, pipe length and internal roughness values were used in the Pipe Flow Expert calculations to ensure that these factors did not effect the calculations.
In each case Pipe Flow Expert solved the individual pipe calculation by finding and using a different flow rate which would produce the identical Pipe Friction Head.

Case 23: Water - Pressure Loss around a Loop

Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 280, Example problem 11.7

Pipe Flow Expert File: Case_23_Water_Pressure_Loss_Around_A_Loop.pfe

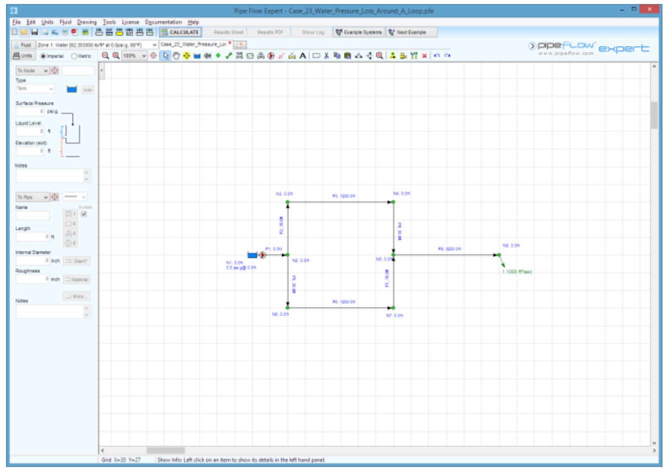
Problem description:

A pipe system contains a loop of unequal size pipes.

The portion of the loop with larger pipe sizes will handle a greater portion of the total flow rate passing through the loop.

The flow rate and pressure entering the loop are specified.

Find the pressure at a point in the pipework 3200 ft downstream of the loop.



Fluid data: Water at 68°F (μ= 2.11 x 10^{-5} lb · s/ft^2).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure at 3200 ft downstream (psig)	88.2	88.3602
Pressure leaving the loop (psig)	93.9	93.9151
Flow rate around upper loop (ft^3/s)	0.3508	0.3491
Flow rate around lower loop (ft^3/s)	0.7492	0.7509

Commentary:

The published data and the calculated results compare well.

Case 24: Bespoke Fluid - Head Required for flow of 20 l/sec

Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 286, Example problem 11.17

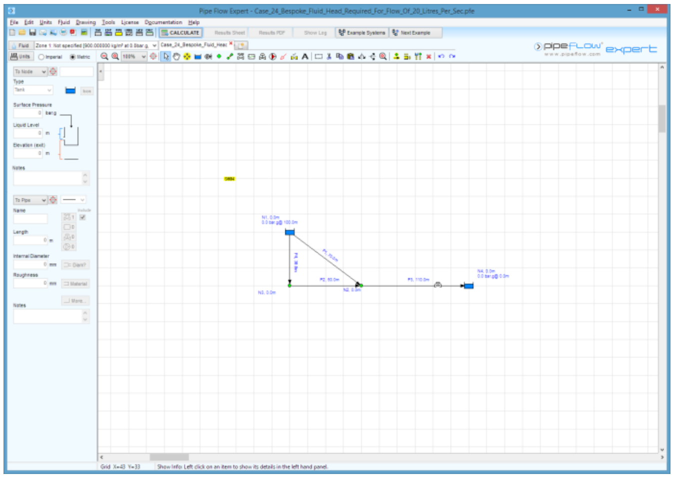
Pipe Flow Expert File: Case_24_Bespoke_Fluid_Head_Required_For_Flow_Of_20_Litres_Per_Sec.pfe

Problem description:

A pipe system connects two tanks in which the fluid levels are different.
Two pipes connected to the tank with the highest fluid level join together at some point and the combined flow from these two pipes is carried by a third pipe towards the tank with the lowest fluid level.

The flow rate of fluid entering the tank with the lowest fluid level is 20 l/s.

Find the difference in fluid levels between the two tanks.



Fluid data: μ = 5 x 10^{-3} Pa · s. Specific gravity = 0.9

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Difference in fluid level (m)	49.06	48.757 (100 -51.243)
Flow rate in pipe 1 (l/s)	1.90	1.894
Flow rate in pipe 2 (l/s)	18.0	18.106
Combined flow rate pipes 1 & 2 (l/s)	19.90	20.000

Commentary:

The published data and the calculated results compare well.
The published text uses a friction factor of 0.114 read from a chart to calculate the head loss for both pipes 1 and 3.

All pipes have different diameters and different inner roughness values and carry different flow rates.
Pipe Flow Expert calculates individual friction factors for each pipe from the Colebrook-White equation.
The calculated friction factors are 0.115 (pipe 1) and 0.113 (pipe 2).
This gives a slightly different calculated head loss for each pipe, but the total fluid head difference in the system is very similar to the published text.

To model this system using Pipe Flow Expert a difference of 100 m between tank fluid levels was used.
A flow control valve was added to the pipe which carries the total flow.
The flow rate setting of this control valve was 20 l/s.
The difference in fluid levels needed to supply a flow rate of 20 l/s can be found by subtracting the pressure introduced by the flow control valve from the difference in the fluid levels. e.g. 100 m – 51.243 m = 48.757 m

Case 25: Ethanol - Laminar Flow

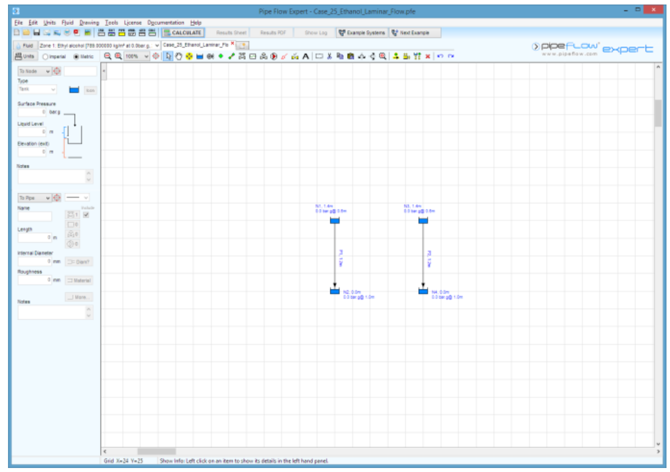
Reference: 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 207, Example problem 9.54

Pipe Flow Expert File: Case_25_Ethanol_Laminar_Flow.pfe

Problem description:

Ethanol at 20°C is transferred from an upper tank to a lower tank via a 2 mm pipe.
The pipe is 1.2 m long, with 0.8 m of pipe dipping into the lower tank.

Calculate the flow rate between the tanks.



Fluid data: Ethanol at 20°C (μ= 1.20 x 10^{-3} Pa · s), density = 788 kg/m^3

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow from upper tank (l/hr) – Pipe 1	7.59	7.60
Flow from upper tank (l/hr) – Pipe 2	7.59	7.60

Commentary:

The published data and the calculated results compare well.
The published text does not list an inner roughness for the pipe.

The flow in this problem is laminar, so the friction factor is independent of the inner roughness of the pipe.
The calculated Reynolds number of 883 indicates that the flow type is well within the laminar flow range.
Two pipes with different inner roughness values (0.046000 mm and 0.000001 mm) were used in the Pipe Flow Expert model to ensure that the variation in the inner roughness of the pipe did not affect the flow rate calculation.

Case 26: Water - Asbestos Cement Pipe Friction Loss

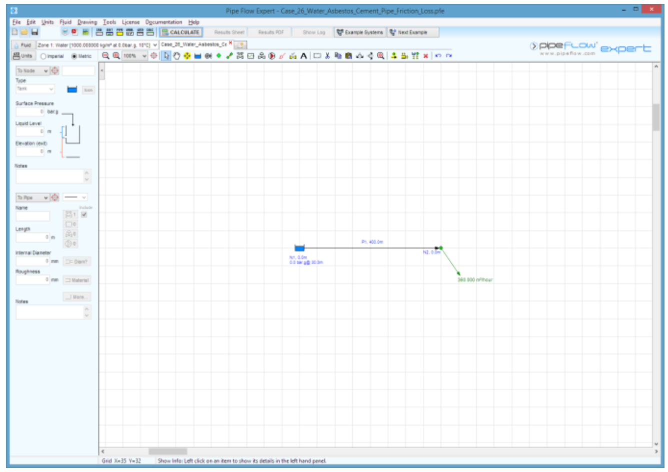
Reference: Basic Principles for the Design of Centrifugal Pump Installations**,** SIHI Group, 1998, SIHI-HALBERG. Page 134, Example of Head Loss Calculation

Pipe Flow Expert File: Case_26_Water_Asbestos_Cement_Pipe_Friction_Loss.pfe

Problem description:

Water flows along a 400 m long asbestos cement pipe at the rate of 360^3/h.
The pipe designation is DN200.

Find the head loss in the pipe.



Fluid data: Water at 10°C.

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Reynolds number	4.9 x 10^5	487458
Fluid Velocity (m/s)	3.2	3.183
Total Head Loss in pipe (m. hd)	16.4	16.425

Commentary:

The published data and the calculated results compare well.

Case 27: Lubrication Oil - Laminar Flow Example 1

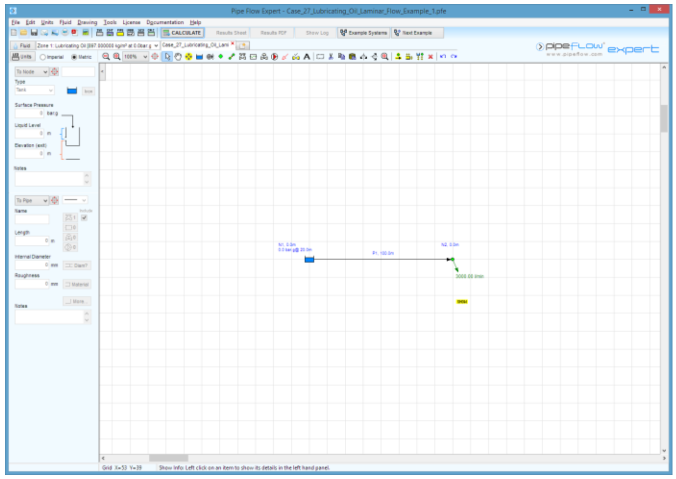
Reference: Flow of Fluids – Technical Paper No 410M, 1999, Crane Co. Page 3-12, Example 1

Pipe Flow Expert File: Case_27_Lubricating_Oil_Laminar_Flow_Example_1.pfe

Problem description:

A 6" diameter schedule 40 steel pipe carries lubricating oil of density 897 kg/m³ and viscosity 450 Centipoise.

Find the pressure drop per 100 meters.



Fluid data: Lubricating Oil, viscosity = 450 Centipoise, density = 897 kg/m³

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure drop per 100 meters (bar g)	1.63	1.6277
Reynolds number	825	824

Commentary:

The published data and the calculated results compare well.

Case 28: Lubrication Oil - Laminar Flow Example 2

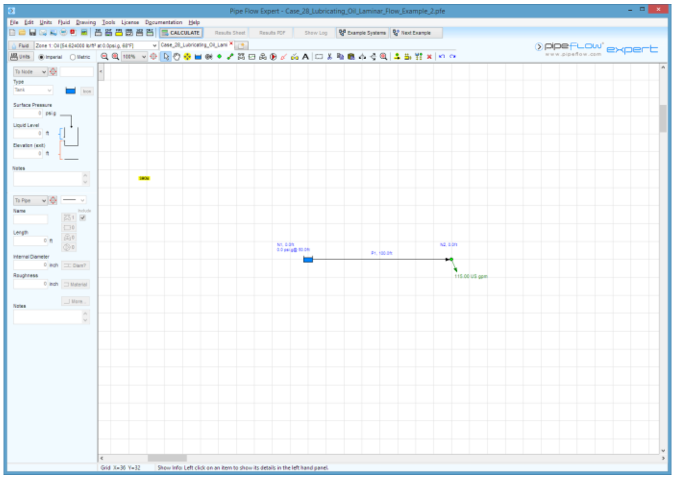
Reference: Flow of Fluids – Technical Paper No 410, 1988, Crane Co. Page 3-12, Example 2.

Pipe Flow Expert File: Case_28_Lubricating_Oil_Laminar_Flow_Example_2.pfe

Problem description:

A 3” diameter schedule 40 carries SAE 10 lube oil at a velocity of 5.0 ft/s

Find the flow rate and the pressure drop per 100 feet.



Fluid data: Oil, viscosity = 95 Centipoise, density = 54.64 lb/ft³

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Flow rate (gpm US)	115	115
Fluid velocity (ft/s)	5.00	4.991
Reynolds number	1100	1092
Pressure drop per 100 feet(psi)	3.40	3.3665

Commentary:

The published data and the calculated results compare well.

Case 29: Water - Bernoulli's Theorem

Reference: Flow of Fluids – Technical Paper No 410M, 1999, Crane Co. Page 4-8, Example 4-14.

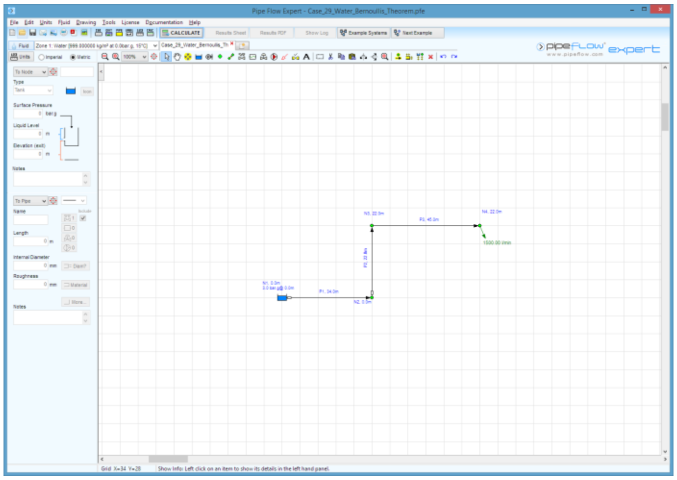
Pipe Flow Expert File: Case_29_Water_Bernoullis_Theorem.pfe

Problem description:

A piping system consisting of 4" and 5" diameter schedule 40 steel pipe carries water at a flow rate of 1500 l/min.

The change in elevation across the system is 22.0 meters.

Find the fluid velocity in the 4" and 5" steel pipes and the pressure difference between the inlet and outlet points of the system.



Fluid data: Water at 15°C

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure difference across the system (bar)	2.60	2.6266 (3.000 – 0.3734)
Fluid velocity in 4" diameter pipe (m/s)	3.04	3.044
Fluid velocity in 5" diameter pipe (m/s)	1.94	1.937

Commentary:

The published data and the calculated results compare well.
The system was modeled in Pipe Flow Expert with a fluid surface pressure of 3.00 bar g at the inlet to the system.
The outlet node had a resulting pressure of 0.3725 bar g.
The pressure difference is obtained by subtracting the outlet pressure from the inlet pressure.

Case 30: Water - Reynolds Number for Smooth Wall Pipe

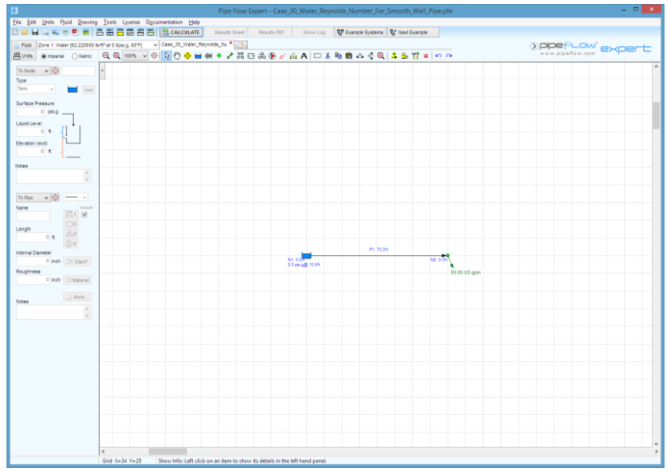
Reference: Flow of Fluids – Technical Paper No 410, 1988, Crane Co. Page 4-1, Example 4-1.

Pipe Flow Expert File: Case_30_Water_Reynolds_Number_For_Smooth_Wall_Pipe.pfe

Problem description:

A 70 foot long 2" diameter plastic pipe (smooth wall) carries water at 80°F. The flow rate is 50 gpm (US).

Find the Reynolds number and the friction factor.



Fluid data: Water at 80°F

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Reynolds number	89600	89702
Friction factor	0.0182	0.0188

Commentary:

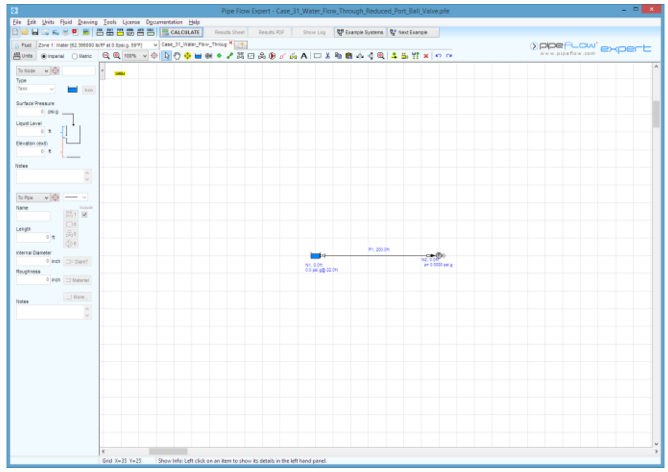
The published data and the calculated results compare well.
Pipe Flow Expert uses the same fluid density and viscosity as the published text to calculate the Reynolds number.
The published text friction factor has been read from a chart for water at 60°F.

Case 31: Water – Flow Through Reduced Port Ball Valve

Reference: Flow of Fluids – Technical Paper No 410, 1988, Crane Co. Page 4-3, Example 4-6.

Pipe Flow Expert File: Case_31_Water_Flow_Through_Reduced_Port_Ball_Valve.pfe

Problem description:



A 200 foot long 3” diameter steel pipe (schedule 40) carries water at 60°F.
The head of fluid in the supply tank is 22 ft.
The piping includes 6 standard 90° elbows and a flanged ball valve with a conical seat.

Find the fluid velocity in the pipe and the rate of discharge.

Fluid data: Water at 60°F

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Fluid Velocity in Pipe (ft/s)	8.5	8.307
Rate of Discharge (gpm US)	196	191.40
Reynolds Number	Not calculated	173201
Friction factor	0.018 (assumed)	0.0195

Commentary:

The published data and the calculated results differ by around 2.4%.
The published data uses an assumed friction factor of 0.018 for a 3” diameter steel pipe.
As a final check in the published data the friction factor is read as from a chart as less than 0.02.
If the chart is read accurately the friction factor is 0.0195.
However the text concludes that difference in the assumed friction factor and the friction factor read from the chart is small enough so as not to require any further correction.
A new valve fitting was created in Pipe Flow Expert to model the flanged ball valve as this item is not included in the database of standard valves and fittings.

Case 32: SAE 10 Lube Oil - Laminar Flow in Valves

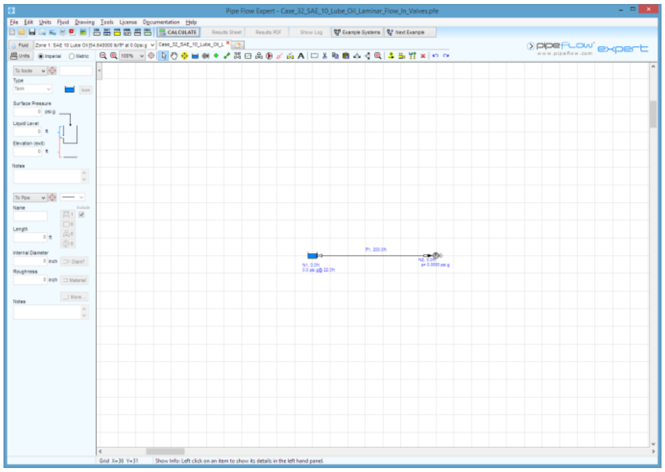
Reference: Flow of Fluids – Technical Paper No 410, 1988, Crane Co. Page 4-4, Example 4-7

Pipe Flow Expert File: Case_32_SAE_10_Lube_Oil_Laminar_Flow_In_Valves.pfe

Problem description:

A 200 foot long 3” diameter steel pipe (schedule 40) carries SAE 10 Lube Oil at 60°F.
The head of fluid in the supply tank is 22 ft.
The piping includes 6 standard 90° elbows and a flanged ball valve with a conical seat.

Find the fluid velocity in the pipe and the rate of discharge.



Fluid data: SAE 10 Lube Oil at 60°F

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Fluid Velocity in Pipe (ft/s)	5.13	5.271
Rate of Discharge (gpm US)	118	121.46
Reynolds Number	1040 (1st Iteration)	1096
Friction factor	0.062 (1st Iteration)	0.05840

Commentary:

The published data and the calculated results differ by around 3%.
The published text acknowledges that the problem has two unknowns and requires a trial and error solution.
The published data results are for the first initial assumption of velocity.
Pipe Flow Expert performs numerous iterations to find a solution which is accurate to within 0.0004 ft head pressure loss.
A new valve fitting was created in Pipe Flow Expert to model the flanged ball valve as this item is not included in the database of standard valves and fittings.

Case 33: SAE 70 Lube Oil - Laminar Flow in Valves

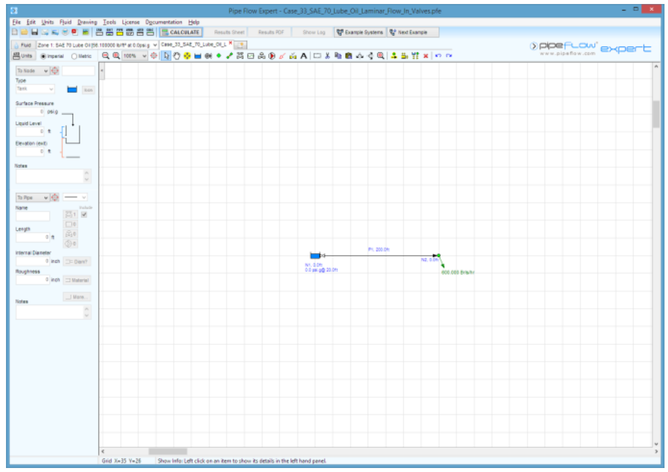
Reference: Flow of Fluids – Technical Paper No 410, 1988, Crane Co. Page 4-4, Example 4-8.

Pipe Flow Expert File: Case_33_SAE_70_Lube_Oil_Laminar_Flow_In_Valves.pfe

Problem description:

A 200 foot long 8” diameter steel pipe (schedule 40) carries SAE 70 Lube Oil at 100°F.
The flow rate is 600 barrels per hour.
The piping includes an 8” globe valve.

Find the pressure loss in the pipe and the valve.



Fluid data: SAE 70 Lube Oil at 100°F

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure Loss (psi)	2.85	2.8675
Reynolds Number	318	318
Friction factor	0.20	0.20112

Commentary:

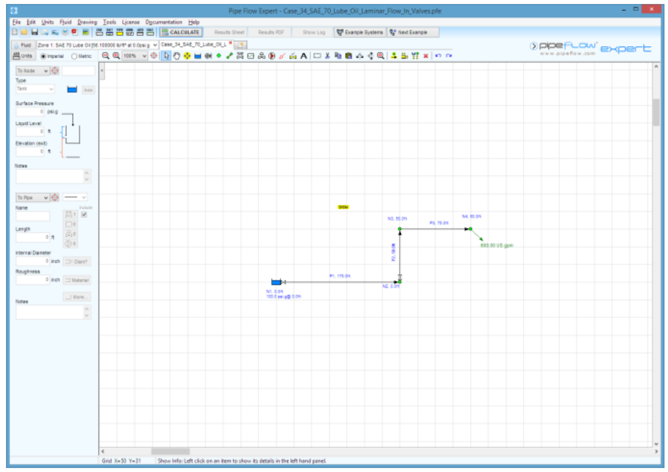
The published data and the calculated results compare well.

Case 34: SAE 70 Lube Oil - Laminar Flow in Valves

Reference: Flow of Fluids – Technical Paper No 410, 1988, Crane Co. Page 4-5, Example 4-9.

Pipe Flow Expert File: Case_34_SAE_70_Lube_Oil_Laminar_Flow_In_Valves.pfe

Problem description:



A piping system consisting of 5" diameter steel pipe (schedule 40) carries SAE 70 Lube Oil at 100°F.
The flow rate is 600 gpm (US).
The piping includes a 5" gate valve and a 5" angle valve.

Find the fluid velocity and the pressure loss across the system.

Fluid data: SAE 70 Lube Oil at 100°F

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure Loss (psi)	56.6	56.6014 (100.000 - 43.3986)
Fluid velocity in pipe (ft/s)	9.60	9.622
Reynolds Number	718	719
Friction factor	0.089	0.08903

Commentary:

The published data and the calculated results compare well.
The system was modeled in Pipe Flow Expert with a fluid surface pressure of 100.00 psi g at the inlet to the system.
The outlet node had a resulting pressure of 43.3986 psi g.
The pressure difference is obtained by subtracting the outlet pressure from the inlet pressure.

Case 35: Water - Flat Heating Coil

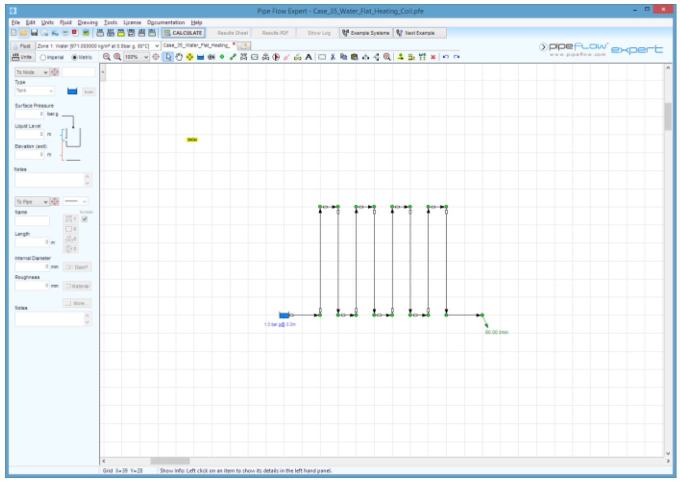
Reference: Flow of Fluids – Technical Paper No 410M, 1999, Crane Co. Page 4-6, Example 4-11.

Pipe Flow Expert File: Case_35_Water_Flat_Heating_Coil.pfe

Problem description:

A heating coil manufactured from 1” diameter steel pipe (schedule 40) is supplied with 60 l/min of water at 80°C. The bends of the heating coil have a 100 mm radius.

Find the pressure loss across the heating coil.



Fluid data: Water at 80°C

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure Loss (bar)	0.152	0.1559 (1.000 – 0.8441)
Reynolds Number	133000	131085
Friction factor	0.024	0.02396
Fluid Viscosity (Centipoise)	0.350	0.354

Commentary:

The published data and the calculated results compare well.
The system was modeled in Pipe Flow Expert with a fluid surface pressure of 1.00 bar g at the inlet to the system.
The outlet node had a resulting pressure of 0.8441 bar g.
The pressure difference is obtained by subtracting the outlet pressure from the inlet pressure.
The 100 mm radius bends in the pipe were modeled in Pipe Flow Expert using two long pipe bend fittings.

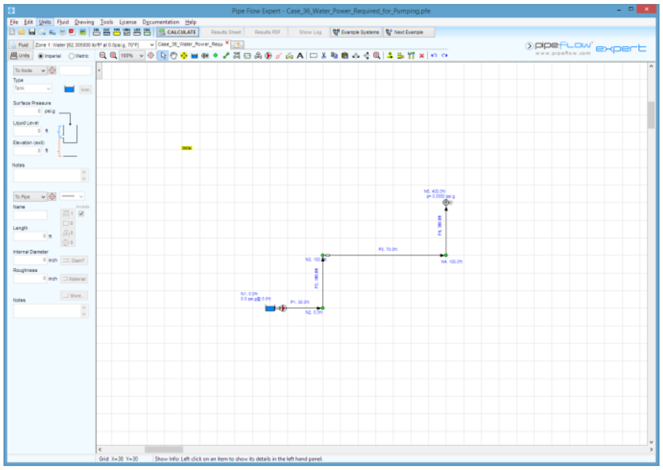
Case 36: Water - Power Required for Pumping

Reference: Flow of Fluids – Technical Paper No 410, 1988, Crane Co. Page 4-9, Example 4-15.

Pipe Flow Expert File: Case_36_Water_Power_Required_for_Pumping.pfe

Problem description:

100 US gallons per minute of water at 70°F is to be pumped through a piping system made from 3" diameter steel pipe (schedule 40).
A globe lift check valve, a gate valve and four standard threaded elbows are incorporated in to the piping system.
.
Find the discharge head required from a pump and the horse power required for pumping if the pump efficiency is 70%.



Fluid data: Water at 70°F

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Discharge Head (ft)	421	420.458
Power Required at 70% pump efficiency. (HP)	15.2	15.233

Commentary:

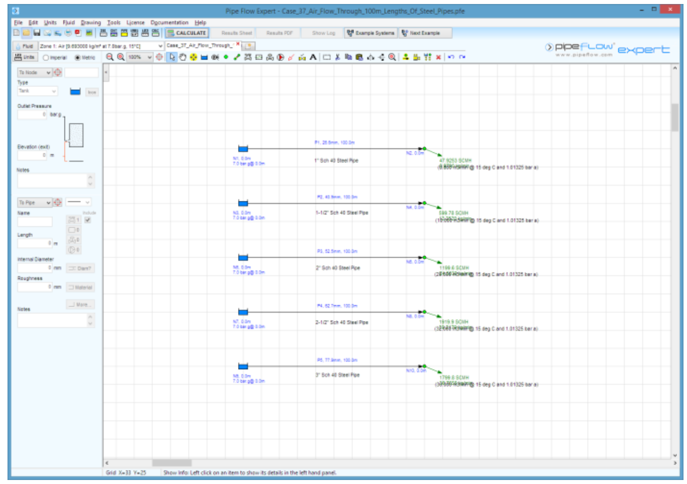
The published data and the calculated results compare well.

Case 37: 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_37_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.

Note: This case is solved here using Pipe Flow Expert's non-compressible calculation engine. See the commentary below for more details. This case has also been solved using Pipe Flow Expert's compressible calculation engine and the results are reported in the separate Compressible Results Verification document (Case 25).

Fluid data: Air at 7 bar gauge and 15°C

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	0.0436
1-1/2" Diameter Schedule 40 Steel Pipe, 100 m long	10.000	1.264	0.640	0.6391
2.0" Diameter Schedule 40 Steel Pipe, 100 m long	20.000	2.528	0.685	0.6854
2-1/2" Diameter Schedule 40 Steel Pipe, 100 m long	32.000	4.046	0.682	0.6900
3.0" Diameter Schedule 40 Steel Pipe, 100 m long	30.000	3.793	0.197	0.1979

Commentary:

The published data and the calculated results compare well.
Since the calculated pressure drop in the system is less than 10% of the pressure at the compressible fluid entry point, then the results may be considered to be reasonably accurate.

If the pressure drop in the pipes is greater than 10% but less than 40% of the pressure at the compressible fluid entry point then the calculations would need to be repeated using the average density of the fluid in the pipeline system (the volumetric flow rates would need to be increased slightly to maintain the same mass flow rate).

If the pressure drop in the pipes is greater than 40% of the pressure at the compressible fluid entry point then the Darcy-Weisbach equation is not suitable and Pipe Flow Expert should be used with the Compressible Flow calculation engine to analyze the system.

Case 38: Air – Flow Through 100ft Lengths of Steel Pipes

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

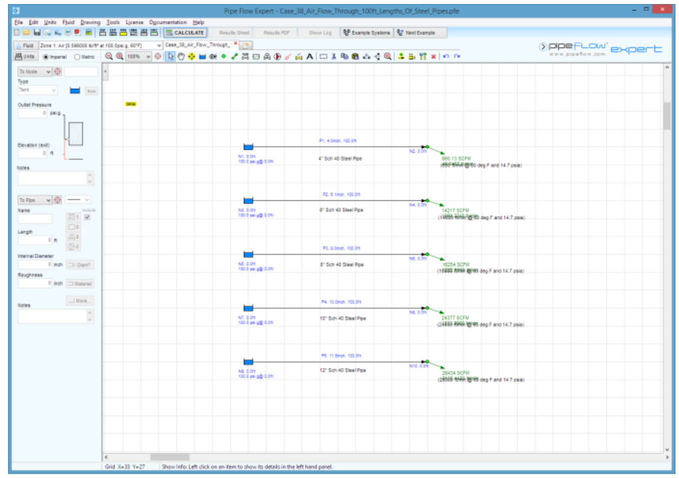
Pipe Flow Expert File: Case_38_Air_Flow_Through_100ft_Lengths_Of_Steel_Pipes.pfe

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.

Note: This case is solved here using Pipe Flow Expert's non-compressible calculation engine. See the commentary below for more details. This case has also been solved using Pipe Flow Expert's compressible calculation engine and the results are reported in the separate Compressible Results Verification document (Case 26).



Fluid data: Air at 100 psi gauge and 60°F

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	0.0857
6.0" Diameter Schedule 40 Steel Pipe, 100 ft long	14000	1794	4.21	4.2741
8.0" Diameter Schedule 40 Steel Pipe, 100 ft long	16000	2051	1.33	1.3460
10.0" Diameter Schedule 40 Steel Pipe, 100 ft long	24000	3076	0.918	0.9275
12.0" Diameter Schedule 40 Steel Pipe, 100 ft long	28000	3588	0.505	0.5099

Commentary:

The published data and the calculated results compare well.
Since the calculated pressure drop in the system is less than 10% of the pressure at the compressible fluid entry point, then the results may be considered to be reasonably accurate.

If the pressure drop in the pipes is greater than 10% but less than 40% of the pressure at the compressible fluid entry point then the calculations would need to be repeated using the average density of the fluid in the pipeline system (the volumetric flow rates would need to be increased slightly to maintain the same mass flow rate).

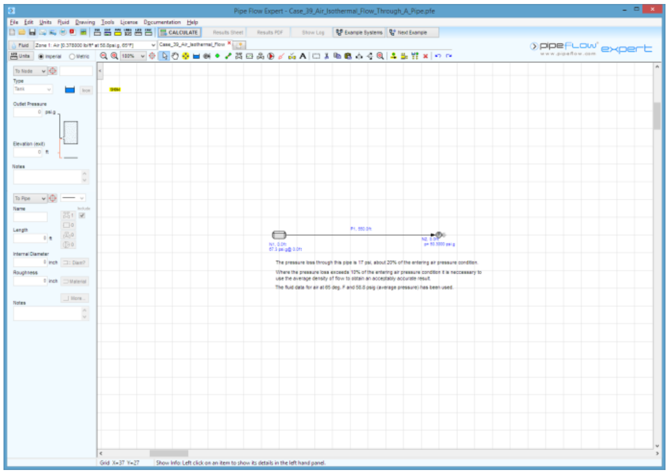
If the pressure drop in the pipes is greater than 40% of the pressure at the compressible fluid entry point then the Darcy-Weisbach equation is not suitable and Pipe Flow Expert should be used with the Compressible Flow calculation engine to analyze the system.

Case 39: Air - Isothermal Flow Through a Pipe

Reference: Theory and Problems of Fluid Mechanics and Hydraulics, 1993, McGraw-Hill, R V Giles, Jack B. Evett, Ph. D., Cheng Liu, M.S., Page 237, Example problem 11.1

Pipe Flow Expert File: Case_39_Air_Isothermal_Flow_Through_A_Pipe.pfe

Problem description:



Air at temperature of 65°F flows through a pipe with 6" internal diameter.
The pipe surface is smooth and the flow is isothermal.
The pressure at the start of a 550 ft long horizontal pipe section is 82 psia (67.3 psig) the pressure at the end of the section is 65 psia (50.3 psig).

Calculate the weight flow rate of the air.

Note: This case is solved here using Pipe Flow Expert's non-compressible calculation engine. See the commentary below for more details. This case has also been solved using Pipe Flow Expert's compressible calculation engine and the results are reported in the separate Compressible Results Verification document (Case 01).

Fluid data: Air at 65°F at an average density of 73.5 psia (58.8 psig)

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Weight of Flow (lb/sec)	14.5	14.6702
Reynolds Number	3030000	3071488
Friction Factor	0.0095 / 0.0097	0.0097

Commentary:

The published data and the calculated results compare well.
The published text assumes an initial friction factor of 0.0095 and this is then used to estimate the weight of flow as 14.5 lb/sec. The weight of flow is then used to recalculate the friction factor as 0.0097.
The new friction factor is compared to the initial assumed friction factor value and is taken as confirmation of the previously calculated weight of flow.

The Pipe Flow Expert program uses the Darcy-Weisbach equation to determine flow rates and pressure loss in pipes. Where the system includes compressible fluids and the pressure loss is greater than 10% of the entering pressure the calculations need to be carried out using the average fluid density to obtain an accurate result.

The average density of the air in the pipe has been used in the Pipe Flow Expert Calculation.

Normally Pipe Flow Expert would be used with the Compressible Flow calculation engine to analyze this system.

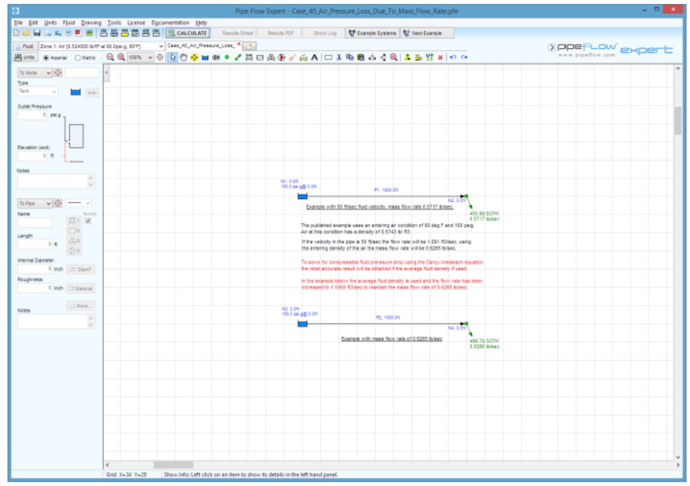
Case 40: Air - Pressure Loss Due to Mass Flow Rate

Reference: Piping Calculations Manual, 2005, McGraw-Hill, E. Shashi Menon, P.E., Page 265, Example 5.8

Pipe Flow Expert File: Case_40_Air_Pressure_Loss_Due_To_Mass_Flow_Rate.pfe

Problem description:

Air at temperature of 80°F and a pressure of 100 psig flows into a steel pipe with 2" internal diameter.
The initial velocity of the air is 50 ft/sec.
The flow is isothermal.
The pipe is horizontal and 1000 ft long.



Calculate the pressure loss in the pipe.

Note: This case is solved here using Pipe Flow Expert's non-compressible calculation engine. See the commentary below for more details. This case has also been solved using Pipe Flow Expert's compressible calculation engine and the results are reported in the separate Compressible Results Verification document (Case 21).

Fluid data: Air at 80°F at an average density of 90 psig

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Pressure Loss (psi)	20.52	20.3626
Weight of Flow (lb/sec)	0.6265	0.6266
Friction Factor	0.020	0.01988

Commentary:

The published data and the calculated results compare well.
The weight of flow is calculated from the fluid data and the initial velocity as 0.6265 lb/sec.
The published text assumes an initial friction factor of 0.020 this is used together with the mass flow rate to estimate the fluid pressure at the end of the pipe.
A further iteration involving the new fluid pressure at the end of the pipe provides the published result.

The average density of the air has been used in the Pipe Flow Expert Calculation.

The Pipe Flow Expert program uses the Darcy-Weisbach equation to determine flow rates and pressure loss in pipes. Where the system includes compressible fluids and the pressure loss is greater than 10% of the entering pressure the calculations need to be carried out using the average fluid density to obtain an accurate result.
In order to maintain the flow rate of 0.6265 lb/sec the flow rate in the pipe has been adjusted to use the average flow velocity that will be present in the pipe.

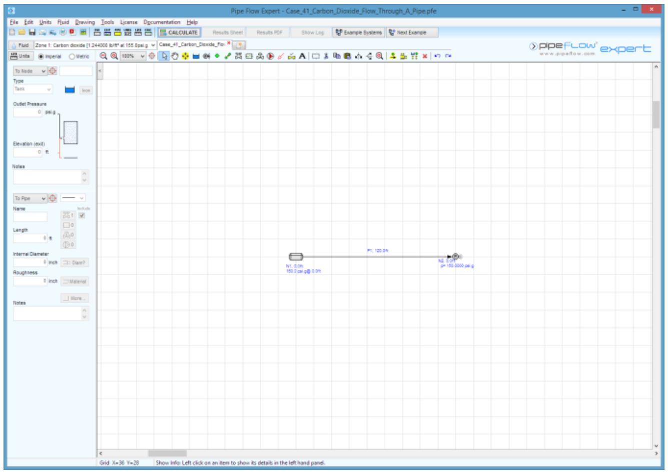
Normally Pipe Flow Expert would be used with the Compressible Flow calculation engine to analyze this system.

Case 41: 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.

Note: This case is solved here using Pipe Flow Expert's non-compressible calculation engine. See the commentary below for more details. This case has also been solved using Pipe Flow Expert's compressible calculation engine and the results are reported in the separate Compressible Results Verification document (Case 27).

Fluid data: Carbon Dioxide at 100°F

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Weight of Flow (lb/sec)	25.3	25.5343
Reynolds Number	5000000	6242864
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.
The Colebrook-White equation is usually considered to be more accurate than a value read from a Moody Chart.

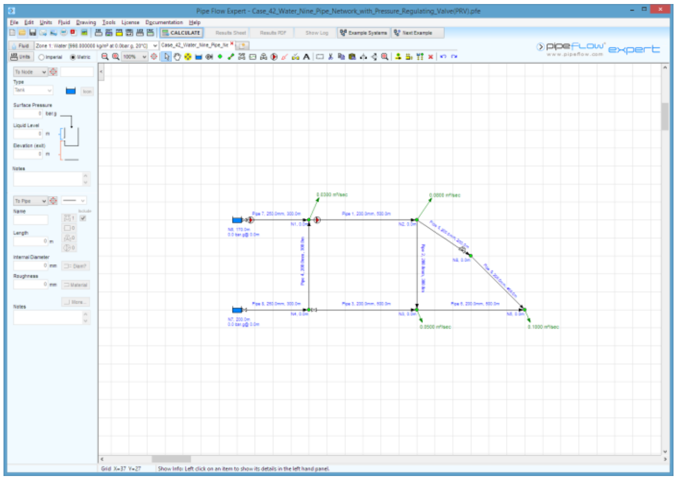
Normally Pipe Flow Expert would be used with the Compressible Flow calculation engine to analyze this system.

Case 42: Water - Nine Pipe Network with Pressure Regulating Valve(PRV)

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 106, Example problem 4.9

Pipe Flow Expert File: Case_42_Water_Nine_Pipe_Network_With_Pressure_Regulating_Valve(PRV).pfe

Problem description:



A network of 9 interconnected pipes delivers water from two reservoirs to outlet demands at various pipework junctions.
The network includes 2 pumps, two globe valves and a meter.
The network has two closed loops and one open loop.

The pressure at a node 8 is controlled by a pressure regulating valve set to 14.5827 psig (equivalent to 149 m head of water as specified in the example text).

Calculate the flow rate in each individual pipe and the pump heads added to the system.

Fluid data: Water at 20° C (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
Q1 Flow rate (m^3/s)	0.1125	0.1131
Q2 Flow rate (m^3/s)	-0.0018	0.0003 (pipe reversed)
Q3 Flow rate (m^3/s	0.1175	0.1169
Q4 Flow rate (m^3/s	0.0792	0.0772
Q5 Flow rate (m^3/s	0.0343	0.0328
Q6 Flow rate (m^3/s	0.0657	0.0672
Q7 Flow rate (m^3/s	0.0633	0.0659
Q8 Flow rate (m^3/s)	0.1967	0.1941
Q9 Flow rate (m^3/s)	0.0343 (same as Q5)	0.0328
Pump 1 - head added	6.18 m fluid	6.183 m fluid
Pump 2 - head added	3.58 m fluid	3.593 m fluid
HGL at PRV Node	149.000 m	149.000 m

Commentary:

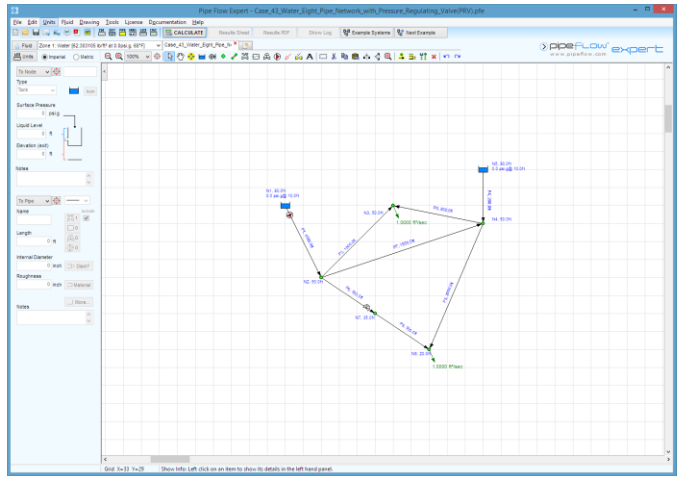
The published data and the calculated results compare well.
Pipe Flow Expert correctly identified that pipe 2 was drawn with the wrong flow direction in the design schematic.
This pipe was reversed and the flow was reported as positive value.
The reference text reports flow as negative values where an incorrect flow direction has been assumed.

Case 43: Water -Eight Pipe Network with Pressure Regulating Valve(PRV)

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 67, Example figure 4.6

Pipe Flow Expert File: Case_43_Water_Eight_Pipe_Network_With_Pressure_Regulating_Valve(PRV).pfe

Problem description:



A network of 8 interconnected pipes delivers water from two reservoirs to outlet demands at two pipework junctions.
The network includes a pump.

The pressure at a node where two pipes join is controlled by a pressure regulating valve set to 8.6527 psig. The elevation of the PRV node is 35 ft.

Calculate the flow rate in each individual pipe and the pump head added to the system.

Fluid data: Water at 20° C (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
P1 Flow rate (ft³/s)	1.11	1.1092
P2 Flow rate (ft³/s)	1.07	1.0697
P3 Flow rate (ft³/s)	0.07	0.0697
P4 Flow rate (ft³/s)	0.89	0.8908
P5 Flow rate (ft³/s)	0.96	0.9677
P6 Flow rate (ft³/s)	0.04	0.0323
P7 Flow rate (ft³/s)	0.01	0.0072
P8 Flow rate (ft³/s)	0.04 (same as P6)	0.0323
Pump - head added	59.1 ft fluid	59.078 ft fluid
HGL at PRV Node N7	55.00 ft	55.000 ft
Pressure at Node N2 (psi)	31.1 (Node 1 in text)	31.1023
Pressure at Node N3 (psi)	20.2 (Node 2 in text)	20.1536
Pressure at Node N4 (psi)	20.1 (Node 3 in text)	20.1091
Pressure at Node N6 (psi)	15.2 (Node 4 in text)	15.1358

Commentary:

The published data and the calculated results compare well.
Pipe Flow Expert correctly identified that pipe 3 was drawn with the wrong flow direction in the design schematic, this pipe was reversed and the flow was reported as positive value.
The reference text notes that the flow direction of pipe 3 has been reversed from the input data.

Case 44: Water -Ten Pipe Network with Back Pressure Valve(BPV)

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters, Page 70, Example figure 4.10

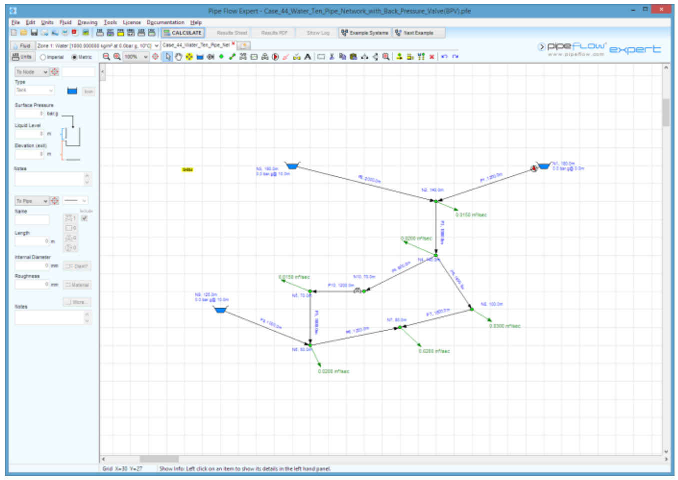
Pipe Flow Expert File: Case_44_Water_Ten_Pipe_Network_With_Back_Pressure_Valve(BPV).pfe

Problem description:

A network of 10 interconnected pipes delivers water from three reservoirs to outlet demands at six pipework junctions. The network includes a pump.

The pressure at a node where two pipes join is controlled by a back pressure valve set to 12.2583 barg. The elevation of the BPV node is 70 ft.

Calculate the flow rate in each individual pipe and the pump head added to the system.



Fluid data: Water at 10° C (assumed).

Result Comparison:

Data Item	Published data	Pipe Flow Expert
P1 Flow rate (m^3/s)	0.102	0.1024
P2 Flow rate (m^3/s)	0.004	0.0036
P3 Flow rate (m^3/s)	0.091	0.0910
P4 Flow rate (m^3/s)	0.006	0.0057
P5 Flow rate (m^3/s)	0.009	0.0093
P6 Flow rate (m^3/s)	0.015	0.0153
P7 Flow rate (m^3/s)	0.035	0.0353
P8 Flow rate (m^3/s)	0.065	0.0653
P9 Flow rate (m^3/s)	0.014	0.0140
P10 Flow rate (m^3/s)	0.006 (same as P4)	0.0057
Pump - head added	34.88 m fluid	34.879 m fluid
HGL at BPV Node N10	195.00 m	195.000 m
Pressure at Node N2 (kPa)	580.7 (Node 1 in text)	581.468
Pressure at Node N4 (kPa)	539.2 (Node 2 in text)	539.595
Pressure at Node N5 (kPa)	579.0 (Node 3 in text)	578.62
Pressure at Node N6 (kPa)	695.6 (Node 4 in text)	695.622
Pressure at Node N6 (kPa)	555.3 (Node 5 in text)	555.355
Pressure at Node N6 (kPa)	683.8 (Node 6 in text)	684.158

Commentary:

The published data and the calculated results compare well.
Pipe Flow Expert correctly identified that pipe 5 and pipe 6 were drawn with the wrong flow direction in the design schematic. These pipes were automatically reversed and the flows were reported as positive values.
The reference text schematic shows the elevation of node N2 as 150 m however the input reference table correctly identifies the elevation as 140.0 m.

Case 45: Water – Sixty Five Pipe Network - 36 Loops – 5 Pumps

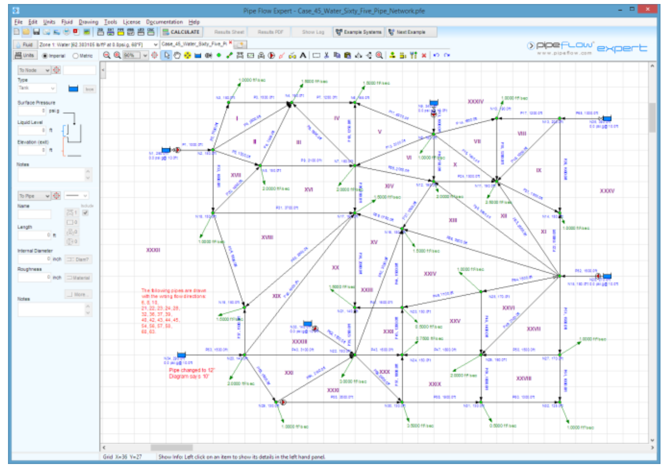
Reference: Analysis of Flow in Pipe Networks, 1976, Publisher Ann Arbor Science, Rowland W. Jeppson, Example problem 9 page 102 -105

Pipe Flow Expert File: Case_45_Water_Sixty_Five_Pipe_Network.pfe

Problem description:

Water is supplied from five reservoirs to a sixty five pipe network. The pipes are connected at twenty nine node points. The network contains 5 pumps.
Out flows from the network occur at each node point.

Find the flow rate and head loss for each pipe.
Find the pressure and Hydraulic Grade Line at each node point.



Fluid data: Water at 68° F (assumed).

Result Comparison:

● = Pipe Flow Expert reversed pipe direction and reported flow as positive

Pipe	Published Flow (ft³/s)	Pipe Flow Expert (ft³/s)
P 1	11.6100	11.6682
P 2	3.1800	3.1979
P 3	2.1800	2.1979
P 4	1.5000	1.5106
P 5	2.2200	2.2298
P 6	-1.1900	● 1.1830
P 7	0.3000	0.3440
P 8	-0.6800	● 0.6815
P 9	0.4900	0.5229
P 10	-1.4300	● 1.4369
P 11	2.6300	2.5927
P 12	2.0600	2.0429
P 13	10.0000	10.0120
P 14	0.9300	0.9905
P 15	1.4900	1.5157
P 16	1.8900	1.8702
P 17	1.5400	1.4571
P 18	1.4700	1.4476
P 19	2.7500	2.6487
P 20	2.7100	2.6216
P 21	-0.2600	● 0.2351
P 22	-1.4500	● 1.3865
P 23	-1.7700	● 1.6927
P 24	-1.7100	● 1.6544
P 25	0.5800	0.5758

Pipe	Published Head Loss (ft)	Pipe Flow Expert Head Loss (ft)
P 1	82.15	82.73
P 2	14.20	14.36
P 3	9.23	9.38
P 4	23.43	23.74
P 5	26.31	26.55
P 6	2.87	2.81
P 7	0.18	0.22
P 8	3.60	3.63
P 9	0.73	0.83
P 10	3.42	3.41
P 11	7.68	7.42
P 12	11.10	10.83
P 13	25.67	27.15
P 14	1.89	2.13
P 15	5.33	5.45
P 16	11.07	10.83
P 17	3.78	3.36
P 18	3.44	3.32
P 19	7.22	6.69
P 20	7.04	6.55
P 21	0.18	0.13
P 22	4.21	3.82
P 23	4.03	3.69
P 24	5.74	5.38
P 25	1.71	1.70

P 26	2.0900	2.0713
P 27	-2.1000	2.0786
P 28	0.0700	• 0.0217
P 29	1.1800	1.1619
P 30	2.7300	2.7058
P 31	1.1400	1.1335
P 32	-0.9200	• 0.8899
P 33	4.7200	4.7300
P 34	3.5100	3.4863
P 35	0.7100	0.7080
P 36	-1.9500	• 1.9296
P 37	-2.7200	• 2.6943
P 38	0.8800	0.8636
P 39	-0.4300	• 0.3942
P 40	-3.7200	• 3.6901
P 41	1.0500	1.0306
P 42	-1.0000	• 0.9865
P 43	-0.8600	• 0.8423
P 44	-0.5000	• 0.5015
P 45	-0.4000	• 0.3940
P 46	1.4500	1.4230
P 47	1.4300	1.4012
P 48	0.3500	0.3338
P 49	2.5500	2.5327
P 50	1.4500	1.4441
P 51	4.2500	4.2280
P 52	9.0300	9.0853
P 53	1.2400	1.2794
P 54	-3.0200	• 3.0118
P 55	3.2700	3.2912
P 56	-1.2100	• 1.1874
P 57	-0.2200	• 0.2029
P 58	-1.2200	• 1.1933
P 59	0.9200	0.9094
P 60	-0.8000	• 0.7839
P 61	1.8000	1.7839
P 62	6.2500	6.2915
P 63	-5.1400	• 5.0346
P 64	2.8000	2.7568
P 65	7.0000	6.7275

P 26	19.84	19.48
P 27	18.13	17.78
P 28	0.02	0.00
P 29	3.26	3.16
P 30	21.37	20.94
P 31	20.22	20.04
P 32	1.88	1.73
P 33	28.18	28.28
P 34	28.34	27.86
P 35	8.01	7.82
P 36	22.30	21.80
P 37	14.28	13.98
P 38	0.85	0.81
P 39	0.13	0.11
P 40	21.31	20.88
P 41	2.40	2.29
P 42	4.25	4.09
P 43	1.63	1.56
P 44	1.72	1.68
P 45	0.90	0.85
P 46	4.75	4.55
P 47	4.87	4.68
P 48	0.79	0.72
P 49	17.59	17.33
P 50	4.21	4.13
P 51	13.38	13.20
P 52	26.61	26.86
P 53	3.32	3.49
P 54	24.63	24.36
P 55	18.65	18.83
P 56	1.55	1.49
P 57	0.08	0.07
P 58	3.78	3.62
P 59	1.17	1.13
P 60	1.15	1.10
P 61	4.23	4.16
P 62	12.87	13.00
P 63	19.47	18.62
P 64	16.80	16.61
P 65	23.88	26.56

Node (text ref)	Published Press. (lb/in²)	Pipe Flow Expert (lb/in²)
N1 (n/a)	n/a	n/a
N2 (1)	104.1	103.2907
N3 (2)	97.9	97.0770
N4 (3)	89.6	88.6939
N5 (4)	92.7	91.8056
N6 (5)	87.3	86.4336
N7 (6)	88.0	87.1218
N8 (7)	84.2	83.1561
N9 (n/a)	n/a	n/a

Node (text ref)	Published HGL. (ft)	Pipe Flow Expert HGL (ft)
N1 (n/a)	Fluid Surface	300.0000
N2 (1)	390.2	388.7300
N3 (2)	376.0	374.3700
N4 (3)	366.7	365.0000
N5 (4)	363.9	362.1900
N6 (5)	366.6	364.7700
N7 (6)	363.3	361.3600
N8 (7)	374.2	372.2000
N9 (n/a)	Fluid Surface	350.0000

N10 (8)	79.0	77.9059
N11 (11)	77.5	76.4725
N12 (12	75.0	74.1433
N13 (9)	76.3	75.0384
N14 (10)	81.9	80.8566
N15 (20)	80.1	79.2045
N16 (13)	71.5	70.7767
N17 (14)	78.8	78.0611
N18 (15)	91.9	91.0567
N19 (16)	79.6	79.0029
N20 (25)	77.8	77.2810
N21 (17)	87.1	86.3629
N22 (24)	82.7	81.9878
N23 (18)	83.4	83.0292
N24 (23)	82.7	82.6617
N25(19)	77.2	76.3452
N26 (22)	81.2	80.36452
N27 (21)	78.65	77.8199
N28 (n/a)	n/a	n/a
N29 (26)	80.7	80.0996
N30 (27)	92.0	91.2857
N31 (28)	93.6	92.8505
N32 (29)	96.3	95.4911
N33 (n/a)	n/a	n/a
N34 (n/a)	n/a	n/a
N35 (n/a)	n/a	n/a

N10 (8)	372.3	370.0700
N11 (11)	368.9	366.7500
N12 (12	363.2	361.3700
N13 (9)	376.1	373.4300
N14 (10)	369.1	366.8800
N15 (20)	364.9	363.0600
N16 (13)	345.0	343.5800
N17 (14)	341.8	340.4200
N18 (15)	362.0	360.4600
N19 (16)	333.8	332.6000
N20 (25)	319.5	318.6200
N21 (17)	340.9	339.6100
N22 (24)	340.8	339.5000
N23 (18)	343.3	341.9000
N24 (23)	342.4	341.0500
N25(19)	348.1	346.4600
N26 (22)	347.3	345.7300
N27 (21)	351.2	349.8600
N28 (n/a)		280.0000
N29 (26)	316.1	315.1300
N30 (27)	342.3	340.9900
N31 (28)	346.1	344.6000
N32 (29)	347.3	345.7100
N33 (n/a)	Fluid Surface	150.0000
N34 (n/a)	Fluid Surface	300.0000
N35 (n/a)	Fluid Surface	400.0000

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

The reference text uses a linear approximation to calculate head losses, and only performs six iterations to find an approximate result. Pipe Flow Expert uses the more accurate Darcy-Weisbach equation and converges to within a pressure balance tolerance of 0.000145 psi.

The reference text indicates that the flow direction in a pipe is opposite to the direction shown on the schematic diagram by reporting the flow as negative value. Pipe Flow Expert automatically reversed the flow direction of the pipes indicated with '●', and reported the flow rates in these pipes as a positive value.

The reference text indicates that the flow in pipe P27 is negative, and this appears to be a printing error, since the flow direction of this pipe is drawn correctly. However the flow direction of pipe P28 is drawn opposite to the actual flow direction and should be reported as a negative value in the text, but this is listed as a positive value.
We believe that the reference text reports the flow direction of these two pipes incorrectly.

The schematic diagram lists pipe P63 as 10" diameter.
These flow and pressure loss values cannot be reconciled with a 10" diameter pipe.
We have assumed that the text calculations were based on 12" diameter for this pipe.
The published results for pipe P63 are: Flow 5.14 ft^3/s with a pressure loss of 19.47 ft hd.
Pipe Flow Expert reports: Flow 5.0346 ft^3/s with a pressure loss of 18.62 ft hd for a 12" diameter pipe.

If the system is solved using a 10" diameter for pipe P63 the flow is 3.941 ft^3/s with a pressure loss of 29.59 ft hd.
The correlation for flows and pressure losses in many other pipes is also lost.
Hence the reference text was not solved with a 10" diameter for pipe P63.

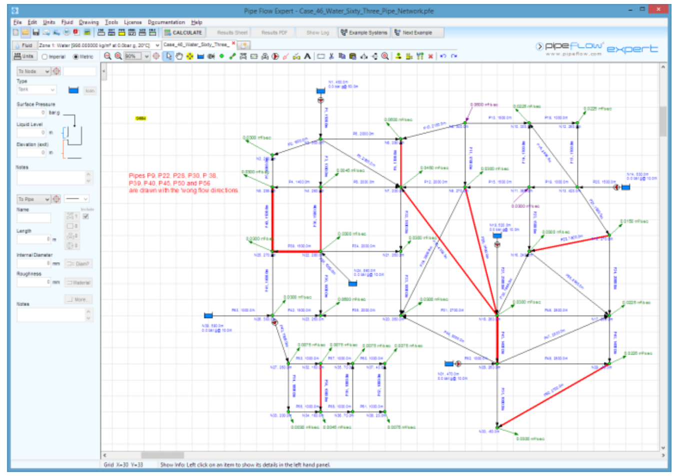
Case 46: Water – Sixty Three Pipe Network - 30 Loops – 5 Pumps

Reference: Analysis of Flow in Pipe Networks, 1976, Publisher Ann Arbor Science, Rowland W. Jeppson, Example problem 10 page 105 -109

Pipe Flow Expert File: Case_46_Water_Sixty_Three_Pipe_Network.pfe

Problem description:
Water is supplied from five reservoirs to a sixty three pipe network. The pipes are connected at thirty three node points. The network contains 5 pumps.
Out flows from the network occur at each node point.

Find the flow rate and head loss for each pipe.
Find the pressure and Hydraulic Grade Line at each node point.



Fluid data: Water at 68° F (assumed).

Result Comparison:

- ● = Pipe Flow Expert reversed pipe direction and reported flow as positive

Pipe	Published Flow (m^3/s)	Pipe Flow Expert (m^3/s)
P 1	0.0869	0.0873
P 2	0.0208	0.0209
P 3	0.0132	0.0133
P 4	0.0153	0.0153
P 5	0.0092	0.0091
P 6	0.0274	0.0276
P 7	0.0254	0.0256
P 8	0.0148	0.0148
P 9	-0.0027	● 0.0027
P 10	0.0299	0.0297
P 11	0.0212	0.0211
P 12	0.0081	0.0080
P 13	0.0089	0.0091
P 14	0.0164	0.0163
P 15	0.0273	0.0270
P 16	0.0107	0.0107
P 17	0.0118	0.0118
P 18	0.0078	0.0077
P 19	0.0243	0.0239
P 20	0.0791	0.0783
P 21	0.0351	0.0349
P 22	-0.0035	● 0.0034
P 23	0.0106	0.0106
P 24	0.0166	0.0165
P 25	0.0119	0.0119

Pipe	Published Head Loss (m)	Pipe Flow Expert Head Loss (m)
P 1	201.1	202.536
P 2	53.6	54.586
P 3	19.1	19.216
P 4	27.4	27.304
P 5	7.2	7.066
P 6	27.5	27.657
P 7	27.3	27.439
P 8	8.3	8.223
P 9	0.2	0.218
P 10	68.4	67.431
P 11	63.1	62.284
P 12	5.1	4.930
P 13	10.1	10.616
P 14	38.1	37.446
P 15	91.0	89.114
P 16	78.9	79.465
P 17	165.5	163.557
P 18	86.5	84.091
P 19	48.4	46.645
P 20	166.9	163.139
P 21	150.0	147.546
P 22	16.3	15.072
P 23	117.7	115.973
P 24	45.8	44.811
P 25	29.7	29.739

P 26	0.0277	0.0280
P 27	0.0805	0.0809
P 28	-0.0043	● 0.0041
P 29	0.0061	0.0061
P 30	-0.0065	● 0.0065
P 31	0.0148	0.0148
P 32	0.0071	0.0071
P 33	0.0046	0.0046
P 34	0.0274	0.0274
P 35	0.0094	0.0094
P 36	0.0219	0.0219
P 37	0.1306	0.1305
P 38	-0.0214	● 0.0213
P 39	-0.0299	● 0.0299
P 40	-0.0238	● 0.0238
P 41	0.0239	0.0239
P 42	0.0287	0.0287
P 43	0.0450	0.0450
P 44	0.0139	0.0140
P 45	-0.0002	● 0.0001
P 46	0.0056	0.0056
P 47	0.0051	0.0052
P 48	0.0167	0.0167
P 49	0.0137	0.0137
P 50	-0.0078	● 0.0078
P 51	0.0222	0.0222
P 52	0.0547	0.0550
P 53	0.0210	0.0210
P 54	0.0165	0.0165
P 55	0.0135	0.0135
P 56	-0.0020	● 0.0020
P 57	0.0116	0.0116
P 58	0.0109	0.0109
P 59	0.0031	0.0031
P 60	0.0072	0.0072
P 61	0.0078	0.0078
P 62	0.0003	0.0003
P 63	0.1276	0.1276

P 26	25.3	25.636
P 27	287.6	289.787
P 28	1.4	1.223
P 29	12.5	12.317
P 30	3.7	3.706
P 31	11.2	11.094
P 32	6.6	6.602
P 33	0.8	0.785
P 34	27.6	27.378
P 35	3.5	3.462
P 36	31.8	31.625
P 37	297.8	300.250
P 38	12.7	12.553
P 39	24.4	24.324
P 40	15.7	15.533
P 41	37.8	37.593
P 42	45.2	44.894
P 43	54.6	54.469
P 44	11.1	11.084
P 45	0.1	0.010
P 46	55.0	55.375
P 47	54.9	55.365
P 48	267.5	266.671
P 49	322.4	322.209
P 50	14.3	14.173
P 51	336.7	336.209
P 52	240.7	242.802
P 53	94.2	93.916
P 54	58.1	57.898
P 55	39.1	38.952
P 56	3.0	2.934
P 57	93.0	92.689
P 58	82.9	82.732
P 59	7.1	7.023
P 60	36.2	36.054
P 61	43.2	42.963
P 62	0.1	0.114
P 63	284.5	286.981

Node (text ref)	Published Press. (m hd)	Pipe Flow Expert (m hd)
N1 (n/a)	n/a	n/a
N2 (1)	8.60	6.41
N3 (2)	5.00	2.83
N4 (4)	29.60	27.20
N5 (3)	7.20	4.89
N6 (5)	1.12	-1.24
N7 (6)	1.34	78.97
N8 (7)	9.50	6.19
N9 (8)	16.40	13.90
N10 (9)	3.40	5.57
N11 (10)	17.50	13.02

Node (text ref)	Published HGL. (m)	Pipe Flow Expert HGL (m)
N1 (n/a)	Fluid Surface	500.00
N2 (1)	308.60	306.41
N3 (2)	255.00	252.83
N4 (4)	289.60	287.20
N5 (3)	262.20	259.89
N6 (5)	281.10	278.76
N7 (6)	281.30	278.97
N8 (7)	349.50	346.19
N9 (8)	286.40	283.90
N10 (9)	339.40	335.57
N11 (10)	377.50	373.02

N12 (11)	0.45	-3.89
N13 (12)	5.93	-0.34
N14 (n/a)	n/a	n/a
N15 (13)	5.88	2.12
N16 (14)	15.60	17.05
N17 (31)	30.10	27.32
N18 (15)	24.90	22.68
N19 (n/a)	n/a	n/a
N20 (16)	13.80	11.59
N21 (17)	14.60	12.37
N22 (18)	22.20	19.75
N23 (21)	20.30	18.13
N24 (n/a)	n/a	n/a
N25(19)	7.70	5.43
N26 (20)	15.50	13.02
N27 (22)	8.40	6.05
N28 (30)	24.80	22.67
N29 (32)	12.50	10.64
N30 (33)	8.20	6.46
N31 (n/a)	n/a	n/a
N32 (24)	14.20	12.13
N33 (23)	10.40	8.15
N34 (25)	11.30	9.20
N36 (26)	11.30	9.44
N37 (28)	18.30	16.47
N38 (29)	5.10	3.39
N39 (n/a)	25.20	23.51

N12 (11)	260.40	256.11
N13 (12)	425.90	419.66
N14 (n/a)	Fluid Surface	540.00
N15 (13)	275.90	272.12
N16 (14)	259.60	257.05
N17 (31)	230.10	227.31
N18 (15)	284.90	282.68
N19 (n/a)	Fluid Surface	530.00
N20 (16)	273.80	271.59
N21 (17)	274.60	272.37
N22 (18)	302.20	299.75
N23 (21)	270.30	268.13
N24 (n/a)	Fluid Surface	600.00
N25(19)	277.70	275.43
N26 (20)	315.50	313.02
N27 (22)	268.40	266.05
N28 (30)	284.80	282.67
N29 (32)	-37.50	-39.37
N30 (33)	-51.80	-53.54
N31 (n/a)	Fluid Surface	480.00
N32 (24)	174.20	172.13
N33 (23)	210.40	208.15
N34 (25)	171.30	169.20
N36 (26)	81.30	79.45
N37 (28)	88.30	86.47
N38 (29)	45.10	43.39
N39 (n/a)	45.20	43.51

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

The reference text uses a linear approximation to calculate head losses.
Pipe Flow Expert uses the more accurate Darcy-Weisbach equation and converges to within a pressure balance tolerance of 0.00001 bar.

The reference text indicates that the flow direction in a pipe is opposite to the direction shown on the schematic diagram by reporting the flow as negative value. Pipe Flow Expert reversed the flow direction of the pipes indicated with '●' automatically, and reported the flow rates in these pipes as a positive value.

The reference text indicates that the out flow from node N14 is 0.045 cfs (should be cms), and this value appears to be incorrect due a printing error. The sum of flows in the pipes entering and leaving node N14 indicate that a flow rate of 0.0045 m^3/s leaves this node. The close correlation of the calculation results indicates that the reference text calculations were based on 0.0045 m^3/s leaving node N14.

The correlation of the HGL values is very good. The reference text lists the HGL at node N6 as 281.3 m and pressure at node N6 as 1.34 m hd, indicating an elevation of 280 m at this node, however the reference lists the elevation of this node at 200 m. Pipe Flow Expert results are based on an elevation of 200 m for Node 6, and hence the results for pressure at this node are affected by the change in elevation. The pressure at the node is calculated as 78.97 m hd.

Using an elevation of 200 m, the HGL is calculated as 278.97 m, which closely agrees with the published HGL of 281.3 m for this node. As this node is completely surrounded by pipes which do not connect to atmosphere the change in elevation does not affect the flow rate through other pipes in the system.

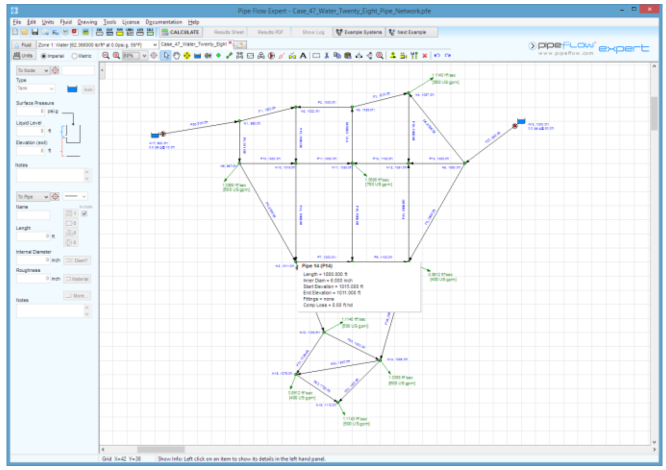
Case 47: Water – Twenty Eight Pipe Network - 3 Pumps

Reference: Analysis of Flow in Pipe Networks, 1976, Publisher Ann Arbor Science, Rowland W. Jeppson, Example problem 6 page 95 - 98

Pipe Flow Expert File: Case_47_Water_Twenty_Eight_Pipe_Network.pfe

Problem description:

Water is supplied from two reservoirs to a twenty eight pipe network. The pipes are connected at sixteen node points. The network contains 3 pumps.
Out flows from the network occur at several node points.



Find the flow rate and head loss for each pipe.
Find the Hydraulic Grade Line at each node point.

Fluid data: Water at 59° F (assumed).

Result Comparison:

● = Pipe Flow Expert reversed pipe direction and reported flow as positive

Pipe	Published Flow (ft³/s)	Pipe Flow Expert (ft³/s)
P 1	2.94	2.7772
P 2	-1.76	● 1.6707
P 3	-0.54	● 0.5778
P 4	1.74	1.7883
P 5	0.88	0.8904
P 6	-2.55	● 2.4480
P 7	-3.35	● 3.2081
P 8	2.17	2.2590
P 9	3.07	3.2297
P 10	-0.44	● 0.3661
P 11	-0.58	● 0.5495
P 12	0.64	0.6207
P 13	0.73	0.6720
P 14	1.32	1.2899
P 15	1.18	1.1065
P 16	0.80	0.7601
P 17	-2.29	● 2.2485
P 18	-0.17	● 0.1478
P 19	0.09	0.0965
P 20	3.27	3.0903
P 21	2.45	2.5527
P 22	-0.04	● 0.1040
P 23	1.15	1.2180
P 24	-0.41	● 0.4435
P 25	6.84	6.7570

Pipe	Published Head Loss (ft)	Pipe Flow Expert Head Loss (ft)
P 1	6.41	6.01
P 2	11.85	12.04
P 3	0.62	0.59
P 4	9.10	8.68
P 5	10.76	9.86
P 6	30.20	28.11
P 7	45.50	43.63
P 8	51.10	54.53
P 9	43.90	35.86
P 10	7.92	3.59
P 11	9.90	6.06
P 12	8.20	8.45
P 13	9.38	8.97
P 14	59.00	58.12
P 15	29.60	26.25
P 16	23.40	20.55
P 17	7.86	8.15
P 18	1.37	0.89
P 19	0.28	0.29
P 20	37.60	40.51
P 21	30.70	33.32
P 22	0.01	0.07
P 23	6.90	7.13
P 24	6.91	7.20
P 25	30.60	34.60

P 26	6.01	6.0069
P 27	3.35	3.3507
P 28	-2.39	● 2.3010

P 26	0.91	0.65
P 27	0.31	0.21
P 28	8.43	6.94

Node	Published Press. (ft hd)	Pipe Flow Expert (psig)
N1	not published	162.6073
N2	not published	146.1446
N3	not published	133.9999
N4	not published	126.0271
N5	not published	119.8254
N6	not published	119.8479
N7	not published	127.2001
N8	not published	114.3679
N9	not published	148.3774
N10	not published	137.8059
N11	not published	133.9343
N12	not published	128.4999
N13	not published	127.4462
N14	not published	116.3962
N15	not published	123.8450
N16	not published	105.5984

Node	Published HGL. (ft)	Pipe Flow Expert HGL (ft)
N1	1365	1365.45
N2	1359	1359.44
N3	1347	1347.40
N4	1348	1347.99
N5	1357	1356.67
N6	1346	1346.81
N7	1316	1318.70
N8	1270	1275.07
N9	1321	1329.60
N10	1329	1333.19
N11	1339	1339.25
N12	1347	1347.70
N13	1392	1394.27
N14	1354	1353.75
N15	1361	1360.95
N16	1354	1353.82

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

The reference text uses the Hazen Williams method with a linear approximation to calculate head losses.
Pipe Flow Expert uses the more accurate Darcy-Weisbach equation and converges to within a pressure balance tolerance of 0.000145 psi.

The reference text indicates that the flow direction in a pipe is opposite to the direction shown on the schematic diagram by reporting the flow as negative value.
Pipe Flow Expert reversed the flow direction of the pipes indicated with '●' automatically, and reported the flow rates in these pipes as a positive value.

The correlation of the HGL values is good, indicating that the calculated pressures at the nodes must be similar to un-published pressures obtained in the reference calculation.

There are differences in the flow rate and head loss calculations for each pipe.
Although the flow and head loss results may not agree to the normal expected accuracy, it will be noted that the results are around the same order of magnitude for the vast majority of the pipes.

The flow and head loss differences are due to errors produced by the Hazen Williams empirical approximation formula, used to produce the reference text results.

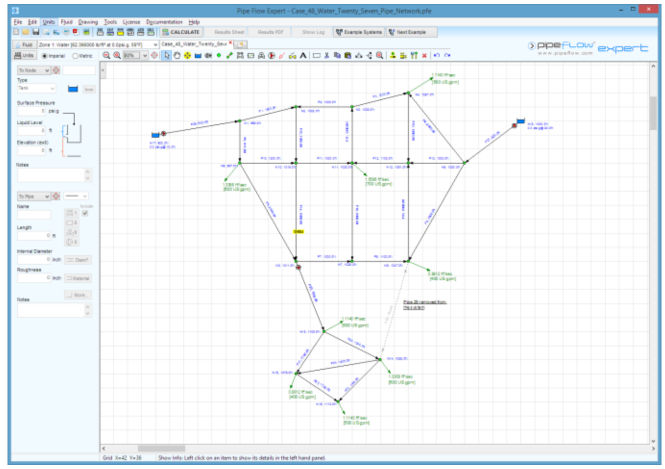
The Hazen Williams formula uses an arbitrary factor 'C' to estimate the head loss based on a particular flow rate.
The same 'C' factor is used for pipes P1 and P2, but when comparing the published results from these pipes it can be seen that the fluid velocities are 3.743 ft/sec and 5.042 ft/sec respectively.
The relative roughness factors are 0.0010 and 0.0015 respectively.
Given these comparisons it is obvious that these pipes cannot have the same friction factor.
Hence the use of the same 'C' factor will produce a degree of error in the published flow and head loss calculations.

Case 48: Water – Twenty Seven Pipe Network - 3 Pumps

Reference: Analysis of Flow in Pipe Networks, 1976, Publisher Ann Arbor Science, Rowland W. Jeppson, Example problem 6 page 98 - 99

Pipe Flow Expert File: Case_48_Water_Twenty_Seven_Pipe_Network.pfe

Problem description:



Water is supplied from two reservoirs to a twenty seven pipe network. The pipes are connected at sixteen node points. The network contains 3 pumps.
Out flows from the network occur at several node points.
The pipe network is based on the twenty eight pipe network in case 47.
Pipe P28 has been removed from the network.

Find the new flow rate and head loss for each pipe.
Find the pressure and Hydraulic Grade Line at each node point.

Fluid data: Water at 59° F (assumed).

Result Comparison:

● = Pipe Flow Expert reversed pipe direction and reported flow as positive

Pipe	Published Flow (ft³/s)	Pipe Flow Expert (ft³/s)
P 1	2.92	2.8138
P 2	-1.90	● 1.8259
P 3	-0.19	● 0.1496
P 4	1.60	1.5885
P 5	1.43	1.4052
P 6	-1.18	● 1.1447
P 7	-1.90	● 1.8358
P 8	1.60	1.6794
P 9	2.62	2.8491
P 10	-0.31	● 0.1671
P 11	-0.25	● 0.1200
P 12	0.43	0.3953
P 13	0.78	0.7010
P 14	0.96	0.9408
P 15	1.02	0.9879
P 16	0.72	0.6912
P 17	-2.09	● 1.9755
P 18	-0.65	● 0.6306
P 19	0.30	0.3249
P 20	1.83	1.7613
P 21	1.52	1.5807
P 22	0.54	0.5202
P 23	0.57	0.5938
P 24	-0.06	● 0.0958
P 25	4.45	4.4560

Pipe	Published Head Loss (ft)	Pipe Flow Expert Head Loss (ft)
P 1	6.35	6.17
P 2	13.76	14.34
P 3	0.09	0.05
P 4	7.83	6.89
P 5	26.30	24.01
P 6	7.38	6.32
P 7	15.89	14.49
P 8	28.79	30.41
P 9	32.88	27.98
P 10	4.06	0.81
P 11	2.09	0.33
P 12	3.95	3.52
P 13	10.60	9.74
P 14	32.85	31.22
P 15	22.47	21.00
P 16	19.04	17.06
P 17	6.63	6.33
P 18	15.71	14.27
P 19	2.77	2.85
P 20	12.73	13.36
P 21	12.57	12.96
P 22	1.72	1.37
P 23	1.89	1.77
P 24	0.16	0.40
P 25	13.84	15.21

P 26	5.55	5.5629
P 27	3.81	3.6947
P 28	closed	Closed

P 26	0.78	0.58
P 27	0.39	0.26
P 28	closed	Closed

Node	Published Press. (ft hd)	Pipe Flow Expert (psig)
N1	163.00	162.5977
N2	146.00	146.0675
N3	133.00	132.9273
N4	125.00	124.7194
N5	118.00	117.7421
N6	121.00	121.6356
N7	128.00	128.4283
N8	127.00	128.2147
N9	150.00	151.7808
N10	139.00	140.0037
N11	134.00	133.6521
N12	126.00	126.0820
N13	160.00	161.0361
N14	161.00	161.7472
N15	166.00	166.2500
N16	150.00	150.3247

Node	Published HGL. (ft)	Pipe Flow Expert HGL (ft)
N1	1365	1365.43
N2	1359	1359.26
N3	1345	1344.92
N4	1345	1344.97
N5	1353	1351.86
N6	1327	1327.85
N7	1319	1321.53
N8	1303	1307.04
N9	1332	1337.45
N10	1336	1338.26
N11	1338	1338.60
N12	1342	1342.12
N13	1470	1471.82
N14	1457	1458.47
N15	1458	1458.86
N16	1455	1457.07

Commentary: The published node pressure and HGL data compare well with the calculated results.

The reference text uses the Hazen Williams method with a linear approximation to calculate head losses.
Pipe Flow Expert uses the more accurate Darcy-Weisbach equation and converges to within a pressure balance tolerance of 0.000145 psi.

The reference text indicates that the flow direction in a pipe is opposite to the direction shown on the schematic diagram by reporting the flow as negative value.
Pipe Flow Expert reversed the flow direction of the pipes indicated with '●' automatically, and reported the flow rates in these pipes as a positive value.

There are differences in the flow rate and head loss calculations for each pipe.
Although the flow and head loss results may not agree to the normal expected accuracy, it will be noted that the results are around the same order of magnitude for the vast majority of the pipes.

The flow and head loss differences are due errors produced by the Hazen Williams empirical approximation formula, used to produce the reference text results.

The Hazen Williams formula uses an arbitrary factor 'C' to estimate the head loss based on a particular flow rate.
The same 'C' factor is used for pipes P1 and P2, but when comparing the published results from these pipes it can that the fluid velocities are 3.718 ft/sec and 5.443 ft/sec respectively.
The relative roughness factors are 0.0010 and 0.0015 respectively.
Given these comparisons it is obvious that these pipes cannot have the same friction factor.
Hence the use of the same 'C' factor will produce a degree of error in the flow and head loss calculations.

Case 49: Water – Fifty One Pipe Network - 30 Loops – 5 Pumps

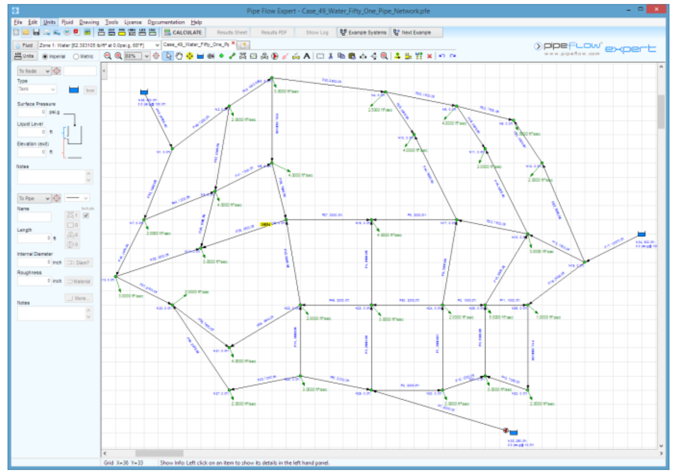
Reference: Analysis of Flow in Pipe Networks, 1976, Publisher Ann Arbor Science, Rowland W. Jeppson, Example problem 8 page 99-101

Pipe Flow Expert File: Case_49_Water_Fifty_One_Pipe_Network.pfe

Problem description:

Water is supplied from two reservoirs to a fifty one pipe network. The pipes are connected at thirty two node points. The network contains one pump. Out flows from the network occur at 27 of the node points.

Find the flow rate and head loss for each pipe.



Fluid data: Water at 68° F (assumed).

Result Comparison:

● = Pipe Flow Expert reversed pipe direction and reported flow as positive

Pipe	Published Flow (ft³/s)	Pipe Flow Expert (ft³/s)
P 1	20.40	20.3982
P 2	20.50	20.4878
P 3	10.50	10.4794
P 4	4.92	4.9235
P 5	-4.16	● 4.1712
P 6	2.76	2.7661
P 7	4.29	4.2943
P 8	4.69	4.6960
P 9	4.83	4.8387
P 10	14.18	14.1935
P 11	2.76	2.7728
P 12	-4.35	● 4.3548
P 13	-6.35	● 6.3548
P 14	1.76	1.7618
P 15	-1.47	● 1.4805
P 16	-6.11	● 6.1276
P 17	-3.02	● 3.0552
P 18	1.60	1.6011
P 19	0.40	0.3989
P 20	-1.06	● 1.0530
P 21	2.56	2.5530
P 22	4.56	4.5530
P 23	-4.31	● 4.3198
P 24	2.62	2.6175

Pipe	Published Head Loss (ft)	Pipe Flow Expert Head Loss (ft)
P 1	5.58	5.55
P 2	11.31	11.31
P 3	3.03	3.02
P 4	0.70	0.70
P 5	26.58	26.60
P 6	0.23	0.23
P 7	18.77	18.78
P 8	11.19	11.20
P 9	17.81	17.83
P 10	12.15	12.16
P 11	3.96	3.97
P 12	19.28	19.31
P 13	2.50	2.49
P 14	3.28	3.28
P 15	1.74	1.76
P 16	1.06	1.06
P 17	0.22	0.22
P 18	4.11	4.09
P 19	0.10	0.10
P 20	0.93	0.91
P 21	0.43	0.42
P 22	0.91	0.90
P 23	14.23	14.25
P 24	10.67	10.65

P 25	1.39	1.3825
P 26	3.24	3.3460
P 27	3.24	3.2477
P 28	3.19	3.1980
P 29	2.63	2.6314
P 30	7.23	7.2285
P 31	-2.73	● 2.7402
P 32	-8.32	● 8.3311
P 33	-10.82	● 10.8288
P 34	-12.82	● 12.8288
P 35	3.02	3.0210
P 36	0.98	0.9790
P 37	17.83	17.8498
P 38	-0.73	● 0.7313
P 39	-8.37	● 8.3808
P 40	12.10	12.1121
P 41	4.57	4.5666
P 42	12.33	12.3341
P 43	12.85	12.8599
P 44	8.34	8.3445
P 45	30.45	30.4630
P 46	27.18	27.1941
P 47	57.63	57.6570
P 48	20.11	20.1184
P 49	-2.61	● 2.6119
P 50	-5.16	● 5.1677
P 51	10.55	10.5690

P 25	1.04	1.03
P 26	8.61	8.62
P 27	16.27	16.26
P 28	7.89	7.89
P 29	5.39	5.38
P 30	65.76	65.75
P 31	0.97	0.97
P 32	8.50	8.49
P 33	1.61	1.61
P 34	5.63	5.62
P 35	7.07	7.05
P 36	0.80	0.79
P 37	8.62	8.61
P 38	0.06	0.06
P 39	6.45	6.44
P 40	3.02	3.01
P 41	1.58	1.57
P 42	13.82	13.81
P 43	10.01	10.00
P 44	5.12	5.11
P 45	18.60	18.60
P 46	9.90	9.90
P 47	7.77	7.74
P 48	8.19	8.18
P 49	7.08	7.07
P 50	27.05	27.07
P 51	3.07	3.07

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

The reference text indicates that the flow direction in a pipe is opposite to the direction shown on the schematic diagram by reporting the flow as negative value.
Pipe Flow Expert reversed the flow direction of the pipes indicated with '●' automatically, and reported the flow rates in these pipes as a positive value.

The reference text indicates that the out flow from node N14 is 4.00 ft^3/s, and that the out flow from node N21 is 3.00 ft^3/s. These outflows appear to have been interchanged, probably due to be a printing error.
Using the published flow rate results, the sum of flows in the pipes entering and leaving node N14 indicate a flow rate of 3.00 ft^3/s leaves this node, the sum of flows in the pipes entering and leaving node N21 indicate a flow rate of 4.00 ft^3/s leaves this node.

The Pipe Flow Expert system is based on these 'corrected' outflow values.

The close correlation of the calculation results indicates that the reference text calculations were based on these 'corrected' outflow values stated above.

There are no published values for pressures and HGL values at the node points.
The reference text only lists the elevations for the fluid surface of the 3 reservoirs.
As all the other nodes are completely surrounded by pipes which do not connect to atmosphere a change in elevation of these nodes would not affect the flow rate through the pipes in the system.

Case 50: Water – Fourteen Pipe Network - With PRV

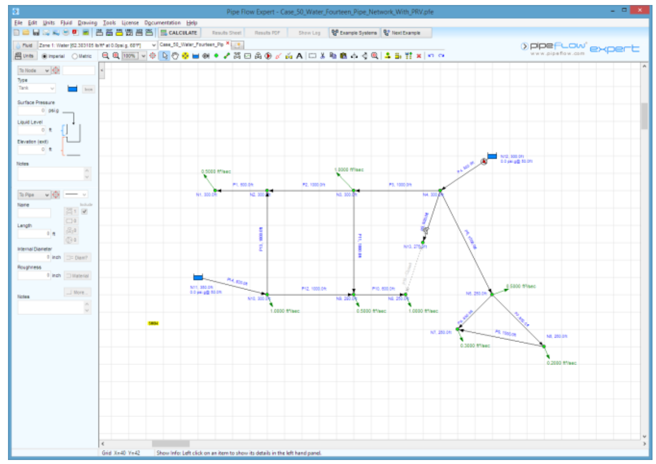
Reference: Analysis of Flow in Pipe Networks, 1976, Publisher Ann Arbor Science, Rowland W. Jeppson, Example problem 2 page 88 - 89

Pipe Flow Expert File: Case_50_Water_Fourteen_Pipe_Network_withPRV.pfe

Problem description:

Water is supplied from a reservoir to a fourteen pipe network. The network contains a pump.
Out flows from the network occur at eight node points.
The network contains a pressure reducing valve.
The downstream pressure at the node leaving the PRV is greater than the PRV setting, therefore the PRV acts a check valve.

Find the new flow rate and head loss for each pipe.
Find the Hydraulic Grade Line values upstream and downstream of the PRV.



Fluid data: Water at 68° F (assumed).

Result Comparison:

Pipe	Published Flow (ft³/s)	Pipe Flow Expert (ft³/s)
P 1	0.50	0.5000
P 2	0.37	0.3704
P 3	2.16	2.1636
P 4	3.16	3.1636
P 5	0.00	0.0000
P 6	1.00	1.0000
P 7	0.25	0.2464
P 8	0.25	0.2536
P 9	0.05	0.0464
P 10	1.00	1.0000
P 11	0.79	0.7932
P 12	0.71	0.7068
P 13	0.13	0.1296
P 14	1.84	1.8364
P 15	n/a	closed

Pipe	Published Head Loss (ft)	Pipe Flow Expert Head Loss (ft)
P 1	2.44	2.42
P 2	0.63	0.63
P 3	19.27	19.26
P 4	6.40	6.40
P 5	0.00	0.00
P 6	6.40	6.37
P 7	1.01	1.00
P 8	1.06	1.05
P 9	0.06	0.06
P 10	2.56	2.55
P 11	2.73	2.71
P 12	2.22	2.17
P 13	0.09	0.09
P 14	2.21	2.20
P 15	n/a	closed

Node	Published Press. (ft hd)	Pipe Flow Expert (psig)
N4	Not stated	50.8793
N8	Not stated	61.9071

Node	Published HGL. (ft)	Pipe Flow Expert HGL (ft)
N1	417.60	417.60
N2	393.08	393.04

Commentary:

The published flow rates, pipe head losses and HGL data compare well with the calculated results.

In the Pipe Flow Expert model, pipe P5 has been split into two pipes of equal length, so that the PRV can be positioned halfway along the original pipe length as shown in the reference text.

Since the pressure at node N8 downstream of the PRV is higher than the PRV pressure setting, the PRV will close and act as a check value preventing back flow in the pipe. Pipe Flow Expert reports that this is the case.
Pipe P15 has then been closed in the Pipe Flow Expert model to represent this situation.

The reference text list the length of pipe P1 as 1000 ft. This is most likely a printing error.
The flow rate of 0.50 ft^3/s with a head loss of 2.44 ft (as stated in the reference text) can only be applicable to a pipe 500 ft long.

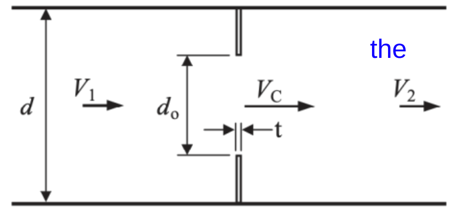
Case 51: Water - Sharp-edged Orifice Loss Coefficient in a Straight Pipe.

Reference: Pipe Flow – A Practical and Comprehensive Guide, 2012, Publisher Wiley, Donald C. Rennels, Hobart M. Hudson, Chapter 13, Page 140

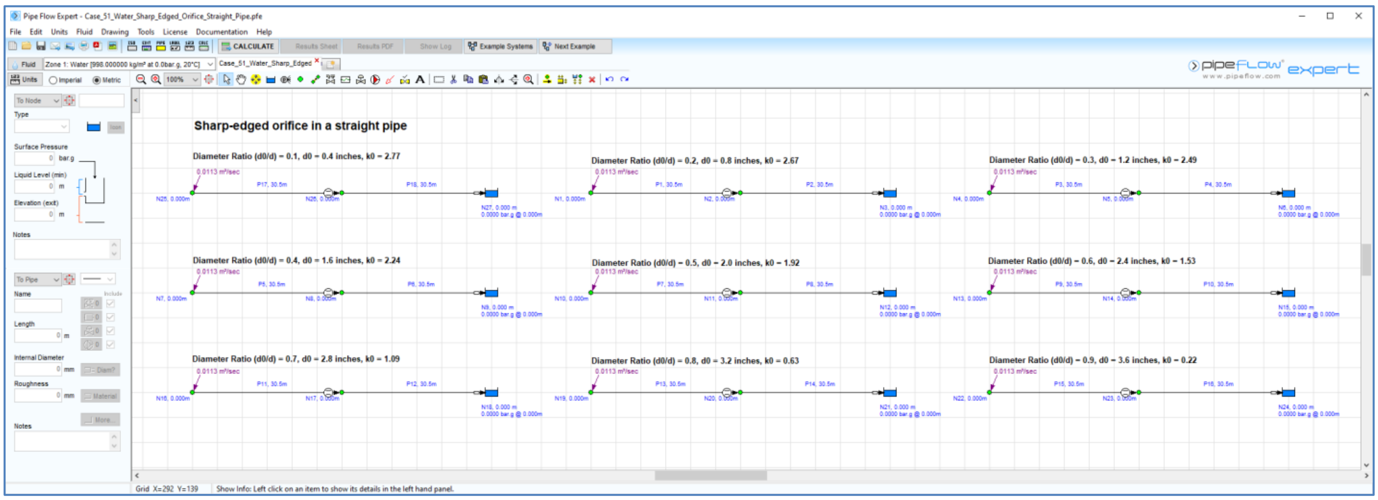
Pipe Flow Expert File: Case_51_Water_Sharp_Edged_Orifice_Straight_Pipe.pfe

Problem description:

A straight pipe contains a sharp-edged single-hole orifice.
Use different diameter ratios ($\beta = d_0/d$) to calculate the loss coefficient (k_0) of the orifice, where d_0 is orifice diameter and d is the pipe diameter.



The published data uses different calculation methods:
Rennels / Hudson, Equation 13.3, ASME Fluid Meters, and Alvi et al.



Pipe Flow Expert Parameters:

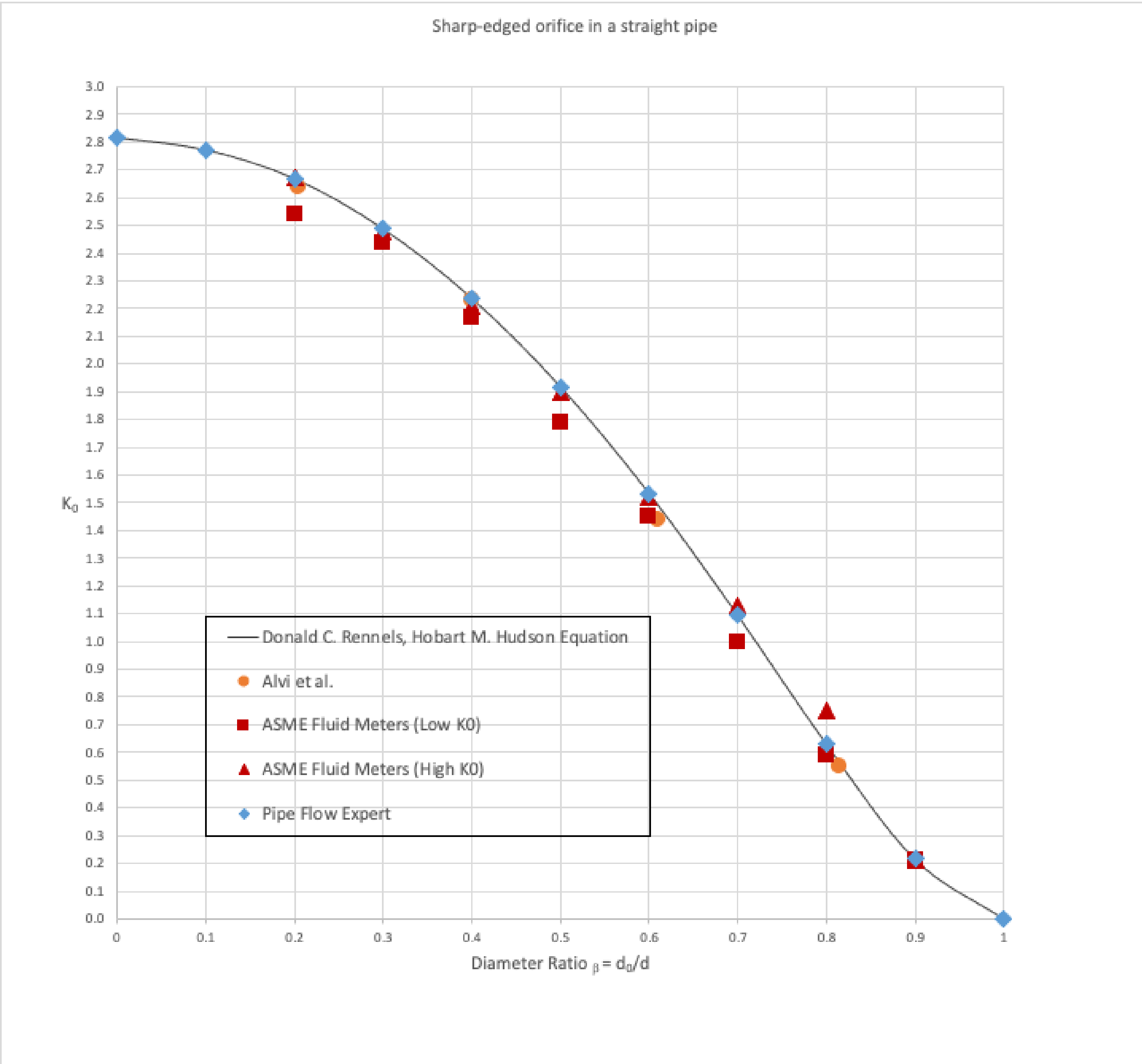
Fluid data: Water at, 68 °F
Pipe data: Internal diameter 4 inches, wall thickness 0.237 inches, roughness 1881 micro-inches

Nine systems, each with an inflow demand of 0.4 ft^3/sec, were used to model orifice diameter to pipe diameter ratios ($\beta = d_0/d$) from 0.1 through to 0.9.

Result Comparison:
Pipe Flow Expert Calculated Results and Published Graph Readings of Orifice Loss Coefficient (k_0):

Orifice Diameter / Pipe Diameter (d_0/d)	ASME Fluid Meters (High k_0)	ASME Fluid Meters (Low k_0)	Alvi et al. (k_0)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)
0.1	-	-	-	2.77	2.77
0.2	2.67	2.54	-	2.67	2.67
0.205	-	-	2.64	-	
0.3	2.48	2.44	-	2.49	2.49
0.4	2.21	2.17	2.23	2.24	2.24
0.5	1.9	1.79	-	1.92	1.92
0.6	1.52	1.45	-	1.53	1.53
0.61	-	-	1.44		
0.7	1.13	1	-	1.09	1.09
0.8	0.749	0.59	-	0.63	0.63
0.815	-	-	0.55		
0.9	0.21	0.21	-	0.22	0.22

Graphical Comparison of Results:



Commentary:

The published k_0 loss coefficients compare well with the calculated results.

Note: Head Loss in m fluid = $(k_0 * v^2) / 2g$

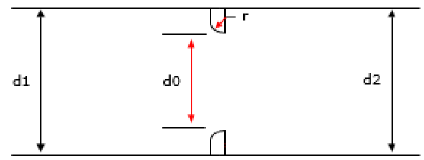
- where v = fluid velocity in m/s at the entrance to the orifice, g = acceleration due to gravity in m/s^2
- k_0 is not the same as a standard k value (which is used in formulas where v = velocity in the pipe)

Case 52: Water - Round-edged Orifice Loss Coefficient in a Straight Pipe.

Reference: Pipe Flow – A Practical and Comprehensive Guide, 2012, Publisher Wiley, Donald C. Rennels, Hobart M. Hudson, Chapter 13, Page 142

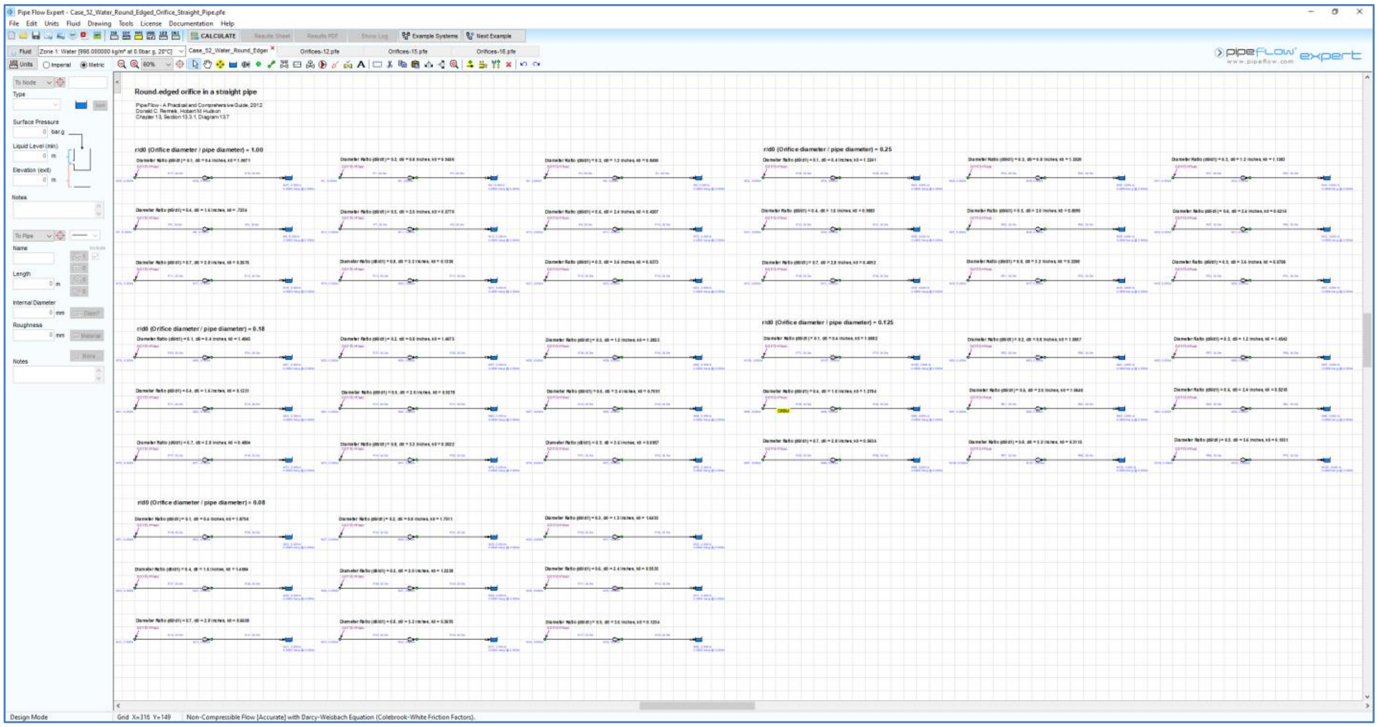
Pipe Flow Expert File: Case_52_Water_Round_Edged_Orifice_Straight_Pipe.pfe

Problem description:
A straight pipe contains a round-edged single-hole orifice. Find the k_0 loss coefficient for the orifice with a rounding radius specified as a ratio against the diameter of the orifice (r/d_0).



Use different orifice diameter to pipe diameter ratios ($\beta = d_0/d$), with varying degrees of rounding to compare the calculated loss coefficient (k_0).

The published data uses different calculation methods for comparison:
Donald C. Rennels, Hobart M. Hudson Equation, Equation 13.6, ASME Fluid Meters, and Alvi et al.



Pipe Flow Expert Parameters:

Fluid data: Water at, 68 °F
Pipe data: Internal Diameter 4 inches, wall thickness 0.237 inches, roughness 1881 micro-inches

The following 45 systems with an inflow demand of 0.4 ft^3/sec were used to model orifices with orifice / pipe diameter ratios ($\beta = d_0/d_1$) from 0.1 through to 0.9.

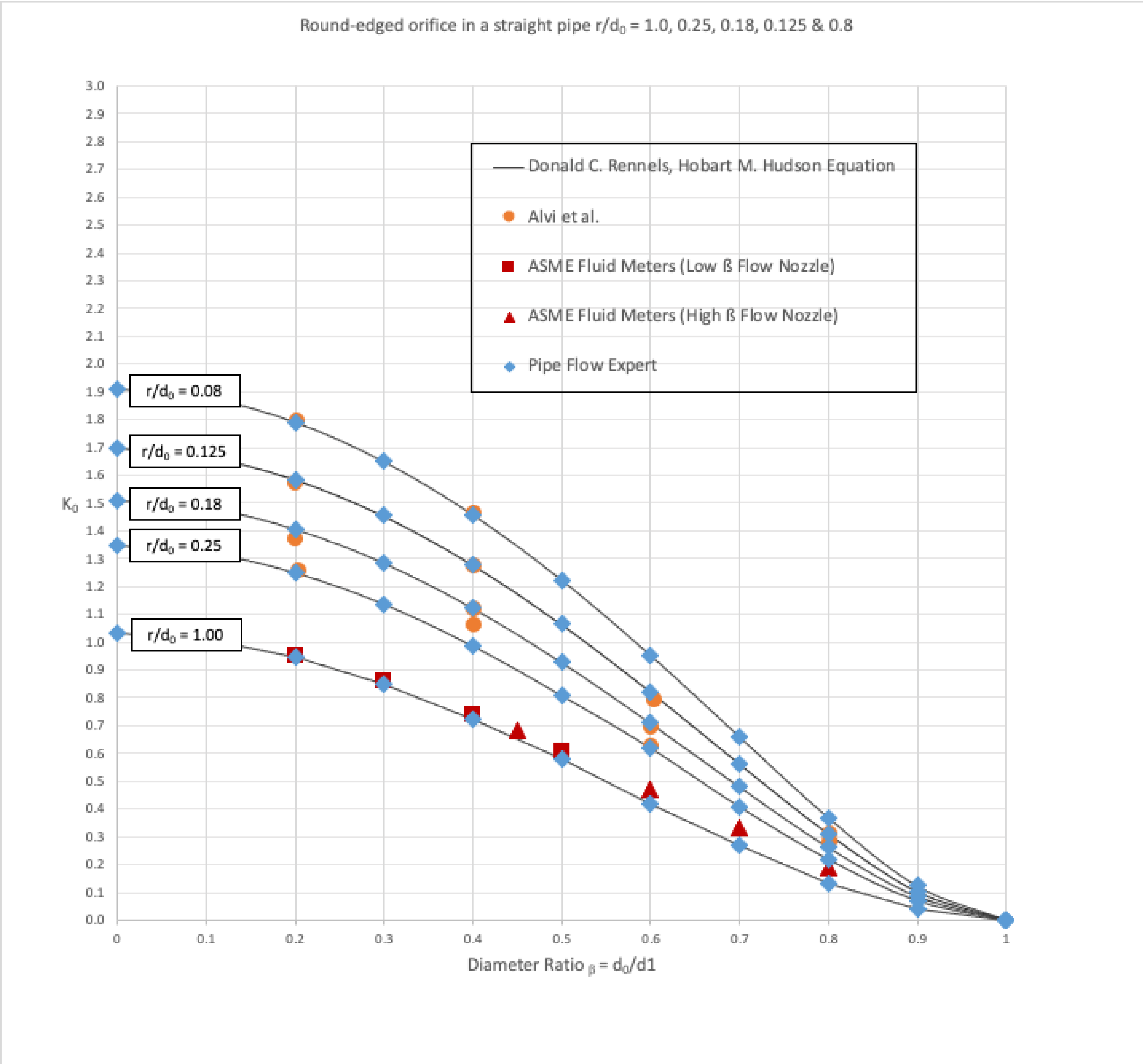
System #	r/d_o (Rounding Radius / Orifice Diameter)
1 – 9	1.00
10 – 18	0.25
19 – 27	0.18
28 – 36	0.125
37 – 45	0.08

Result Comparison:

Pipe Flow Expert Calculated Results and Published Graph Readings of Orifice Loss Coefficient (k_0):

Orifice Diameter / Pipe Diameter (d_0/d_1)	Rounding Radius / Orifice Diameter (r/d_0)	Donald C. Rennels, Hobart M. Hudson (k_0)	ASME Fluid Meters Low β Flow Nozzle (k_0)	ASME Fluid Meters High β Flow Nozzle (k_0)	Alvi et al. (k_0)	Pipe Flow Expert (k_0)
0.1	1.0	1.01	-	-	-	1.01
0.2	1.0	0.95	0.95	-	-	0.95
0.3	1.0	0.85	0.86	-	-	0.85
0.4	1.0	0.72	0.74	-	-	0.72
0.45	1.0	-	-	0.68	-	-
0.5	1.0	0.58	0.61	-	-	0.58
0.6	1.0	0.42	-	0.47	-	0.42
0.7	1.0	0.27	-	0.33	-	0.27
0.8	1.0	0.13	-	0.19	-	0.13
0.9	1.0	0.04	-	-	-	0.04
0.1	0.25	1.32	-	-	-	1.32
0.2	0.25	1.25	-	-	1.255	1.25
0.3	0.25	1.14	-	-	-	1.14
0.4	0.25	0.99	-	-	1.06	0.99
0.5	0.25	0.81	-	-	-	0.81
0.6	0.25	0.62	-	-	0.625	0.62
0.7	0.25	0.41	-	-	-	0.41
0.8	0.25	0.22	-	-	0.28	0.22
0.9	0.25	0.07	-	-	-	0.07
0.1	0.18	1.48	-	-	-	1.48
0.2	0.18	1.41	-	-	1.37	1.41
0.3	0.18	1.29	-	-	-	1.29
0.4	0.18	1.12	-	-	1.12	1.12
0.5	0.18	0.93	-	-	-	0.93
0.6	0.18	0.71	-	-	0.695	0.71
0.7	0.18	0.48	-	-	-	0.48
0.8	0.18	0.26	-	-	0.31	0.26
0.9	0.18	0.09	-	-	-	0.09
0.1	0.125	1.67	-	-	-	1.67
0.2	0.125	1.59	-	-	1.57	1.59
0.3	0.125	1.45	-	-	-	1.45
0.4	0.125	1.28	-	-	1.275	1.28
0.5	0.125	1.06	-	-	-	1.06
0.6	0.125	0.82	-	-	.79	0.82
0.7	0.125	0.56	-	-	-	0.56
0.8	0.125	0.31	-	-	-	0.31
0.9	0.125	0.10	-	-	-	0.10
0.1	0.08	1.88	-	-	-	1.88
0.2	0.08	1.79	-	-	1.795	1.79
0.3	0.08	1.65	-	-	-	1.65
0.4	0.08	1.46	-	-	1.465	1.46
0.5	0.08	1.22	-	-	-	1.22
0.6	0.08	0.95	-	-	-	0.95
0.7	0.08	0.66	-	-	-	0.66
0.8	0.08	0.37	-	-	-	0.37
0.9	0.08	0.12	-	-	-	0.12

Graphical Comparison of Results:



Commentary:

The published k_0 loss coefficients compare well with the calculated results.

Note: Head Loss in m fluid = $(k_0 * v^2) / 2g$

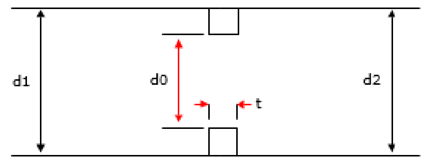
- where v = fluid velocity in m/s at the entrance to the orifice, g = acceleration due to gravity in m/s^2
- k_0 is not the same as a standard k value (which is used in formulas where v = velocity in the pipe)

Case 53: Water - Thick-edged Orifice Loss Coefficient in a Straight Pipe.

Reference: Pipe Flow – A Practical and Comprehensive Guide, 2012, Publisher Wiley, Donald C. Rennels, Hobart M. Hudson, Chapter 13, Page 146

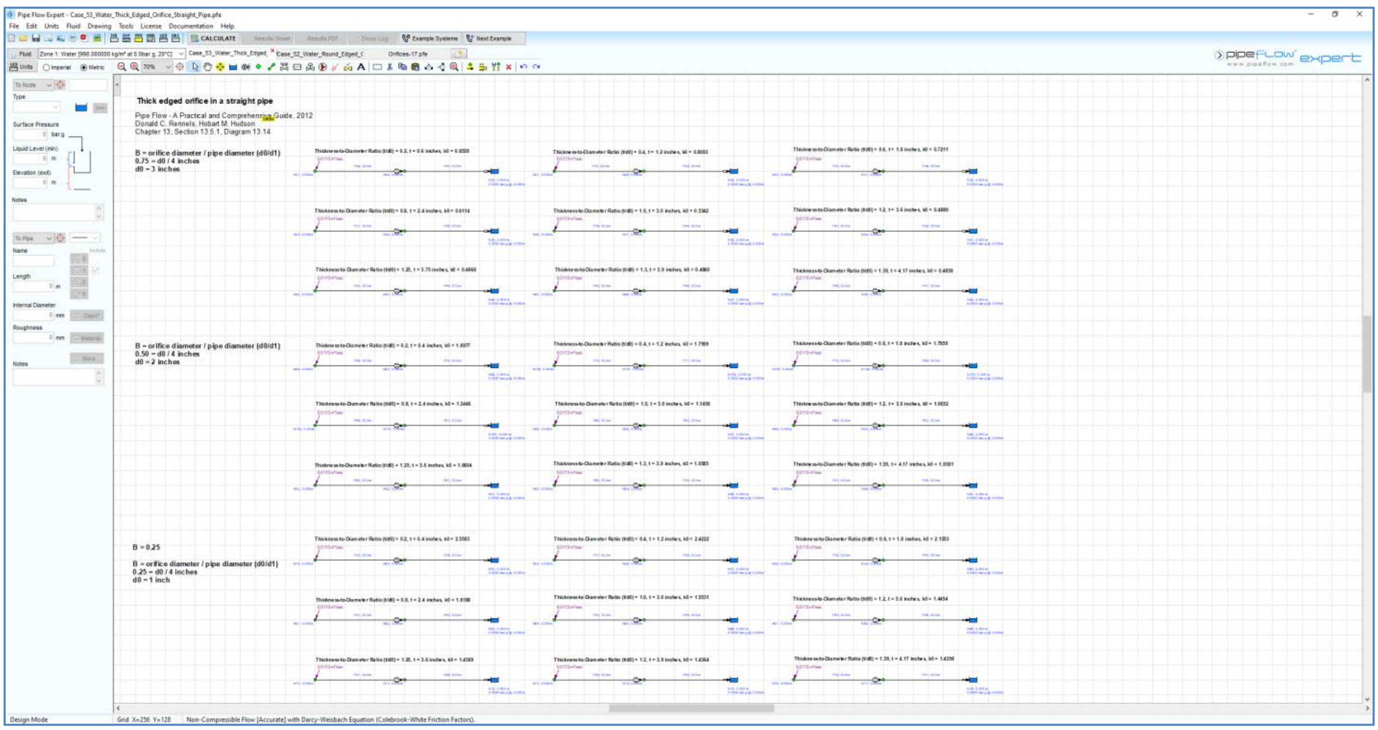
Pipe Flow Expert File: Case_53_Water_Thick_Edged_Orifice_Straight_Pipe.pfe

Problem description:
A straight pipe contains a thick-edged single-hole orifice. Find the k_0 loss coefficient for the orifice with thickness specified as a ratio against the diameter of the orifice (t/d_0).



Use different orifice thickness to orifice diameter ratios (t/d_0) to compare the calculated orifice loss coefficient (k_0) across a range of different orifice diameter to pipe diameter ratios.

The published data uses different calculation methods for comparison:
Donald C. Rennels, Hobart M. Hudson, Equation 13.13, James A.J., Sanderson E. W.



Pipe Flow Expert Parameters:

Fluid data: Water at, 68 °F
Pipe data: Internal diameter 4 inches, wall thickness 0.237 inches, roughness 1881 micro-inches

The following 27 systems, each with an inflow demand of 0.4 ft³/sec, were used to model orifices with a thickness / diameter ratio (t/d_0) ranging from 0.2 through to 2.0.

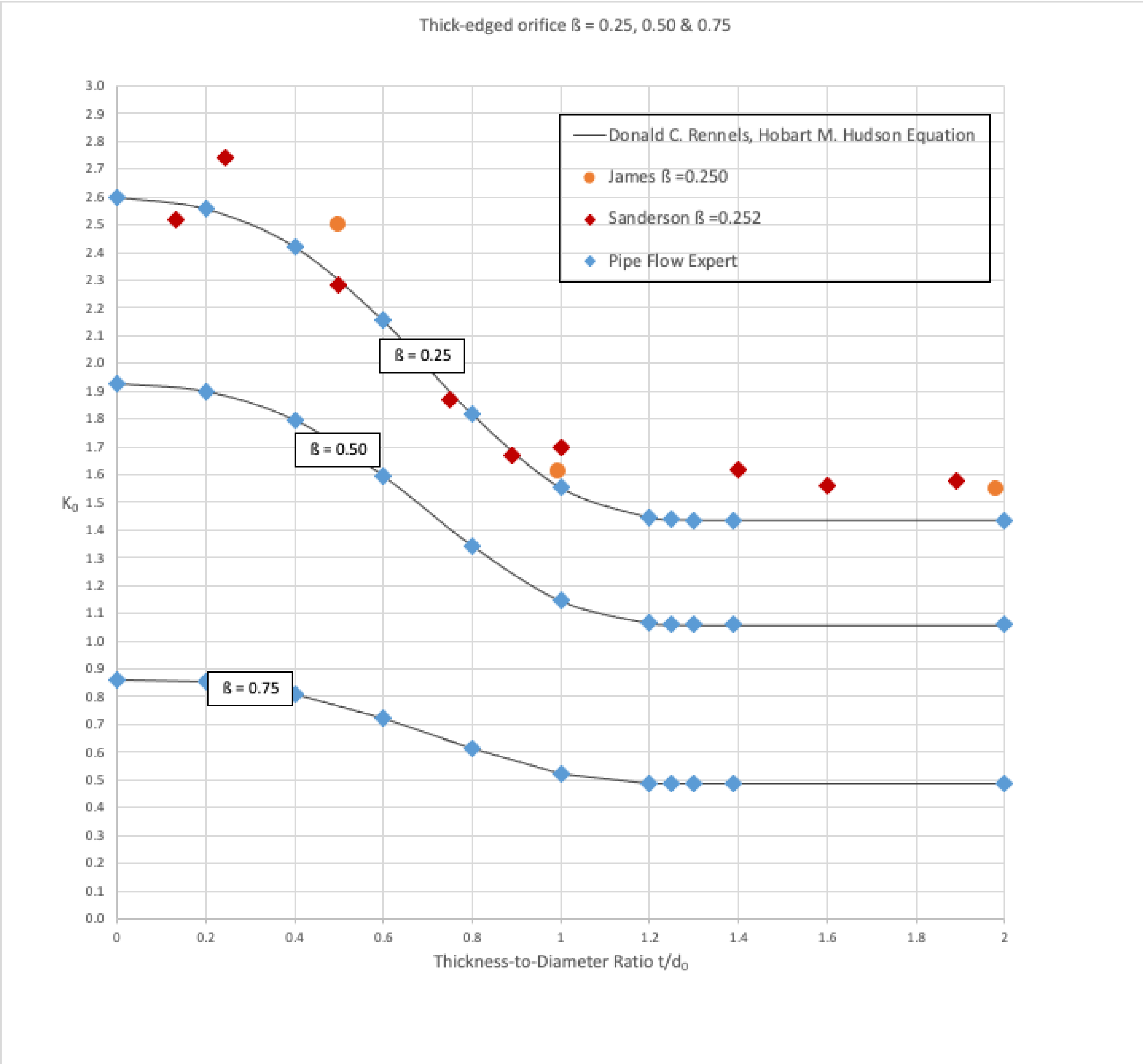
System #	$\beta = d_0/d_1$ (Orifice Diameter / Pipe Diameter)
1 – 9	0.75
10 – 18	0.50
19 – 27	0.25

Result Comparison:

Pipe Flow Expert Calculated Results and Published Graph Readings of Orifice Loss Coefficient (k_0):

Orifice Thickness / Orifice Diameter (t/d_0)	Orifice Diameter / Pipe Diameter ($\beta = d_0/d_1$)	Donald C. Rennels, Hobart M. Hudson (k_0)	James (k_0)	Sanderson (β = 0.252) (k_0)	Pipe Flow Expert (k_0)
0.2	0.75	0.8539	-	-	0.8539
0.4	0.75	0.8093	-	-	0.8093
0.6	0.75	0.7211	-	-	0.7211
0.8	0.75	0.6114	-	-	0.6114
1.0	0.75	0.5243	-	-	0.5243
1.2	0.75	0.4889	-	-	0.4889
1.25	0.75	0.4868	-	-	0.4868
1.3	0.75	0.4860	-	-	0.4860
1.39	0.75	0.4858	-	-	0.4858
2	0.75	0.4858	-	-	0.4858
0.2	0.5	1.8977	-	-	1.8977
0.4	0.5	1.7959	-	-	1.7959
0.6	0.5	1.5947	-	-	1.5947
0.8	0.5	1.3446	-	-	1.3446
1.0	0.5	1.1458	-	-	1.1458
1.2	0.5	1.0652	-	-	1.0652
1.25	0.5	1.0604	-	-	1.0604
1.3	0.5	1.0585	-	-	1.0585
1.39	0.5	1.0581	-	-	1.0581
2	0.5	1.0581	-	-	1.0581
0.132	0.25	-	-	2.52	-
0.2	0.25	2.6000	-	-	2.6000
0.245	0.25	-	-	2.74	-
0.4	0.25	2.5583	-	-	2.5583
0.5	0.25	-	2.5	2.28	-
0.6	0.25	2.4222	-	-	2.4222
0.75	0.25	-	1.87	-	-
0.8	0.25	2.1553	-	-	2.1553
0.995	0.25	-	1.61		-
1.0	0.25	1.8188	-	1.7	1.8188
1.2	0.25	1.5531	-	-	1.5531
1.25	0.25	1.4454	-	-	1.4454
1.3	0.25	1.4389	-	-	1.4389
1.39	0.25	1.4364	-	-	1.4364
1.4	0.25	-	-	1.62	-
1.6	0.25	-	-	1.56	-
1.89	0.25	-	1.55	1.58	-
2	0.25	1.4358	-	-	1.4358

Graphical Comparison of Results:



Commentary:

The published k_0 loss coefficients compare well with the calculated results.

Note: Head Loss in m fluid = (k_0 * v^2) / 2g

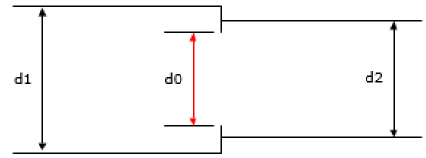
- where v = fluid velocity in m/s at the entrance to the orifice, g = acceleration due to gravity in m/s^2
- k_0 is not the same as a standard k value (which is used in formulas where v = velocity in the pipe)

Case 54: Water - Sharp-edged Orifice Loss Coefficient in a Transition.

Reference: Pipe Flow – A Practical and Comprehensive Guide, 2012, Publisher Wiley, Donald C. Rennels, Hobart M. Hudson, Chapter 13, Page 146

Pipe Flow Expert File: Case_54_Water_Sharp_Edged_Orifice_Transition_Section.pfe

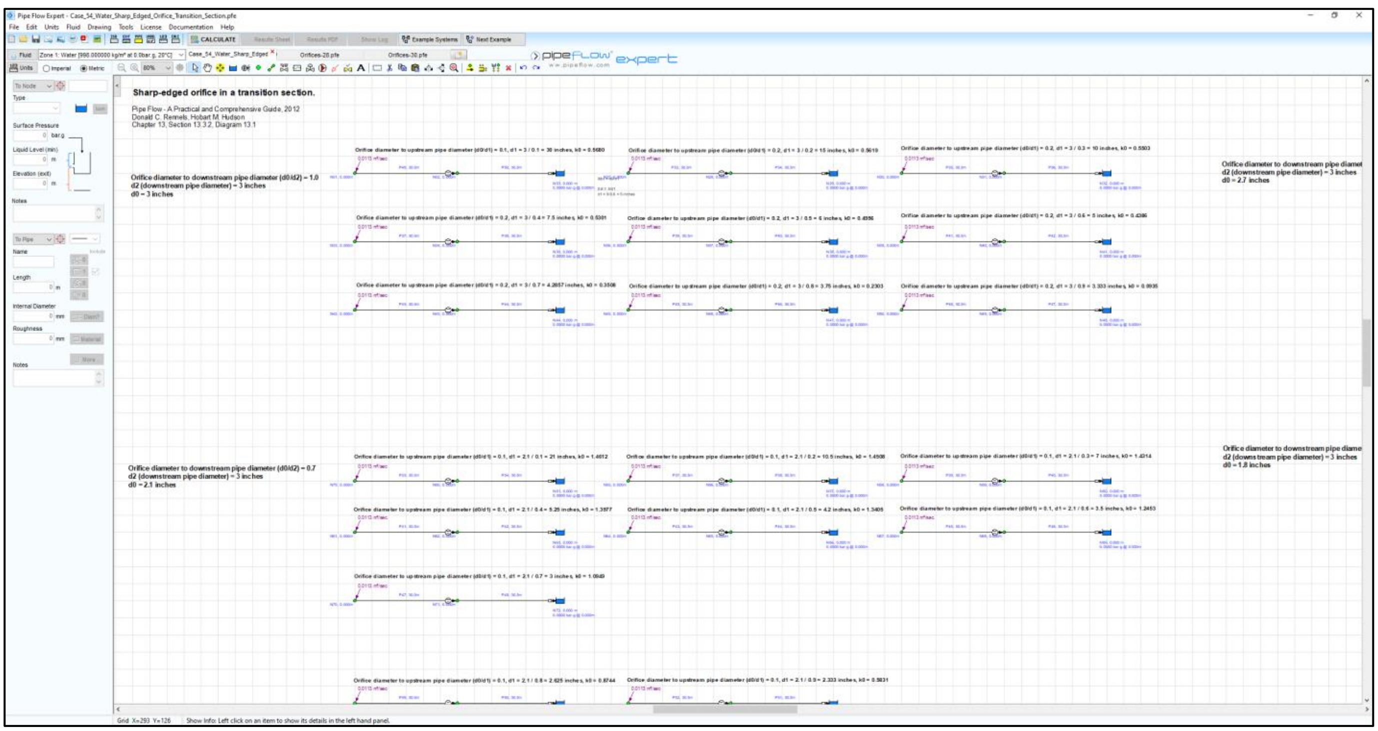
Problem description:



A transition section of pipe contains a sharp-edged single-hole orifice. The orifice diameter to upstream pipe diameter ratio is specified as d_0/d_1. The orifice diameter to downstream pipe diameter ratio is specified as d_0/d_2.

Use different orifice diameter to pipe diameter ratios, for both d_0/d_1 and d_0/d_2 to compare the calculated orifice loss coefficient (k_0) to published results.

The published data for comparison uses the following calculation method: Donald C. Rennels, Hobart M. Hudson, Equation 13.5.



Pipe Flow Expert Parameters:

Fluid data: Water at, 68 °F

Ninety individual systems, each with inflow demands of 0.4 ft^3/sec, were used to model a range of orifice diameter to upstream diameter ratios (d0/d1) over a set of orifice diameter / downstream diameter ratios (d0/d2).

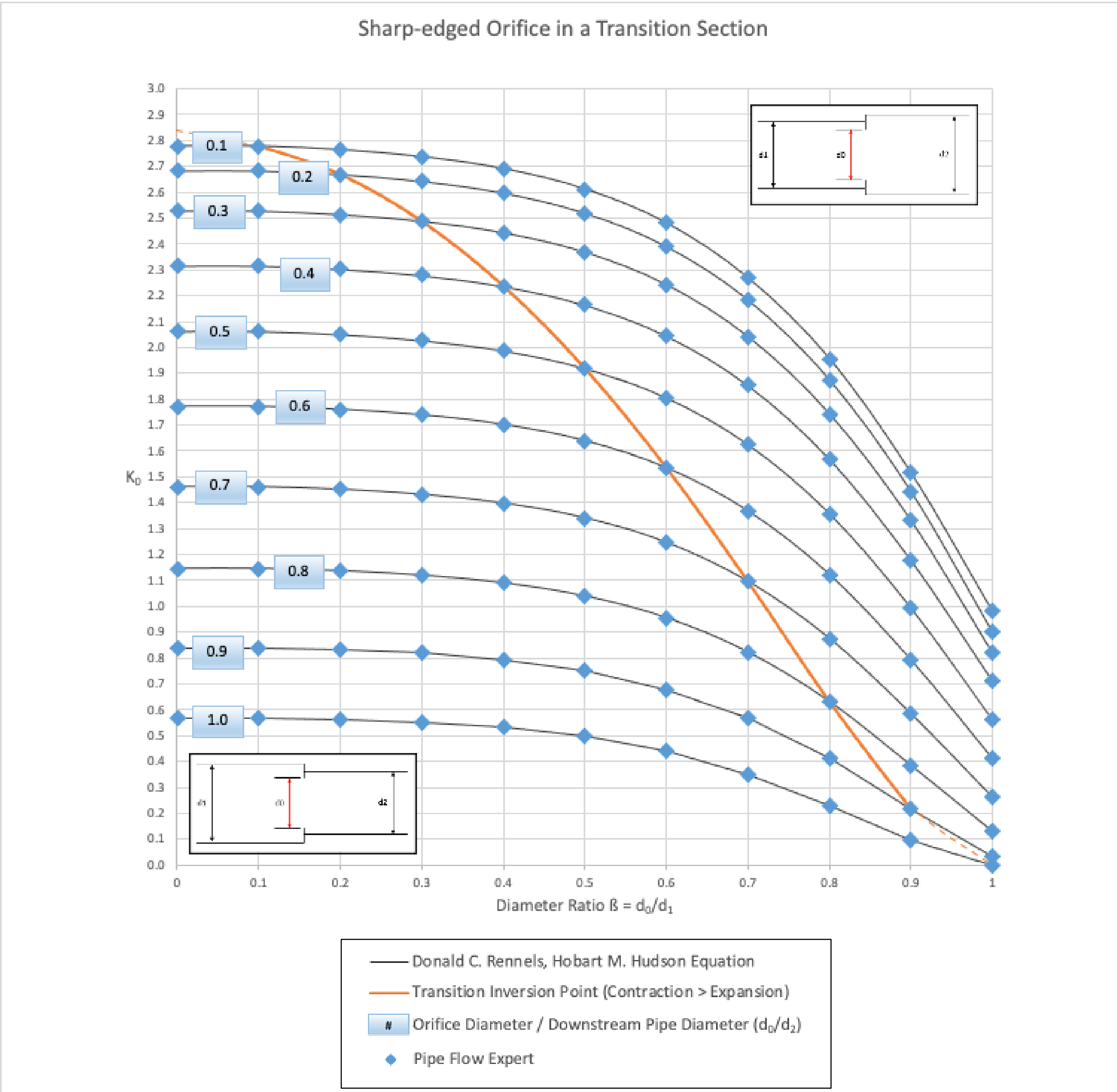
Result Comparison:

Pipe Flow Expert Calculated Results and Published Graph Readings of Orifice Loss Coefficient (k_0):

Orifice Diameter / Upstream Diameter (d_0/d_1)	Orifice Diameter / Downstream Pipe Diameter (d_0/d2)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)	Transition Type
0.1	1.0	0.5680	0.5680	Contraction
0.2	1.0	0.5619	0.5619	Contraction
0.3	1.0	0.5503	0.5503	Contraction
0.4	1.0	0.5301	0.5301	Contraction
0.5	1.0	0.4956	0.4956	Contraction
0.6	1.0	0.4386	0.4386	Contraction
0.7	1.0	0.3508	0.3508	Contraction
0.8	1.0	0.2303	0.2303	Contraction
0.9	1.0	0.0935	0.0935	Contraction
0.1	0.9	0.8400	0.8400	Contraction
0.2	0.9	0.8322	0.8322	Contraction
0.3	0.9	0.8177	0.8177	Contraction
0.4	0.9	0.7926	0.7926	Contraction
0.5	0.9	0.7495	0.7495	Contraction
0.6	0.9	0.6783	0.6783	Contraction
0.7	0.9	0.5656	0.5656	Contraction
0.8	0.9	0.4095	0.4095	Contraction
0.9	0.9	0.2153	0.2153	Straight
0.1	0.8	1.1445	1.1445	Contraction
0.2	0.8	1.1354	1.1354	Contraction
0.3	0.8	1.1182	1.1182	Contraction
0.4	0.8	1.0886	1.0886	Contraction
0.5	0.8	1.0380	1.0380	Contraction
0.6	0.8	0.9540	0.9540	Contraction
0.7	0.8	0.8219	0.8219	Contraction
0.8	0.8	0.6310	0.6310	Straight
0.9	0.8	0.3849	0.3849	Expansion
0.1	0.7	1.4612	1.4612	Contraction
0.2	0.7	1.4508	1.4508	Contraction
0.3	0.7	1.4314	1.4314	Contraction
0.4	0.7	1.3977	1.3977	Contraction
0.5	0.7	1.3405	1.3405	Contraction
0.6	0.7	1.2453	1.2453	Contraction
0.7	0.7	1.0949	1.0949	Straight
0.8	0.7	0.8744	0.8744	Expansion
0.9	0.7	0.5831	0.5831	Expansion
0.1	0.6	1.7721	1.7721	Contraction
0.2	0.6	1.7606	1.7606	Contraction
0.3	0.6	1.7391	1.7391	Contraction
0.4	0.6	1.7021	1.7021	Contraction
0.5	0.6	1.6390	1.6390	Contraction
0.6	0.6	1.5341	1.5341	Straight
0.7	0.6	1.3675	1.3675	Expansion
0.8	0.6	1.1218	1.1218	Expansion
0.9	0.6	0.7916	0.7916	Expansion
0.1	0.5	2.0615	2.0615	Contraction
0.2	0.5	2.0491	2.0491	Contraction
0.3	0.5	2.0260	2.0260	Contraction

Orifice Diameter / Upstream Diameter (d_0/d_1)	Orifice Diameter / Downstream Pipe Diameter (d_0/d2)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)	Transition Type
0.4	0.5	1.9860	1.9860	Contraction
0.5	0.5	1.9180	1.9180	Straight
0.6	0.5	1.8049	1.8049	Expansion
0.7	0.5	1.6244	1.6244	Expansion
0.8	0.5	1.3575	1.3575	Expansion
0.9	0.5	0.9927	0.9927	Expansion
0.1	0.4	2.3163	2.3163	Contraction
0.2	0.4	2.3032	2.3032	Contraction
0.3	0.4	2.2787	2.2787	Contraction
0.4	0.4	2.2363	2.2363	Straight
0.5	0.4	2.1643	2.1643	Expansion
0.6	0.4	2.0445	2.0445	Expansion
0.7	0.4	1.8533	1.8533	Expansion
0.8	0.4	1.5683	1.5683	Expansion
0.9	0.4	1.1768	1.1768	Expansion
0.1	0.3	2.5257	2.5257	Contraction
0.2	0.3	2.5120	2.5120	Contraction
0.3	0.3	2.4864	2.4864	Straight
0.4	0.3	2.4422	2.4422	Expansion
0.5	0.3	2.3671	2.3671	Expansion
0.6	0.3	2.2420	2.2420	Expansion
0.7	0.3	2.0415	2.0415	Expansion
0.8	0.3	1.7435	1.7435	Expansion
0.9	0.3	1.3318	1.3318	Expansion
0.1	0.2	2.6813	2.6813	Contraction
0.2	0.2	2.6671	2.6671	Straight
0.3	0.2	2.6408	2.6408	Expansion
0.4	0.2	2.5953	2.5953	Expansion
0.5	0.2	2.5179	2.5179	Expansion
0.6	0.2	2.3891	2.3891	Expansion
0.7	0.2	2.1831	2.1831	Expansion
0.8	0.2	1.8747	1.8747	Expansion
0.9	0.2	1.4435	1.4435	Expansion
0.1	0.1	2.7770	2.7770	Straight
0.2	0.1	2.7626	2.7626	Expansion
0.3	0.1	2.7358	2.7358	Expansion
0.4	0.1	2.6895	2.6895	Expansion
0.5	0.1	2.6108	2.6108	Expansion
0.6	0.1	2.4798	2.4798	Expansion
0.7	0.1	2.2680	2.2680	Expansion
0.8	0.1	1.9557	1.9557	Expansion
0.9	0.1	1.5154	1.5154	Expansion

Graphical Comparison of Results:



Commentary:

The published k_0 loss coefficients compare well with the calculated results.

The transition curve, shown in orange, identifies where the switch point from a contraction to an expansion. To the left of the transition curve, the internal diameter of the upstream pipe is larger than the diameter of the downstream pipe (these are contractions). To the right of the transition curve the internal diameter of the upstream pipe is smaller than the diameter of the downstream pipe (these are expansions).

Note: Head Loss in m fluid = $(k_0 * v^2) / 2g$

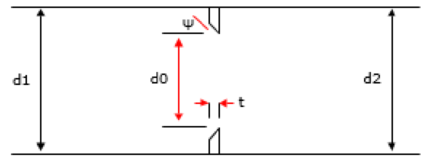
- where v = fluid velocity in m/s at the entrance to the orifice, g = acceleration due to gravity in m/s^2
- k_0 is not the same as a standard k value (which is used in formulas where v = velocity in the pipe)

Case 55: Water – 5^o Bevel-edged Orifice Loss Coefficient in a Straight Pipe.

Reference: Pipe Flow – A Practical and Comprehensive Guide, 2012, Publisher Wiley, Donald C. Rennels, Hobart M. Hudson, Chapter 13, Page 145

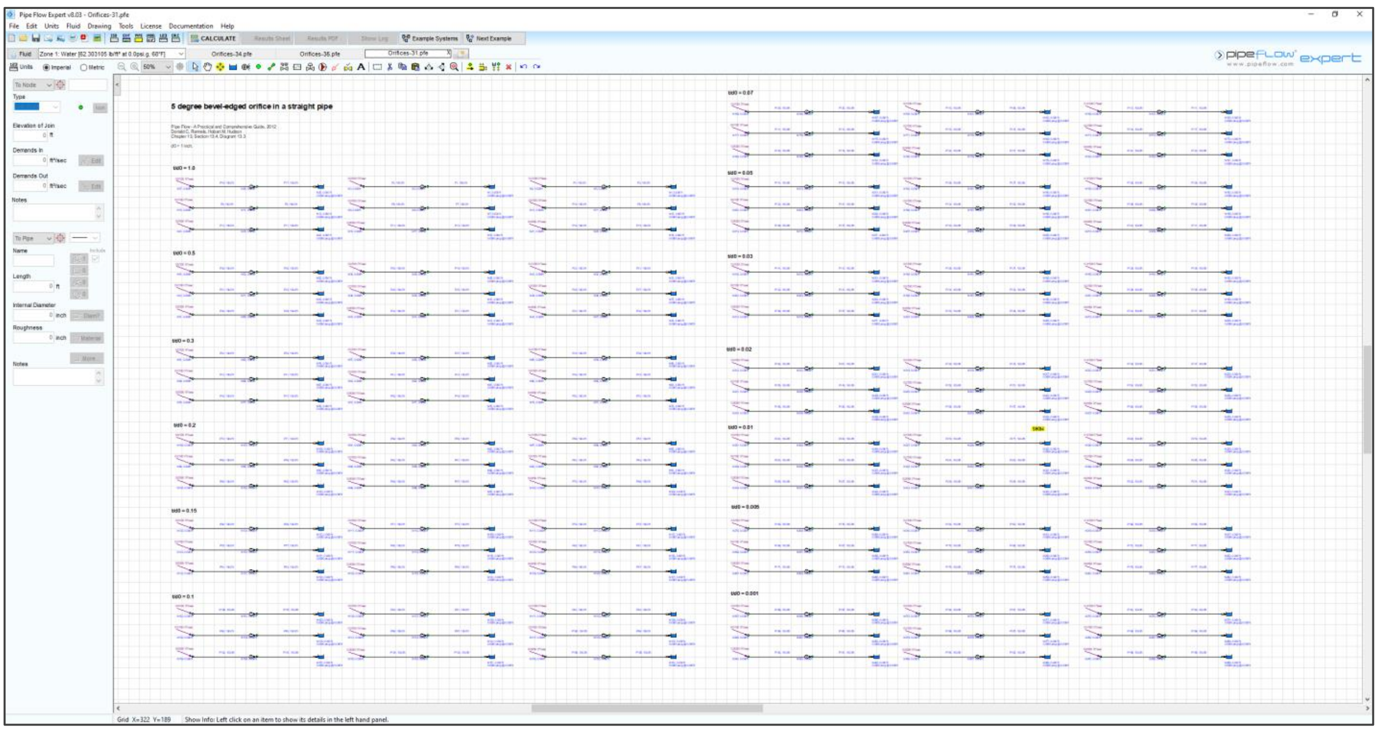
Pipe Flow Expert File: Case_55_Water_5deg_Bevel_Edged_Orifice_Straight_Pipe.pfe

Problem description:



A straight pipe contains a 5º bevel-edged single-hole orifice. The orifice diameter to pipe diameter is specified by the ratio d_0/d_1. The orifice thickness to orifice diameter is specified by the ratio t/d_0.

Use different orifice thickness to orifice diameter ratios (t/d_0) to compare the loss coefficient (k0) through the orifice with varying orifice diameter to pipe diameter ratios (d_0/d).



Pipe Flow Expert Parameters:

Fluid data: Water at, 68 °F

One hundred and sixty-nine individual systems with inflow demands of 0.01 ft^3/sec were used to model a range of bevel thickness to orifice diameter ratios (t/d_0) across a range of orifice diameter to pipe diameter ratios (d_0/d).

Result Comparison:

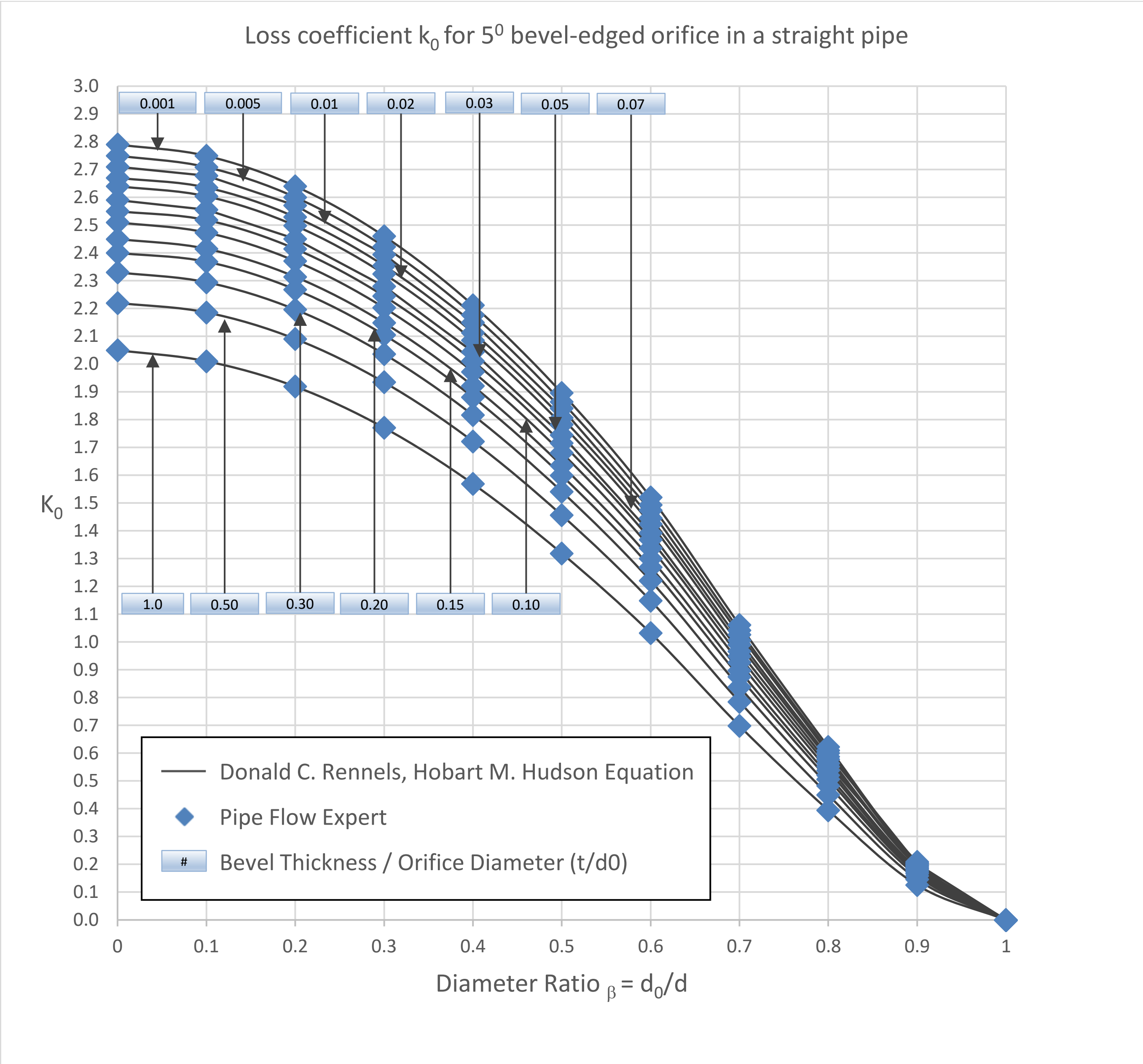
Pipe Flow Expert Calculated Results and Published Graph Readings of Orifice Loss Coefficient (k_0):

Orifice Diameter / Pipe Diameter (d_0/d)	Orifice Thickness / Pipe Diameter (t/d_0)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)
0.1	1.0	2.0103	2.0103
0.2	1.0	1.9193	1.9193

Orifice Diameter / Pipe Diameter (d_0/d)	**Orifice Thickness / Pipe Diameter (t/d_0)**	**Donald C. Rennels, Hobart M. Hudson (k_0)**	**Pipe Flow Expert (k_0)**
0.3	1.0	1.7709	1.7709
0.4	1.0	1.5691	1.5691
0.5	1.0	1.3191	1.3191
0.6	1.0	1.0323	1.0323
0.7	1.0	0.6980	0.6980
0.8	1.0	0.3946	0.3946
0.9	1.0	0.1255	0.1255
0.1	0.5	2.1859	2.1859
0.2	0.5	2.0906	2.0906
0.3	0.5	1.9347	1.9347
0.4	0.5	1.7220	1.7220
0.5	0.5	1.4563	1.4563
0.6	0.5	1.1486	1.1486
0.7	0.5	0.7849	0.7849
0.8	0.5	0.4497	0.4497
0.9	0.5	0.1465	0.1465
0.1	0.3	2.2945	2.2945
0.2	0.3	2.1965	2.1965
0.3	0.3	2.0360	2.0360
0.4	0.3	1.8164	1.8164
0.5	0.3	1.5412	1.5412
0.6	0.3	1.2204	1.2204
0.7	0.3	0.8385	0.8385
0.8	0.3	0.4834	0.4834
0.9	0.3	0.1591	0.1591
0.1	0.2	2.3684	2.3684
0.2	0.2	2.2685	2.2685
0.3	0.2	2.1050	2.1050
0.4	0.2	1.8807	1.8807
0.5	0.2	1.5989	1.5989
0.6	0.2	1.2692	1.2692
0.7	0.2	0.8750	0.8750
0.8	0.2	0.5062	0.5062
0.9	0.2	0.1676	0.1676
0.1	0.15	2.4149	2.4149
0.2	0.15	2.3140	2.3140
0.3	0.15	2.1484	2.1484
0.4	0.15	1.9212	1.9212
0.5	0.15	1.6352	1.6352
0.6	0.15	1.3000	1.3000
0.7	0.15	0.8979	0.8979
0.8	0.15	0.5206	0.5206
0.9	0.15	0.1728	0.1728
0.1	0.1	2.4732	2.4732
0.2	0.1	2.3708	2.3708
0.3	0.1	2.2028	2.2028
0.4	0.1	1.9720	1.9720
0.5	0.1	1.6808	1.6808
0.6	0.1	1.3385	1.3385
0.7	0.1	0.9265	0.9265
0.8	0.1	0.5384	0.5384
0.9	0.1	0.1793	0.1793
0.1	0.07	2.5181	2.5181
0.2	0.07	2.4146	2.4146
0.3	0.07	2.2447	2.2447
0.4	0.07	2.0110	2.0110
0.5	0.07	1.7158	1.7158
0.6	0.07	1.3681	1.3681
0.7	0.07	0.9485	0.9485
0.8	0.07	0.5522	0.5522
0.9	0.07	0.1842	0.1842

Orifice Diameter / Pipe Diameter (d_0/d)	Orifice Thickness / Pipe Diameter (t/d_0)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)
0.1	0.05	2.6037	2.6037
0.2	0.05	2.4980	2.4980
0.3	0.05	2.3245	2.3245
0.4	0.05	2.0854	2.0854
0.5	0.05	1.7826	1.7826
0.6	0.05	1.4245	1.4245
0.7	0.05	0.9904	0.9904
0.8	0.05	0.5782	0.5782
0.9	0.05	0.1935	0.1935
0.1	0.03	2.6354	2.6354
0.2	0.03	2.5290	2.5290
0.3	0.03	2.3541	2.3541
0.4	0.03	2.1130	2.1130
0.5	0.03	1.8073	1.8073
0.6	0.03	1.4455	1.4455
0.7	0.03	1.0060	1.0060
0.8	0.03	0.5878	0.5878
0.9	0.03	0.1969	0.1969
0.1	0.02	2.7088	2.7088
0.2	0.02	2.6006	2.6006
0.3	0.02	2.4226	2.4226
0.4	0.02	2.1769	2.1769
0.5	0.02	1.8646	1.8646
0.6	0.02	1.4939	1.4939
0.7	0.02	1.0419	1.0419
0.8	0.02	0.6101	0.6101
0.9	0.02	0.2048	0.2048
0.1	0.01	2.7492	2.7492
0.2	0.01	2.6400	2.6400
0.3	0.01	2.4603	2.4603
0.4	0.01	2.2120	2.2120
0.5	0.01	1.8962	1.8962
0.6	0.01	1.5206	1.5206
0.7	0.01	1.0617	1.0617
0.8	0.01	0.6224	0.6224
0.9	0.01	0.2091	0.2091
0.1	0.005	2.5550	2.5550
0.2	0.005	2.4510	2.4510
0.3	0.005	2.2795	2.2795
0.4	0.005	2.0435	2.0435
0.5	0.005	1.7449	1.7449
0.6	0.005	1.3927	1.3927
0.7	0.005	0.9668	0.9668
0.8	0.005	0.5635	0.5635
0.9	0.005	0.1883	0.1883
0.1	0.001	2.6781	2.6781
0.2	0.001	2.5706	2.5706
0.3	0.001	2.3939	2.3939
0.4	0.001	2.1501	2.1501
0.5	0.001	1.8406	1.8406
0.6	0.001	1.4736	1.4736
0.7	0.001	1.0269	1.0269
0.8	0.001	0.6008	0.6008
0.9	0.001	0.2015	0.2015

Graphical Comparison of Formula:



Commentary:

The published loss coefficients compare well with the calculated results.

Bevel Limit: There is a point where beveling is limited by the available radial distance between the pipe wall and the face of the orifice. For a 5^0 bevel angle this limitation occurs when d_0/d is greater than about 0.87 and hence this is not significant when considering the points on the above graph.

Note: Head Loss in m fluid = $(k_0 * v^2) / 2g$

- where v = fluid velocity in m/s at the entrance to the orifice, g = acceleration due to gravity in m/s^2
- k_0 is not the same as a standard k value (which is used in formulas where v = velocity in the pipe)

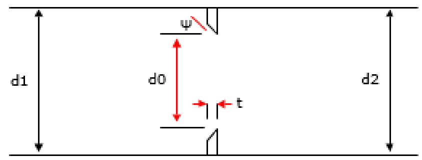
Case 56: Water – 45^o Bevel-edged Orifice Loss Coefficient in a Straight Pipe.

Reference: Pipe Flow – A Practical and Comprehensive Guide, 2012, Publisher Wiley,
Donald C. Rennels, Hobart M. Hudson, Chapter 13, Page 145

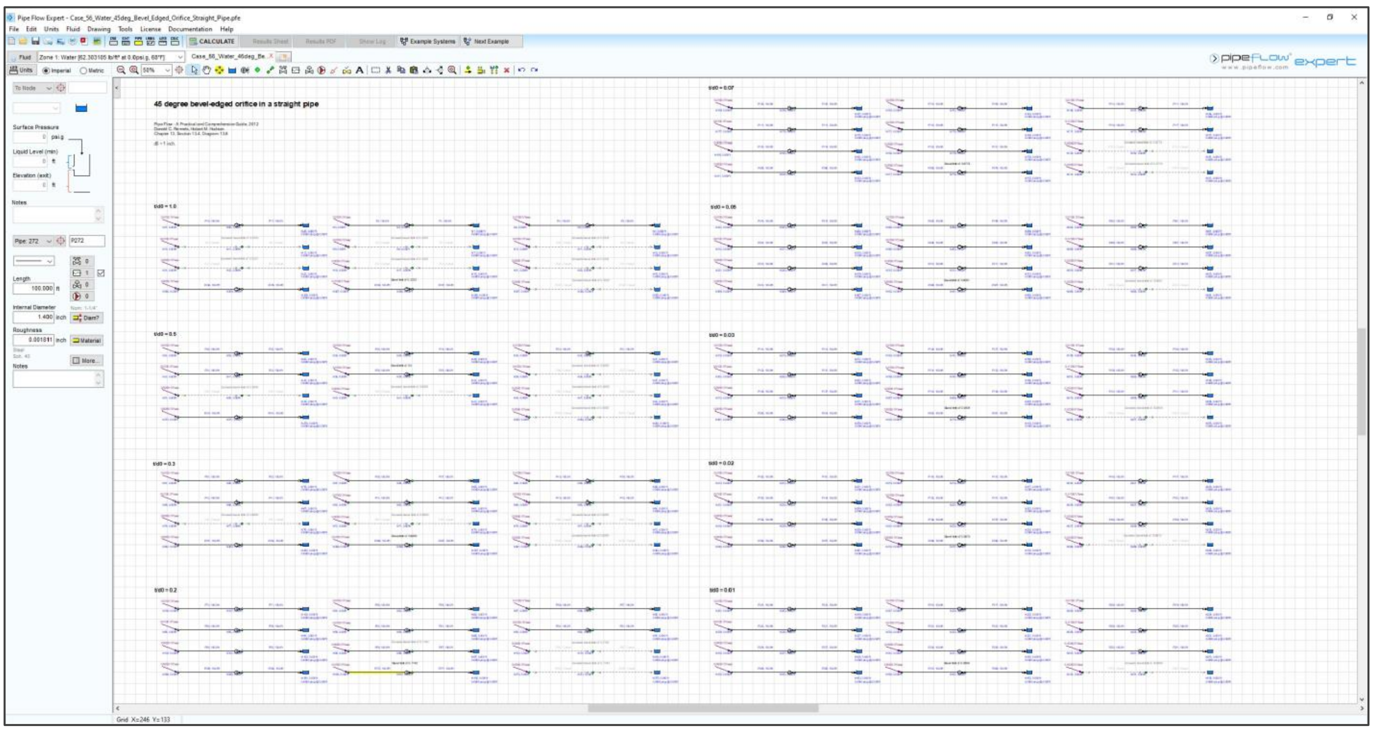
Pipe Flow Expert File: Case_56_Water_5deg_Bevel_Edged_Orifice_Straight_Pipe.pfe

Problem description:

A straight pipe contains a 45^o bevel-edged single-hole orifice. The orifice diameter to pipe diameter is specified by the ratio d_0/d_1. The orifice thickness to orifice diameter is specified by the ratio t/d_0.



Use different orifice thickness to orifice diameter ratios (t/d_0) to compare the loss coefficient (k0) through the orifice with varying orifice diameter to pipe diameter ratios (d_0/d).



Pipe Flow Expert Parameters:

Fluid data: Water at, 68 °F

One hundred and forty-three individual systems with inflow demands of 0.01 ft^3/sec were used to model a range of bevel thickness to orifice diameter ratios (t/d_0) across a range of orifice diameter to pipe diameter ratios (d_0/d).

Result Comparison:

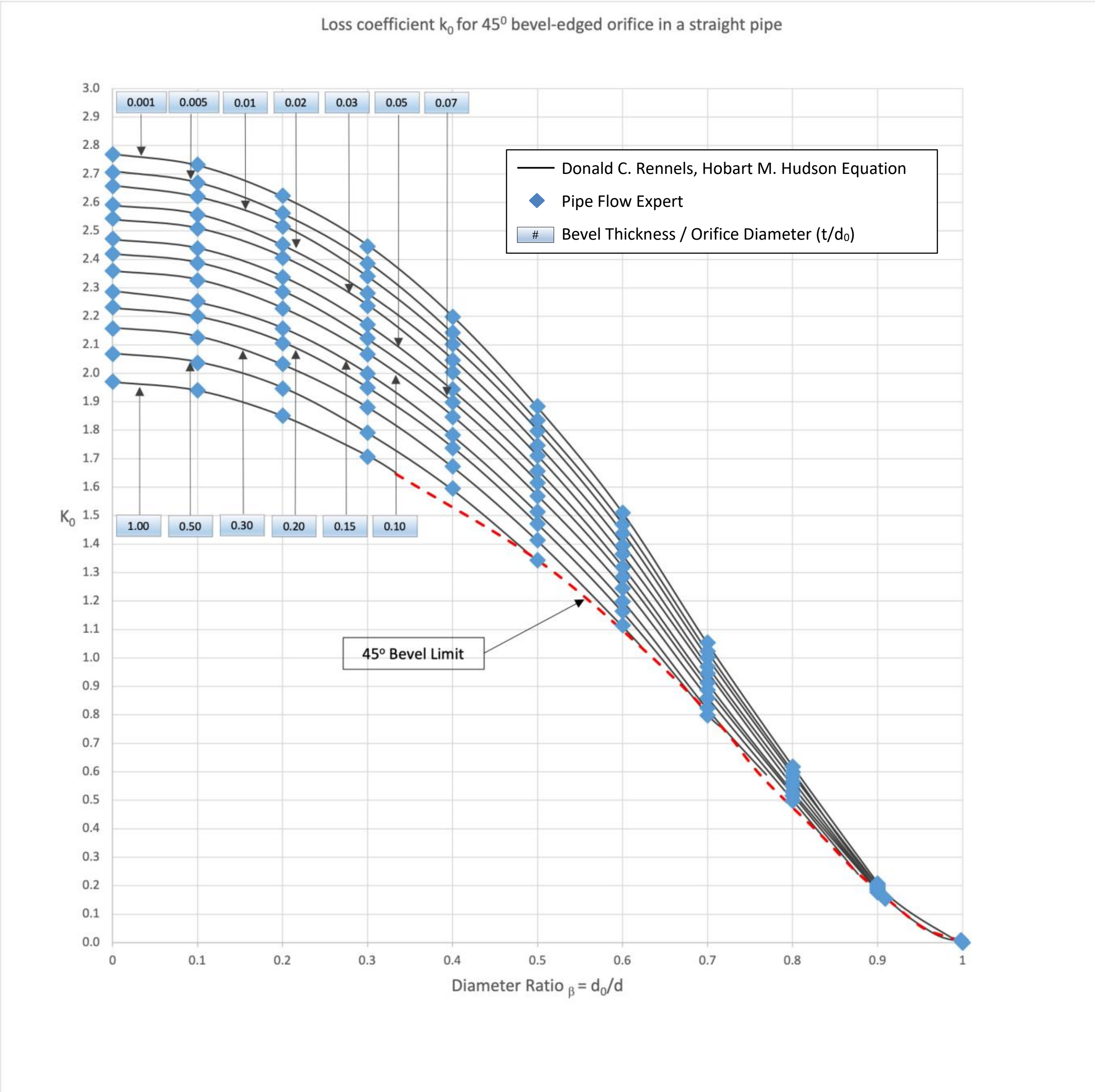
Pipe Flow Expert Calculated Results and Published Graph Readings of Orifice Loss Coefficient (k_0):

Orifice Diameter / Pipe Diameter (d_0/d)	Orifice Thickness / Pipe Diameter (t/d_0)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)
0.1	1.0	1.94	1.9400
0.2	1.0	1.85	1.8514
0.3	1.0	1.71	1.7065
0.4	1.0	Bevel Limit Exceeded	Bevel Limit Exceeded
0.5	1.0	Bevel Limit Exceeded	Bevel Limit Exceeded
0.6	1.0	Bevel Limit Exceeded	Bevel Limit Exceeded
0.7	1.0	Bevel Limit Exceeded	Bevel Limit Exceeded
0.8	1.0	Bevel Limit Exceeded	Bevel Limit Exceeded
0.9	1.0	Bevel Limit Exceeded	Bevel Limit Exceeded
0.1	0.5	2.04	2.0367
0.2	0.5	1.95	1.9457
0.3	0.5	1.79	1.7910
0.4	0.5	1.59	1.5949
0.5	0.5	1.34	1.3439
0.6	0.5	Bevel Limit Exceeded	Bevel Limit Exceeded
0.7	0.5	Bevel Limit Exceeded	Bevel Limit Exceeded
0.8	0.5	Bevel Limit Exceeded	Bevel Limit Exceeded
0.9	0.5	Bevel Limit Exceeded	Bevel Limit Exceeded
0.1	0.3	2.13	2.1256
0.2	0.3	2.03	2.0323
0.3	0.3	1.88	1.8800
0.4	0.3	1.67	1.6723
0.5	0.3	1.41	1.4135
0.6	0.3	1.11	1.1144
0.7	0.3	Bevel Limit Exceeded	Bevel Limit Exceeded
0.8	0.3	Bevel Limit Exceeded	Bevel Limit Exceeded
0.9	0.3	Bevel Limit Exceeded	Bevel Limit Exceeded
0.1	0.2	2.20	2.2004
0.2	0.2	2.11	2.1053
0.3	0.2	1.95	1.9497
0.4	0.2	1.74	1.7372
0.5	0.2	1.47	1.4717
0.6	0.2	1.16	1.1635
0.7	0.2	0.80	0.7983
0.8	0.2	Bevel Limit Exceeded	Bevel Limit Exceeded
0.9	0.2	Bevel Limit Exceeded	Bevel Limit Exceeded
0.1	0.15	2.25	2.2535
0.2	0.15	2.16	2.1570
0.3	0.15	2.00	1.9992
0.4	0.15	1.78	1.7832
0.5	0.15	1.51	1.5129
0.6	0.15	1.20	1.1982
0.7	0.15	0.82	0.8240
0.8	0.15	Bevel Limit Exceeded	Bevel Limit Exceeded
0.9	0.15	Bevel Limit Exceeded	Bevel Limit Exceeded

Orifice Diameter / Pipe Diameter (d_0/d)	**Orifice Thickness / Pipe Diameter (t/d_0)**	**Donald C. Rennels, Hobart M. Hudson (k_0)**	**Pipe Flow Expert (k_0)**
0.1	0.1	2.33	2.3261
0.2	0.1	2.23	2.2278
0.3	0.1	2.07	2.0667
0.4	0.1	1.85	1.8461
0.5	0.1	1.57	1.5690
0.6	0.1	1.25	1.2455
0.7	0.1	0.86	0.8590
0.8	0.1	0.50	0.4978
0.9	0.1	Bevel Limited Exceeded	Bevel Limit Exceeded
0.1	0.07	2.39	2.3862
0.2	0.07	2.29	2.2863
0.3	0.07	2.12	2.1225
0.4	0.07	1.90	1.8980
0.5	0.07	1.62	1.6154
0.6	0.07	1.29	1.2850
0.7	0.07	0.89	0.8878
0.8	0.07	0.52	0.5156
0.9	0.07	Bevel Limit Exceeded	Bevel Limit Exceeded
0.1	0.05	2.44	2.4385
0.2	0.05	2.34	2.3372
0.3	0.05	2.17	2.1712
0.4	0.05	1.94	1.9432
0.5	0.05	1.66	1.6559
0.6	0.05	1.32	1.3185
0.7	0.05	0.91	0.9129
0.8	0.05	0.53	0.5310
0.9	0.05	Bevel Limit Exceeded	Bevel Limit Exceeded
0.1	0.03	2.51	2.5087
0.2	0.03	2.41	2.4056
0.3	0.03	2.24	2.2365
0.4	0.03	2.00	2.0039
0.5	0.03	1.71	1.7101
0.6	0.03	1.36	1.3641
0.7	0.03	0.95	0.9465
0.8	0.03	0.55	0.5517
0.9	0.03	Bevel Limit Exceeded	Bevel Limit Exceeded
0.1	0.02	2.56	2.5563
0.2	0.02	2.45	2.4520
0.3	0.02	2.28	2.2808
0.4	0.02	2.05	2.0451
0.5	0.02	1.75	1.7469
0.6	0.02	1.40	1.3951
0.7	0.02	0.97	0.9693
0.8	0.02	0.57	0.5657
0.9	0.02	0.19	0.1896
0.1	0.01	2.62	2.6216
0.2	0.01	2.52	2.5157
0.3	0.01	2.34	2.3416
0.4	0.01	2.10	2.1016
0.5	0.01	1.80	1.7975
0.6	0.01	1.44	1.4376
0.7	0.01	1.00	1.0006
0.8	0.01	0.59	0.5850
0.9	0.01	0.20	0.1962
0.1	0.005	2.67	2.6694

Orifice Diameter / Pipe Diameter (d_0/d)	**Orifice Thickness / Pipe Diameter (t/d_0)**	**Donald C. Rennels, Hobart M. Hudson (k_0)**	**Pipe Flow Expert (k_0)**
0.2	0.005	2.56	2.5623
0.3	0.005	2.39	2.3861
0.4	0.005	2.14	2.1430
0.5	0.005	1.83	1.8345
0.6	0.005	1.47	1.4687
0.7	0.005	1.02	1.0236
0.8	0.005	0.60	0.5990
0.9	0.005	0.20	0.2011
0.1	0.001	2.73	2.7329
0.2	0.001	2.62	2.6241
0.3	0.001	2.45	2.4452
0.4	0.001	2.20	2.1980
0.5	0.001	1.88	1.8837
0.6	0.001	1.51	1.5102
0.7	0.001	1.05	1.0541
0.8	0.001	0.62	0.6178
0.9	0.001	0.21	0.2076

Graphical Comparison of Formula:



Commentary:

The published loss coefficients compare well with the calculated results.

Bevel Limit: There is a point where beveling is limited by the available radial distance between the pipe wall and the face of the orifice. The dashed red line on the above graph plots the bevel limit cut off point across each t/d_o line. Points below the dashed red line are not valid and should not be calculated. The Pipe Flow Expert software reports a 'Bevel Limit Exceeded' message for any defined orifice data that is in this region.

Note: Head Loss in m fluid = $(k_0 * v^2) / 2g$

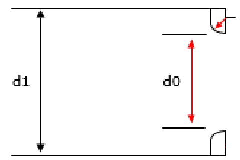
- where v = fluid velocity in m/s at the entrance to the orifice, g = acceleration due to gravity in m/s^2
- k_0 is not the same as a standard k value (which is used in formulas where v = velocity in the pipe)

Case 57: Water – Round-edged Orifice Loss Coefficient discharging to a reservoir.

Reference: Pipe Flow – A Practical and Comprehensive Guide, 2012, Publisher Wiley, Donald C. Rennels, Hobart M. Hudson, Chapter 12, Page 133

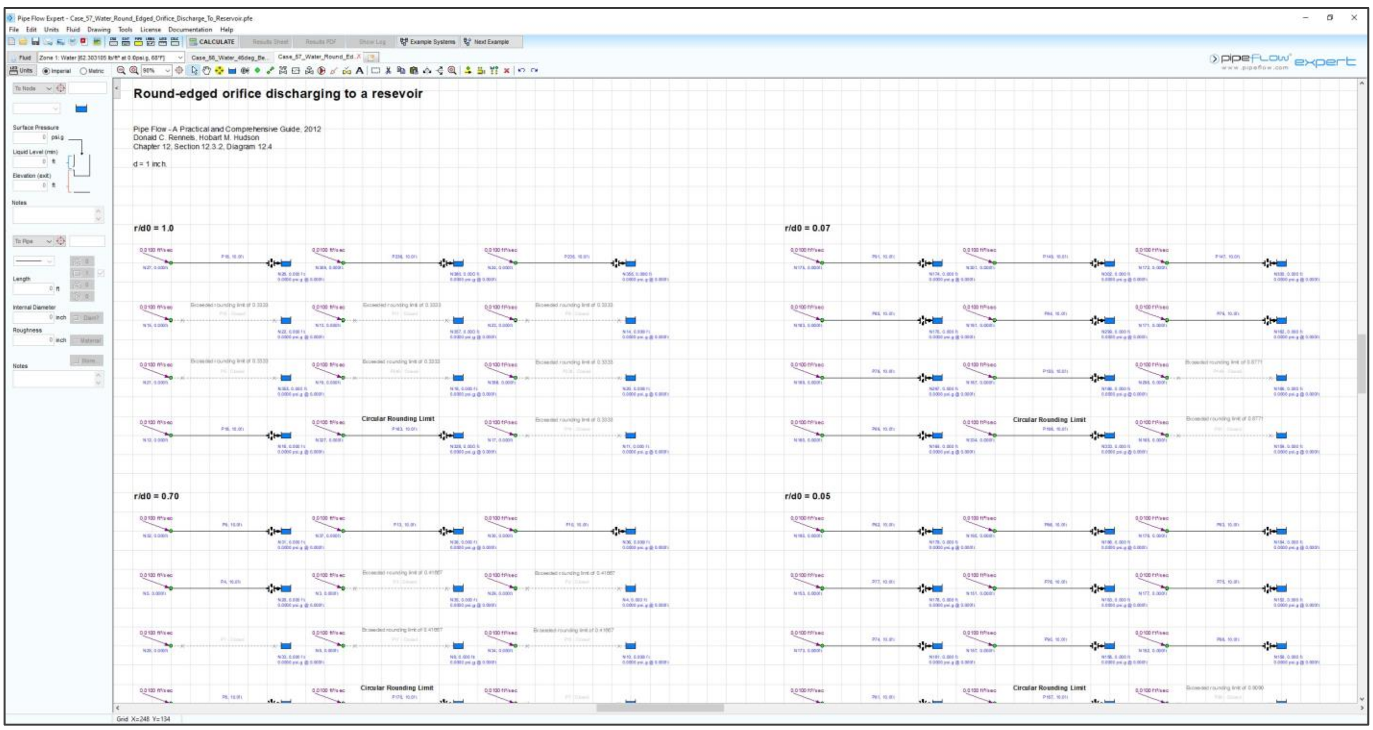
Pipe Flow Expert File: Case_57_Water_Round_Edged_Orifice_Discharge_To_Reservoir.pfe

Problem description:



A straight pipe contains a round-edged single-hole orifice which discharges to a reservoir (atmosphere). The orifice diameter to pipe diameter is specified by the ratio d_0/d_1. The orifice rounding radius to orifice diameter is specified by the ratio r/d_0.

Use different orifice rounding radius' to orifice diameter ratios (r/d_0) to compare the loss coefficient (k0) through the orifice with varying orifice diameter to pipe diameter ratios (d_0/d).



Pipe Flow Expert Parameters:

Fluid data: Water at, 68 °F

One hundred and seventy-nine individual systems with inflow demands of 0.01 ft^3/sec were used to model a range of orifice rounding radius to orifice diameter ratios (r/d_0) across a range of orifice diameter to pipe diameter ratios (d_0/d).

Result Comparison:

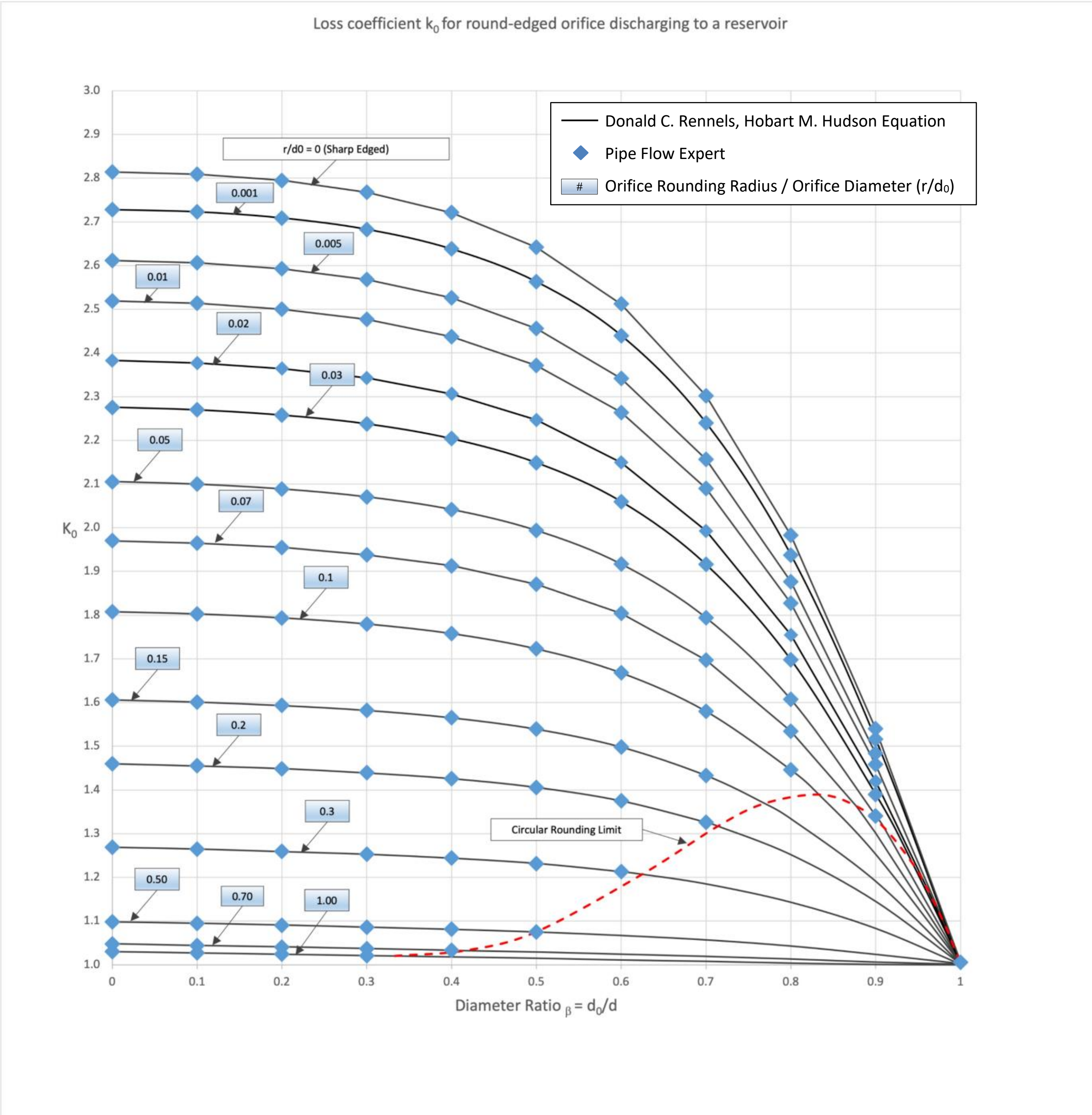
Pipe Flow Expert Calculated Results and Published Graph Readings of Orifice Loss Coefficient (k_0):

Orifice Diameter / Pipe Diameter (d_0/d)	Orifice Rounding Radius / Pipe Diameter (r/d_0)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)
0.1	1.0	1.027	1.027
0.2	1.0	1.024	1.024
0.3	1.0	1.021	1.0209
0.4	1.0	1.018	Rounding Limit Exceeded
0.5	1.0	1.015	Rounding Limit Exceeded
0.6	1.0	1.011	Rounding Limit Exceeded
0.7	1.0	1.008	Rounding Limit Exceeded
0.8	1.0	1.004	Rounding Limit Exceeded
0.9	1.0	1.001	Rounding Limit Exceeded
0.1	0.7	1.044	1.0442
0.2	0.7	1.041	1.0406
0.3	0.7	1.037	1.0369
0.4	0.7	1.033	1.0331
0.5	0.7	1.029	Rounding Limit Exceeded
0.6	0.7	1.024	Rounding Limit Exceeded
0.7	0.7	1.019	Rounding Limit Exceeded
0.8	0.7	1.013	Rounding Limit Exceeded
0.9	0.7	1.006	Rounding Limit Exceeded
0.1	0.5	1.095	1.0946
0.2	0.5	1.091	1.0905
0.3	0.5	1.086	1.0862
0.4	0.5	1.081	1.0812
0.5	0.5	1.075	1.0751
0.6	0.5	1.067	Rounding Limit Exceeded
0.7	0.5	1.057	Rounding Limit Exceeded
0.8	0.5	1.043	Rounding Limit Exceeded
0.9	0.5	1.024	Rounding Limit Exceeded
0.1	0.3	1.269	1.2647
0.2	0.3	1.265	1.2594
0.3	0.3	1.259	1.2528
0.4	0.3	1.253	1.244
0.5	0.3	1.244	1.2315
0.6	0.3	1.232	1.2131
0.7	0.3	1.185	Rounding Limit Exceeded
0.8	0.3	1.143	Rounding Limit Exceeded
0.9	0.3	1.083	Rounding Limit Exceeded
0.1	0.2	1.455	1.4552
0.2	0.2	1.449	1.4485
0.3	0.2	1.439	1.4393
0.4	0.2	1.426	1.426
0.5	0.2	1.406	1.4059
0.6	0.2	1.317	1.375
0.7	0.2	1.252	1.3263
0.8	0.2	1.252	Rounding Limit Exceeded
0.9	0.2	1.145	Rounding Limit Exceeded
0.1	0.15	1.601	1.6011
0.2	0.15	1.593	1.5934
0.3	0.15	1.582	1.5822
0.4	0.15	1.565	1.5654
0.5	0.15	1.539	1.5392
0.6	0.15	1.498	1.4984

Orifice Diameter / Pipe Diameter (d_0/d)	Orifice Rounding Radius / Pipe Diameter (r/d_0)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)
0.7	0.15	1.433	1.4333
0.8	0.15	1.334	Rounding Limit Exceeded
0.9	0.15	1.191	Rounding Limit Exceeded
0.1	0.1	1.803	1.8027
0.2	0.1	1.794	1.7936
0.3	0.1	1.78	1.7795
0.4	0.1	1.758	1.7578
0.5	0.1	1.723	1.7231
0.6	0.1	1.668	1.6681
0.7	0.1	1.580	1.5800
0.8	0.1	1.446	1.4459
0.9	0.1	1.253	Rounding Limit Exceeded
0.1	0.07	1.965	1.9648
0.2	0.07	1.955	1.9546
0.3	0.07	1.938	1.9383
0.4	0.07	1.913	1.9125
0.5	0.07	1.871	1.8708
0.6	0.07	1.804	1.8042
0.7	0.07	1.697	1.6971
0.8	0.07	1.534	1.5342
0.9	0.07	1.301	Rounding Limit Exceeded
0.1	0.05	2.1	2.0999
0.2	0.05	2.089	2.0888
0.3	0.05	2.071	2.0707
0.4	0.05	2.042	2.0415
0.5	0.05	1.994	1.9939
0.6	0.05	1.917	1.9174
0.7	0.05	1.794	1.7942
0.8	0.05	1.607	1.6071
0.9	0.05	1.341	1.3408
0.1	0.03	2.2700	2.2699
0.2	0.03	2.2580	2.2578
0.3	0.03	2.2380	2.2378
0.4	0.03	2.2040	2.2040
0.5	0.03	2.1490	2.1488
0.6	0.03	2.0600	2.0597
0.7	0.03	1.9160	1.9160
0.8	0.03	1.6980	1.6980
0.9	0.03	1.3900	1.3896
0.1	0.02	2.377	2.377
0.2	0.02	2.364	2.3643
0.3	0.02	2.343	2.3425
0.4	0.02	2.306	2.3064
0.5	0.02	2.247	2.2465
0.6	0.02	2.149	2.1494
0.7	0.02	1.993	1.9925
0.8	0.02	1.755	1.755
0.9	0.02	1.42	1.4199
0.1	0.01	2.514	2.5136
0.2	0.01	2.5	2.5002
0.3	0.01	2.477	2.4767
0.4	0.01	2.437	2.4372
0.5	0.01	2.371	2.3712
0.6	0.01	2.264	2.2638
0.7	0.01	2.09	2.0901

Orifice Diameter / Pipe Diameter (d_0/d)	Orifice Rounding Radius / Pipe Diameter (r/d_0)	Donald C. Rennels, Hobart M. Hudson (k_0)	Pipe Flow Expert (k_0)
0.8	0.01	1.827	1.8272
0.9	0.01	1.458	1.4582
0.1	0.005	2.606	2.6064
0.2	0.005	2.593	2.5926
0.3	0.005	2.568	2.5679
0.4	0.005	2.526	2.5262
0.5	0.005	2.456	2.456
0.6	0.005	2.342	2.3416
0.7	0.005	2.156	2.1564
0.8	0.005	1.876	1.8762
0.9	0.005	1.484	1.4839
0.1	0.001	2.723	2.723
0.2	0.001	2.709	2.7088
0.3	0.001	2.683	2.6827
0.4	0.001	2.638	2.6382
0.5	0.001	2.563	2.5628
0.6	0.001	2.44	2.4396
0.7	0.001	2.24	2.2397
0.8	0.001	1.938	1.9376
0.9	0.001	1.516	1.5161
0.1	0 (Sharp Edge)	2.809	2.8093
0.2	0 (Sharp Edge)	2.795	2.7949
0.3	0 (Sharp Edge)	2.768	2.7679
0.4	0 (Sharp Edge)	2.721	2.7213
0.5	0 (Sharp Edge)	2.642	2.6422
0.6	0 (Sharp Edge)	2.512	2.5124
0.7	0 (Sharp Edge)	2.302	2.3016
0.8	0 (Sharp Edge)	1.983	1.9832
0.9	0 (Sharp Edge)	1.54	1.5398

Graphical Comparison of Formula:



Commentary: The published loss coefficients compare well with the calculated results.

Rounding Limit: There is a point where circular rounding is limited by the available radial distance between the pipe wall and the face of the orifice. The dashed red line on the above graph plots the rounding limit cut off point across each r/d_0 line. Points below the dashed red line imply elliptical rounding and calculations for this are not supported. The Pipe Flow Expert software reports a 'Rounding Limit Exceeded' message for any defined orifice data that is in this region.

Note: Head Loss in m fluid = $(k_0 * v^2) / 2g$

- where v = fluid velocity in m/s at the entrance to the orifice, g = acceleration due to gravity in m/s^2
- k_0 is not the same as a standard k value (which is used in formulas where v = velocity in the pipe)

References

1. Piping Calculations Manual, 2005, McGraw-Hill

   E. Shashi Menon, P.E

2. Hydraulics of Pipeline Systems, 2000, CRC Press LLC

   Bruce E. Larock, Rowland W. Jeppson, Gary Z. Watters

3. Cameron Hydraulic Data **,** 18th Edition, 1994, Ingersoll-Dresser Pumps

4. 2500 Solved Problems in Fluid Mechanics and Hydraulics, 1989, McGraw-Hill

   Jack B. Evett Ph. D., Cheng Liu M.S.

5. Basic Principles for the Design of Centrifugal Pump Installations**,** SIHI Group, 1998, SIHI-HALBERG

6. Flow of Fluids – Technical Paper No 410M, 1999, Crane Co.

7. Flow of Fluids – Technical Paper No 410, 1988, Crane Co.

8. Theory and Problems of Fluid Mechanics and Hydraulics, 1993, McGraw-Hill

   R V Giles, Jack B. Evett Ph. D., Cheng Liu M.S.

9. Analysis of Flow in Pipe Networks, 1976, Ann Arbor Science Publishers Inc.

   Rowland W. Jeppson.

10. Flow through Long Orifices, 1961, Nottingham University

    James, A. J.

11. Flow through Long Orifices, 1962, Nottingham University

    Sanderson E. W.

12. Fluid Meters, Their Theory and Application, 6th Ed., 1971, Report of ASME

    Bean, H. S.

13. Loss Characteristics of Orifices and Nozzles, Journal of Fluids Engineering, 1978, ASME

    Alvi, S. H., K. Sridharan, and N. S. Lakshmana Rao

14. Pipe Flow – A Practical and Comprehensive Guide, 2012, Wiley

    Donald C. Rennels, Hobart M. Hudson