FluidFlow

RESULTS VERIFICATION

1 INTRODUCTION

FluidFlow software is designed to allow the modelling of fluid behaviour within complex piping systems, and accurately predict how the system will work for a given set of design conditions. The software uses a number of well-established models and correlations to solve the piping systems.

The purpose of this document is to verify the accuracy of FluidFlow against published design examples from the available literature on the subject. To that end, a number of case studies are detailed below, in which the published data is compared to the solutions provided by FluidFlow. Each case will be accompanied by a brief description, and a summary of the design inputs used in the calculations.

The cases have been categorised by fluid type as follows;

- Liquids (Incompressible Flow).
- Gases (Compressible Flow).
- Two-Phase Liquid-Gas Flow.
- Non-Newtonian/Non-Settling Slurry Flow/Pulp & Paper Stock.
- Settling Slurry Flow.

The results generated by FluidFlow for liquids, gases, two-phase fluids and slurries are rigorously tested and verified against published data and real-world operating systems on a continuous basis. An extensive library of Quality Assurance test models are also installed with the software.

As FluidFlow is continuously undergoing development, each new version of the software is benchmarked using the above procedures.

FluidFlow has been used successfully in industry since it was first launched 1984. The software has undergone extensive development since first launched ensuring the product is up to date, includes the very latest solution technology and offers engineers a fast and effective design simulation tool.

Quality Assurance is an integral part of our business ethic. From our software design approach through to our released product, FluidFlow is developed to the highest quality and standard.

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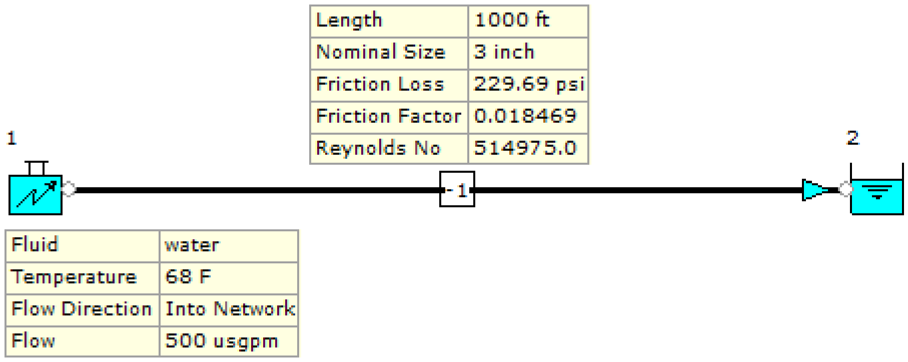
2 Liquid Calculations

2.1 Case 1: Pressure drop of Water in a Turbulent Pipe Flow.

Reference: Fluid Flow Handbook, 2002, McGraw-Hill, Jamal Saleh, Pg 8.13, Example 8.2.

Description: 500 gallons per minute at 68°F water flows in a horizontal 3" schedule 40 commercial steel pipe. Determine the pressure loss in psi and head loss per 1000ft of flow distance.



FluidFlow Model

User Number	-1	
Flow	500	usgpm
Friction Loss	229.7	psi
Pressure Gradient	5195.8	Pa/m
Loss Correlation	Darcy	
Economic Velocity	4.10	ft/s
Exact Economic Size	7.06	in
Size	3.07	in
In Fluid Phase	Liquid	
In Stagnation Pressure	244.4	psi a
In Static Pressure	241.2	psi a
In Velocity	21.73	ft/s
In Stag. Temperature	68.0	F
In Static Temperature	68.0	F
In Density	62.36	lb/ft3
Out Fluid Phase	Liquid	
Out Stagnation Pressure	14.7	psi a
Out Static Pressure	11.5	psi a
Out Velocity	21.75	ft/s
Out Stag. Temperature	68.0	F
Out Static Temperature	68.0	F
Out Density	62.32	lb/ft3
Composition Mass %	water	100.0%
Reynolds No	514975	
Friction Factor	0.018469	

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Friction Factor	0.0184	0.018469
Reynolds Number	514000	514975
Head loss (fluid ft per 1000ft length)	526	530
Pressure Drop (Psi)	227	229

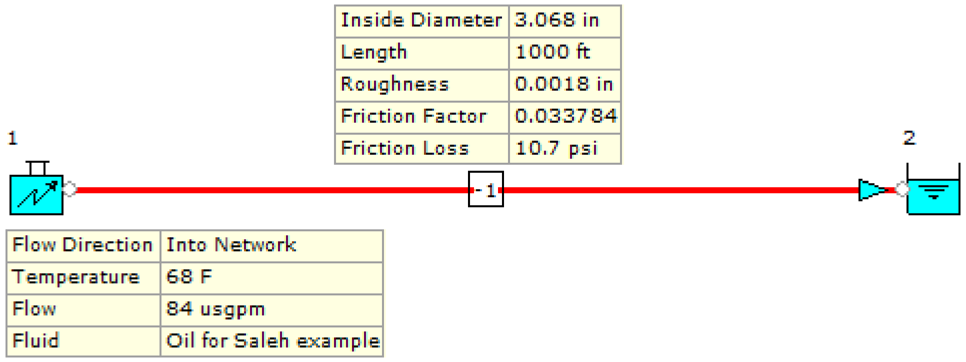
Commentary:

The handbook results for Reynolds number have been rounded to 514000 whereas FluidFlow has calculated the value accurately. This will have a subtle effect on the calculated friction factor and therefore, the overall calculated pressure loss result. It is therefore considered that the FluidFlow result is highly accurate.

2.2 Case 2: Pressure drop of Oil in a Turbulent Pipe Flow.

Reference: Fluid Flow Handbook, 2002, McGraw-Hill, Jamal Saleh, Pg 8.15, Example 8.3.

Description: 120 barrels per hour of an oil flows in a horizontal commercial steel pipe with an I.D. of 3.068 in. Determine the pressure loss in psi and head loss per 1000ft of flow distance. The oil has a SG = 0.9, and kinematic viscosity = 10 cSt.



FluidFlow Model

User Number	-1	
Flow	84	usgpm
Friction Loss	10.7	psi
Pressure Gradient	241.3	Pa/m
Loss Correlation	Darcy	
Economic Velocity	3.53	ft/s
Exact Economic Size	3.12	in
Size	3.07	in
In Fluid Phase	Liquid	
In Stagnation Pressure	25.4	psi a
In Static Pressure	25.3	psi a
In Velocity	3.65	ft/s
In Stag. Temperature	68.0	F
In Static Temperature	68.0	F
In Density	56.19	lb/ft3
Out Fluid Phase	Liquid	
Out Stagnation Pressure	14.7	psi a
Out Static Pressure	14.6	psi a
Out Velocity	3.65	ft/s
Out Stag. Temperature	68.0	F
Out Static Temperature	68.0	F
Out Density	56.19	lb/ft3
Composition Mass %	for Saleh exam	100.0%
Reynolds No	7823	
Friction Factor	0.033784	

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Friction Factor	0.034	0.033784
Reynolds Number	7826	7823
Head loss (fluid ft per 1000ft length)	27.5	27.3
Pressure Drop (Psi)	10.7	10.7

Commentary:

The results compare very favourably, with error margins of 0.8 percent or less. This can be attributed to the rounding up of the friction factor in the published data.

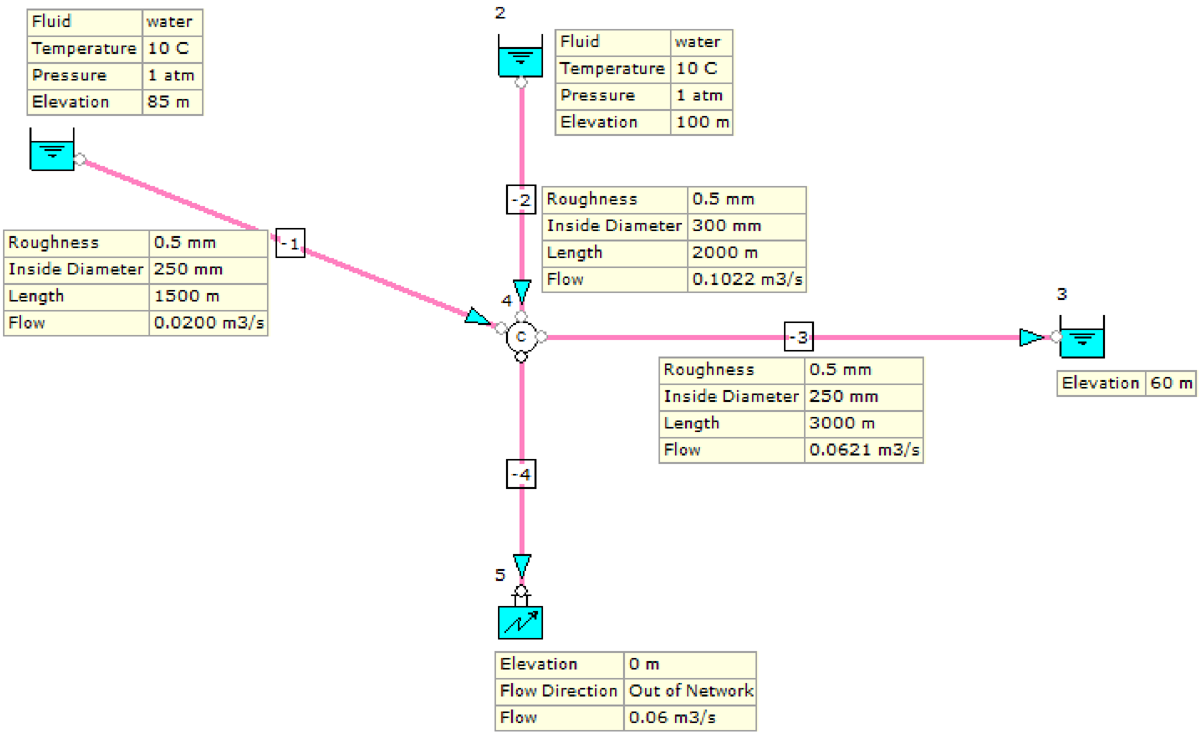
2.3 Case 3: Three Reservoir System.

Reference: Hydraulics of Pipeline Systems, 2000, CRC Press LLC, Larock, Jeppson and Watters, Pg 26, Example 2.7.

Description: Three reservoirs of increasing elevation are connected, with a flow demand out of the system at the connection point of 0.06m3/s. The elevations of the 3 reservoirs are 100m, 85m, and 60m.

The highest reservoir is connected via a 2000m long pipe of I.D. 300mm. The second highest is connected via a 1500m long pipe of I.D. 250mm. The lowest reservoir is connected via a 3000m long pipe of I.D. 250mm. Pipe roughness for all pipes is 0.5mm.

Determine the flows into or out of each of the reservoirs.



FluidFlow Model

User Number	-4	
Element Type	Steel Pipe, Duct or Tube	
Flow	0.0600	m3/s
Friction Loss	0.2	Pa
Pressure Gradient	1.7	Pa/m
Loss Correlation	Darcy	
Economic Velocity	1.23	m/s
Exact Economic Size	248.8	mm
Size	500.0	mm
In Fluid Phase	Liquid	
In Stagnation Pressure	921916	Pa a
In Static Pressure	921869	Pa a
In Velocity	0.31	m/s
In Stag. Temperature	10.0	C
In Static Temperature	10.0	C
In Density	1000	kg/m3
Out Fluid Phase	Liquid	
Out Stagnation Pressure	921916	Pa a
Out Static Pressure	921869	Pa a
Out Velocity	0.31	m/s
Out Stag. Temperature	10.0	C
Out Static Temperature	10.0	C
Out Density	1000	kg/m3
Composition Mass %	water	100.0%
Reynolds No	117092.0	
Friction Factor	0.017984	

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Flow from highest reservoir (m^3/s)	0.1023	0.1022
Flow from middle reservoir (m^3/s)	0.02	0.02
Flow into lowest reservoir (m^3/s)	0.0622	0.06

Commentary:

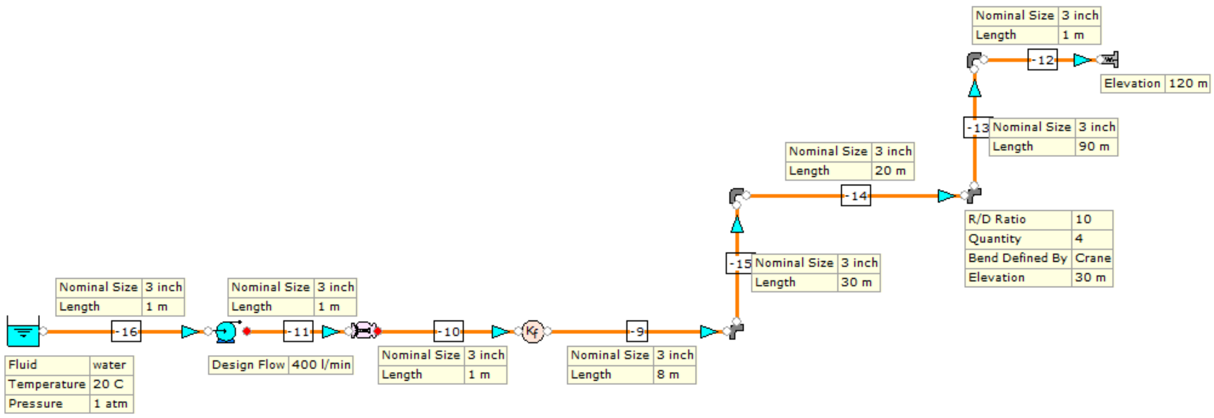
The results compare very well with the hand calculation.

2.4 Case 4: Crane Example 4-15 (Technical Paper No. 410).

Reference: Crane Technical Paper No. 410, Example 4-15, Page 4-9.

Description: Determine the total discharge head requirement for the pumped system featuring a lift check valve and gate valve over a differential elevation of 120M.

All pipes shall be 3 inch Schedule 40 and the pump design flow rate shall be 400 l/min.



FluidFlow Model

User Number	16	
Element Type	Centrifugal Pump	
Duty Flow	400	l/min
Duty Pressure Rise	127.2	m Fluid
Duty NPSH Available	10.1	m Fluid
In Fluid Phase	Liquid	
In Stagnation Pressure	101066	Pa a
In Static Pressure	100089	Pa a
In Velocity	1.40	m/s
In Stag. Temperature	20	C
In Static Temperature	20	C
In Density	998	kg/m3
In Viscosity	1.00	cP
Out Fluid Phase	Liquid	
Out Stagnation Pressure	1346194	Pa a
Out Static Pressure	1345218	Pa a
Out Velocity	1.40	m/s
Out Stag. Temperature	20	C
Out Static Temperature	20	C
Out Density	999	kg/m3
Out Viscosity	1.00	cP
Composition Mass %	water	100.0%

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Duty Pressure Rise (m fluid)	127	127.2

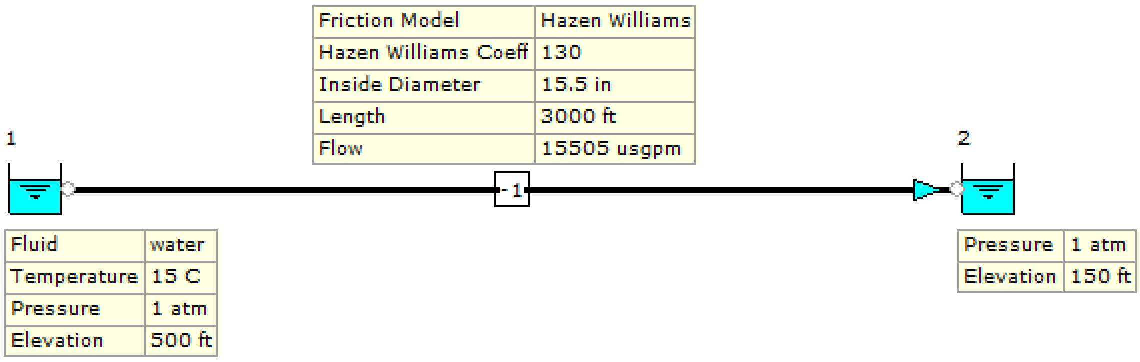
Commentary:

The results compare very well with the hand calculation.

2.5 Case 5: Gravity Fed System.

Reference: Piping Calculations Manual, Example 1.19, Page 48.

Description: A gravity fed system consists of a 16 inch, 3000 ft long pipeline with a supply tank elevation of 500 ft and a discharge tank elevation of 150 ft. Calculate the flow rate through this flow system using a Hazen Williams Coefficient of 130.



FluidFlow Model

User Number	**-1**	
Element Type	**Steel Pipe, Duct or Tube**	
Flow	**15505**	usgpm
Friction Loss	**151.6**	psi
Pressure Gradient	**0.0504**	psi/ft
Loss Correlation	**Hazen Williams**	
Economic Velocity	**3.80**	ft/s
Exact Economic Size	**40.86**	in
Size	**15.50**	in
In Fluid Phase	**Liquid**	
In Stagnation Pressure	**14.7**	psi a
In Static Pressure	**10.0**	psi a
In Velocity	**26.38**	ft/s
In Stag. Temperature	**59.0**	F
In Static Temperature	**59.0**	F
In Density	**62.37**	lb/ft3
Out Fluid Phase	**Liquid**	
Out Stagnation Pressure	**14.7**	psi a
Out Static Pressure	**10.0**	psi a
Out Velocity	**26.38**	ft/s
Out Stag. Temperature	**59.0**	F
Out Static Temperature	**59.0**	F
Out Density	**62.37**	lb/ft3
Composition Mass %	**water**	100.0%

Calculated Results

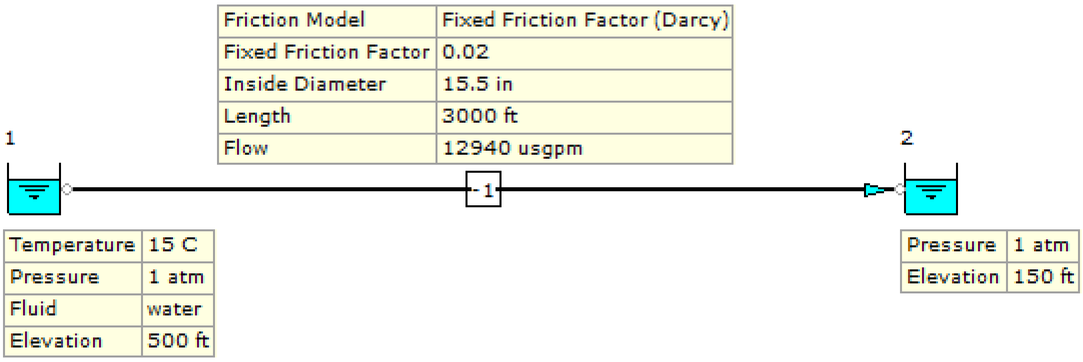
Result Comparison:

Description	Published Data	FluidFlow Results
Flow Rate (usgpm)	15484	15505

Commentary:

The FluidFlow results when using the Hazen Williams correlations compare very well with the hand calculation.

This example was then updated to use a fixed friction factor of 0.02.



FluidFlow Model

User Number	**-1**	
Element Type	**Steel Pipe, Duct or Tube**	
Flow	**12940**	usgpm
Friction Loss	**151.6**	psi
Pressure Gradient	**0.0504**	psi/ft
Loss Correlation	**Darcy [fixed friction fact**	
Economic Velocity	**3.83**	ft/s
Exact Economic Size	**37.18**	in
Size	**15.50**	in
In Fluid Phase	**Liquid**	
In Stagnation Pressure	**14.7**	psi a
In Static Pressure	**11.4**	psi a
In Velocity	**22.02**	ft/s
In Stag. Temperature	**59.0**	F
In Static Temperature	**59.0**	F
In Density	**62.37**	lb/ft3
Out Fluid Phase	**Liquid**	
Out Stagnation Pressure	**14.7**	psi a
Out Static Pressure	**11.4**	psi a
Out Velocity	**22.02**	ft/s
Out Stag. Temperature	**59.0**	F
Out Static Temperature	**59.0**	F
Out Density	**62.37**	lb/ft3
Composition Mass %	**water**	100.0%

Calculated Results

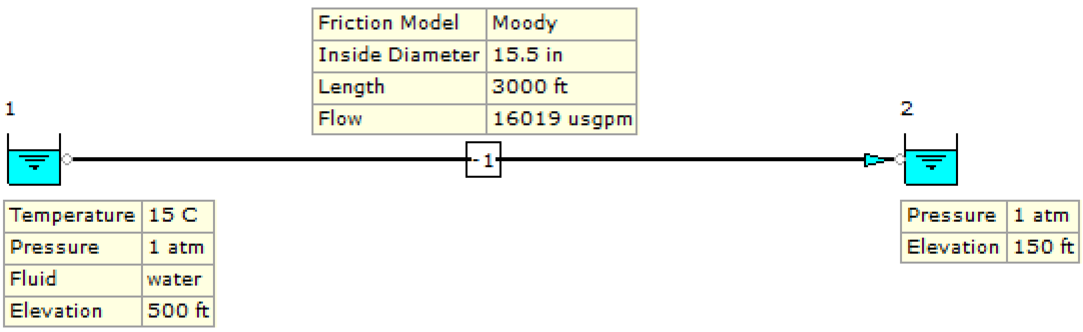
Result Comparison:

Description	Published Data	FluidFlow Results
Flow Rate (usgpm)	12949	12940

Commentary:

The FluidFlow results when using a fixed friction factor compare very well with the hand calculation.

This example was then updated to use the Moody relationship.



FluidFlow Model

User Number	**-1**	
Element Type	**Steel Pipe, Duct or Tube**	
Flow	**16019**	usgpm
Friction Loss	**151.6**	psi
Pressure Gradient	**0.0504**	psi/ft
Loss Correlation	**Darcy**	
Economic Velocity	**3.79**	ft/s
Exact Economic Size	**41.56**	in
Size	**15.50**	in
In Fluid Phase	**Liquid**	
In Stagnation Pressure	**14.7**	psi a
In Static Pressure	**9.7**	psi a
In Velocity	**27.26**	ft/s
In Stag. Temperature	**59.0**	F
In Static Temperature	**59.0**	F
In Density	**62.37**	lb/ft3
Out Fluid Phase	**Liquid**	
Out Stagnation Pressure	**14.7**	psi a
Out Static Pressure	**9.7**	psi a
Out Velocity	**27.26**	ft/s
Out Stag. Temperature	**59.0**	F
Out Static Temperature	**59.0**	F
Out Density	**62.37**	lb/ft3
Composition Mass %	**water**	100.0%
Reynolds No	**2873072.7**	
Friction Factor	**0.013049**	

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Flow Rate (usgpm)	16186	16019

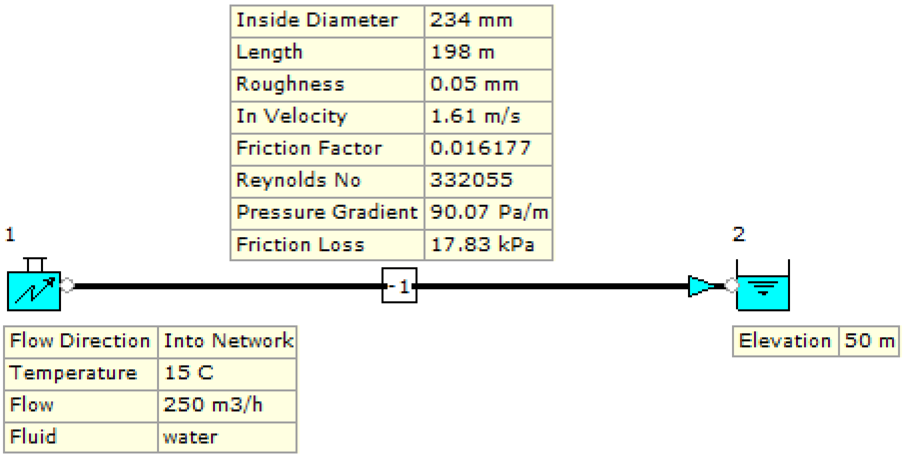
Commentary:

The slight difference in results can be attributed to the rounding of values in the handbook for Reynolds Number and friction factor. Overall, the results compare well.

2.6 Case 6: Fire Piping System.

Reference: Piping Calculations Manual, Example 2.11, Pg 102.

Description: A 234mm diameter steel pipe is used to transport water from a fire pump to a fire protection water distribution piping system. Calculate the friction factor and pressure gradient at a flow rate of 250 m3/h. Assume a pipe roughness of 0.05mm. Use Moody to calculate the pressure loss and determine the pump pressure required if the pipe length is 198m. The delivery point is located at a height of 50 m.



FluidFlow Model

User Number	-1	
Element Type	Steel Pipe, Duct or Tube	
Flow	250	m3/h
Friction Loss	17.8	kPa
Pressure Gradient	90.1	Pa/m
Loss Correlation	Darcy	
Economic Velocity	1.24	m/s
Exact Economic Size	266.7	mm
Size	234.0	mm
In Fluid Phase	Liquid	
In Stagnation Pressure	508	kPa g
In Static Pressure	506	kPa g
In Velocity	1.61	m/s
In Stag. Temperature	15.0	C
In Static Temperature	15.0	C
In Density	999	kg/m3
In Viscosity	1.137	cP
Out Fluid Phase	Liquid	
Out Stagnation Pressure	0	kPa g
Out Static Pressure	-1	kPa g
Out Velocity	1.62	m/s
Out Stag. Temperature	15.0	C
Out Static Temperature	15.0	C
Out Density	999	kg/m3
Out Viscosity	1.138	cP
Composition Mass %	water	100.0%
Reynolds No	332054.7	
Friction Factor	0.016177	

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Friction Factor	0.0162	0.0162
Pressure Gradient (kPa/m)	0.0897	0.0900
Pump Pressure (kPa)	508	508
Pipe Velocity (m/s)	1.61	1.61

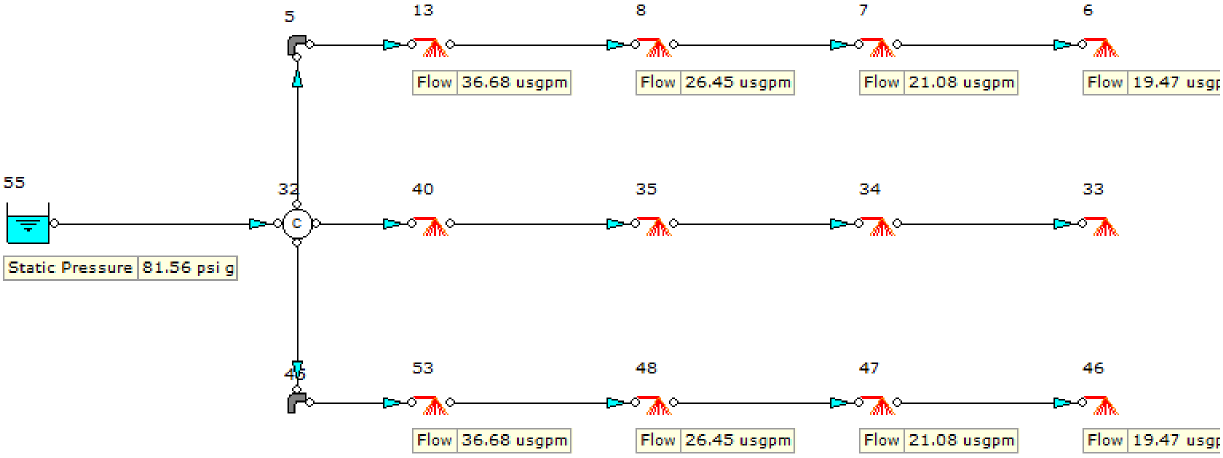
Commentary:

The results compare very well with the hand calculation.

2.7 Case 7: Fire Sprinkler System.

Reference: Piping Calculations Manual, Example 2.17, Pg 128.

Description: A sprinkler system for a small warehouse has three branch pipes with four sprinkler heads, each spaced at 12ft apart. The branch lines are spaced 15ft apart and connect to a riser pipe 20ft high from the fire pump. The riser pipe is 2 inch schedule 40. The branch lines are 1 inch schedule 40 except for the section from the top of the riser to the first sprinkler on each branch line, which is 1.5 inch schedule 40. All sprinklers have a 0.5 inch orifice with K = 5.6. Use a Hazen Williams C factor of 100 for all pipes. Calculate the flow through each sprinkler.



FluidFlow Model

User Number	55	
Flow	319.50	usgpm
Stagnation Pressure	87.85	psi g
Static Pressure	81.56	psi g
Temperature	68.0	F
Density	62.33	lb/ft3
Viscosity	1.001	cP
Specific Heat Capacity	4182.91	J/kg C
Composition Mass %	water	100.0%

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Inlet Static Pressure (psig)	83.16	81.56
Total Flow Rate (usgpm)	319.5	319.5
Sprinkler 1 Flow Rate (usgpm)	37.65	36.68
Sprinkler 1 Pressure (psig)	45.20	42.90
Sprinkler 2 Flow Rate (usgpm)	27.19	26.45
Sprinkler 2 Pressure (psig)	23.58	22.30
Sprinkler 3 Flow Rate (usgpm)	21.65	21.08
Sprinkler 3 Pressure (psig)	14.95	14.18
Sprinkler 4 Flow Rate (usgpm)	20	19.47
Sprinkler 4 Pressure (psig)	12.76	12.09

Commentary:

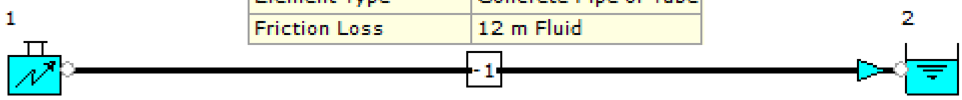
The FluidFlow results for this entire system compare very well with the hand calculation. This system is based on using the Hazen Williams friction loss approach.

2.8 Case 8: Pumping Facility.

Reference: Piping Calculations Manual, Example 3.12, Pg 152.

Description: A concrete pipe with a 2 M I.D. is used to transport water from a pumping facility to a storage tank 5 km away. Calculate the pressure loss in kPa/km due to friction at a flow rate of 34,000 m^3/h. Use the Hazen Williams equation with a C factor of 140. If a delivery pressure of 400 kPa must be maintained at the delivery point and the storage tank is at an elevation of 200 M above that of the pumping facility. Calculate the pressure required at the pumping facility at the given flow rate.

Length	5 km
Inside Diameter	2 m
Friction Model	Hazen Williams
Hazen Williams Coeff	140
Element Type	Concrete Pipe or Tube
Friction Loss	12 m Fluid



Elevation	0 ft
Flow Direction	Into Network
Flow	34000 m3/h
Temperature	15 C
Fluid	water

Elevation	200 m
Pressure	400 kPa g

FluidFlow Model

User Number	-1	
Element Type	Concrete Pipe or Tube	
Flow	34000	m3/h
Friction Loss	12	m Fluid
Pressure Gradient	24.24	Pa/m
Loss Correlation	Hazen Williams	
Economic Velocity	1.09	m/s
Exact Economic Size	3320.1	mm
Size	2000.0	mm
In Fluid Phase	Liquid	
In Stagnation Pressure	2481	kPa g
In Static Pressure	2477	kPa g
In Velocity	3.01	m/s
In Stag. Temperature	15.0	C
In Static Temperature	15.0	C
In Density	1000	kg/m3
Out Fluid Phase	Liquid	
Out Stagnation Pressure	400	kPa g
Out Static Pressure	395	kPa g
Out Velocity	3.01	m/s
Out Stag. Temperature	15.0	C
Out Static Temperature	15.0	C
Out Density	999	kg/m3
Composition Mass %	water	100.0%
Reynolds No	1000.0	
Friction Factor	0.080000	

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Pressure Gradient (kPa/km)	24.38	24.24
Pressure Required at Pump (kPa)	2483	2481

Commentary:

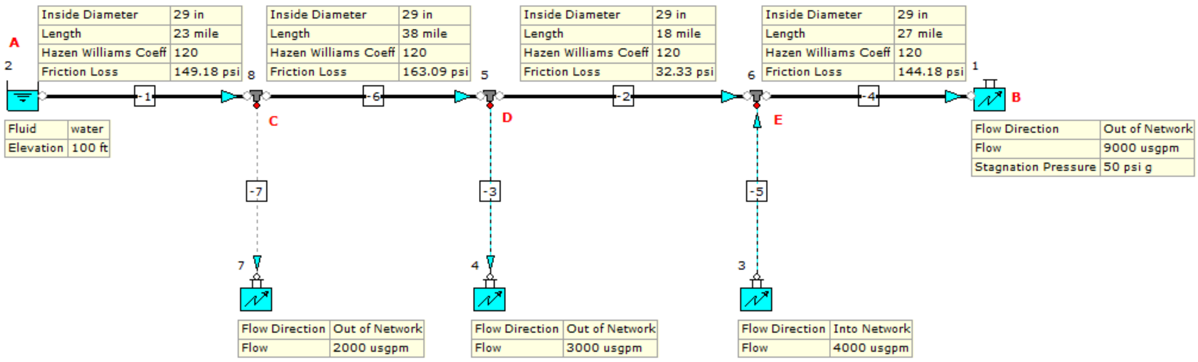
The FluidFlow results for this entire system compare very well with the hand calculation. This system is based on using the Hazen Williams friction loss approach.

2.9 Case 9: 106 Mile Piping System.

Reference: Piping Calculations Manual, Example 1.26, Pg 67.

Description: A 29 inch I.D. pipeline with a total length of 106 miles is used to transport 10000 gal/min with intermediate deliveries at C & D of 2000 and 3000 gal/min respectively. At point E, 4000 gal/min of water is injected into the pipeline so that a total of 9000 gal/min is delivered to the terminus at B at 50 psi. Calculate the pressure loss in each section of pipework using a Hazen Williams C factor of 120 whilst taking into account changes in system elevation. The system elevations details are as follows;

A = 100ft, B = 340ft, C = 180ft, D = 150ft & E = 280ft.



FluidFlow Model

User Number	-6	
Flow	7992	usgpm
Friction Loss	163.09	psi
Pressure Gradient	0.0027	psi/m
Loss Correlation	Hazen Williams	
Economic Velocity	3.933	ft/s
Exact Economic Size	28.82	in
Size	29.00	in
In Fluid Phase	Liquid	
In Stagnation Pressure	364	psi g
In Static Pressure	364	psi g
In Velocity	3.885	ft/s
In Stag. Temperature	68.0	F
In Static Temperature	68.0	F
In Density	62.39	lb/ft3
Out Fluid Phase	Liquid	
Out Stagnation Pressure	270	psi g
Out Static Pressure	270	psi g
Out Velocity	3.886	ft/s
Out Stag. Temperature	68.0	F
Out Static Temperature	68.0	F
Out Density	62.37	lb/ft3
Composition Mass %	water	100.0%

Calculated Results

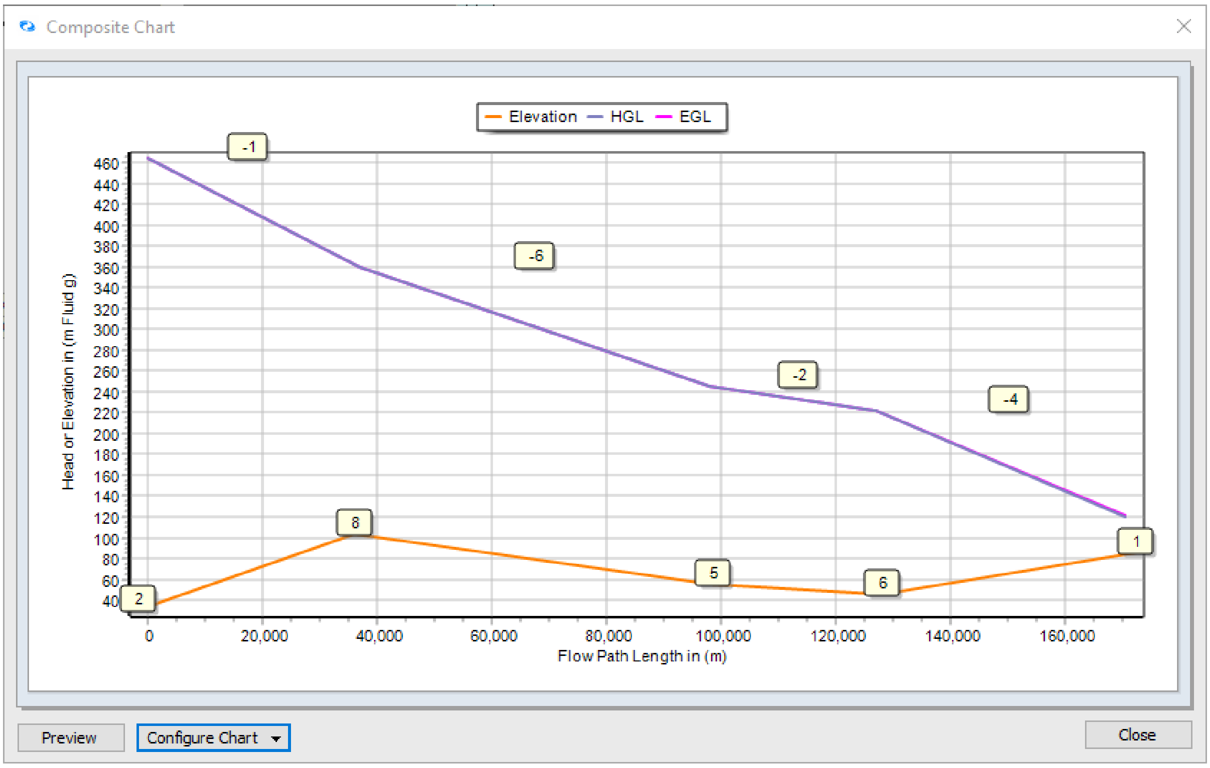
Result Comparison:

Description	Published Data	FluidFlow Results
Pressure Loss (psi) (Pipe Section A – C)	149.96	149.18
Pressure Loss (psi) (Pipe Section C – D)	163.81	163.09
Pressure Loss (psi) (Pipe Section D – E)	32.49	32.33
Pressure Loss (psi) (Pipe Section E – B)	144.76	144.18

Commentary:

The FluidFlow results for this entire system compare very well with the hand calculation. This system is based on using the Hazen Williams friction loss approach.

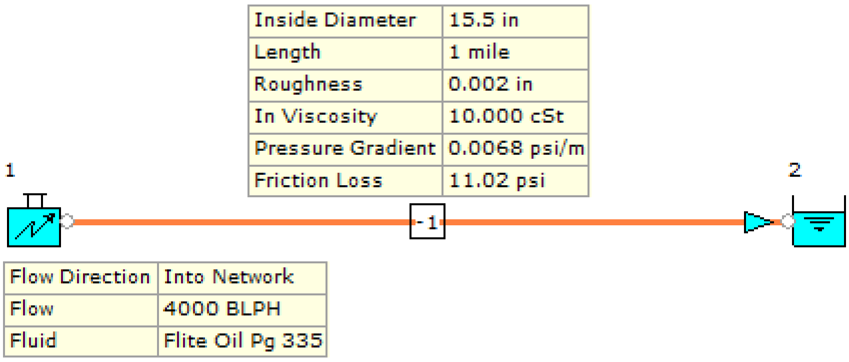
FluidFlow has also generated the HGL/EGL for the system as follows:



2.10 Case 10: 1 Mile Oil Piping System.

Reference: Piping Calculations Manual, Example 6.16, Pg 335.

Description: A petroleum oil with SG 0.85 and 10 cSt viscosity flows through a 15.5 inch I.D. pipeline at a flow rate of 4000 bbl/h. The absolute roughness of the pipe is estimated to be 0.002 in. Calculate the pressure loss due to friction in a mile of pipe length using the Colebrook-White equation.



FluidFlow Model

User Number	-1	
Flow	2798	usgpm
Friction Loss	11.02	psi
Pressure Gradient	0.0068	psi/m
Loss Correlation	Darcy	
Economic Velocity	3.768	ft/s
Exact Economic Size	17.42	in
Size	15.50	in
In Fluid Phase	Liquid	
In Stagnation Pressure	11	psi g
In Static Pressure	11	psi g
In Velocity	4.761	ft/s
In Stag. Temperature	68.0	F
In Static Temperature	68.0	F
In Density	53.06	lb/ft3
Out Fluid Phase	Liquid	
Out Stagnation Pressure	0	psi g
Out Static Pressure	0	psi g
Out Velocity	4.761	ft/s
Out Stag. Temperature	68.0	F
Out Static Temperature	68.0	F
Out Density	53.06	lb/ft3
Composition Mass %	Flite Oil Pg 335	100.0%

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Friction Loss (psi/mile)	11.01	11.02
Pipe Velocity (ft/s)	4.76	4.76

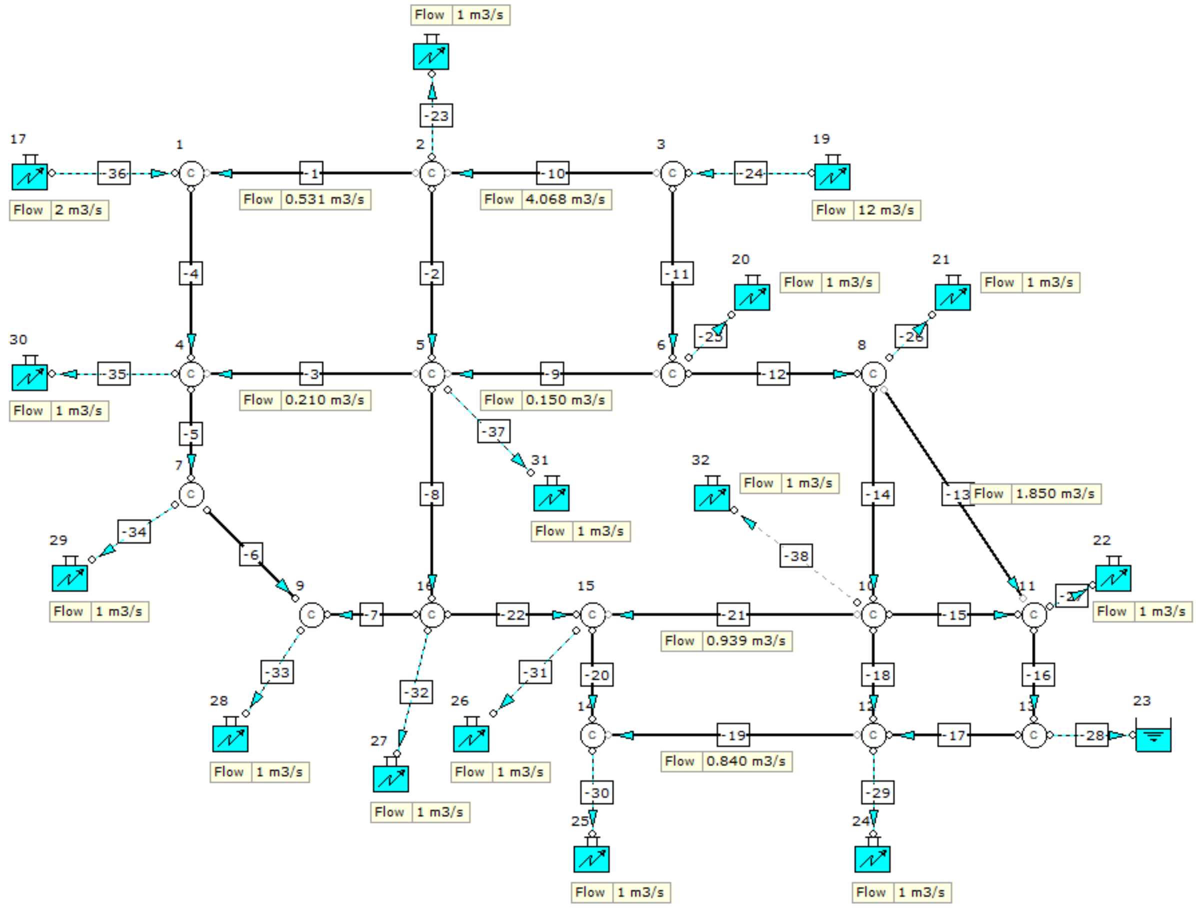
Commentary:

The FluidFlow results for this entire system compare very well with the hand calculation over a distance of 1 mile for this oil transportation line.

2.11 Case 11: 14 km Pipe Network.

Reference: 2500 Solved Problems in Fluid Mechanics, Example 13.31, Pg 349.

Description: Determine the flow in m^3/s in each branch pipe in the water distribution pipe network. The network is made up of over 14km of pipework. The pipelines will be solved using the Hazen-Williams Relationships.



FluidFlow Model

Result Comparison:

Pipe Number	Published Data (m^3/s)	FluidFlow Results (m^3/s)
Pipe 1	0.532	0.531
Pipe 2	2.537	2.537
Pipe 3	0.211	0.210
Pipe 4	2.532	2.531
Pipe 5	1.742	1.742
Pipe 6	0.742	0.742
Pipe 7	0.258	0.258

Pipe 8	1.478	1.477
Pipe 9	0.152	0.150
Pipe 10	4.068	4.068
Pipe 11	7.932	7.932
Pipe 12	6.780	6.785
Pipe 13	1.848	1.850
Pipe 14	3.932	3.936
Pipe 15	0.942	0.945
Pipe 16	1.790	1.796
Pipe 17	0.790	0.789
Pipe 18	1.050	1.051
Pipe 19	0.840	0.840
Pipe 20	0.160	0.160
Pipe 21	0.940	0.939
Pipe 22	0.220	0.220

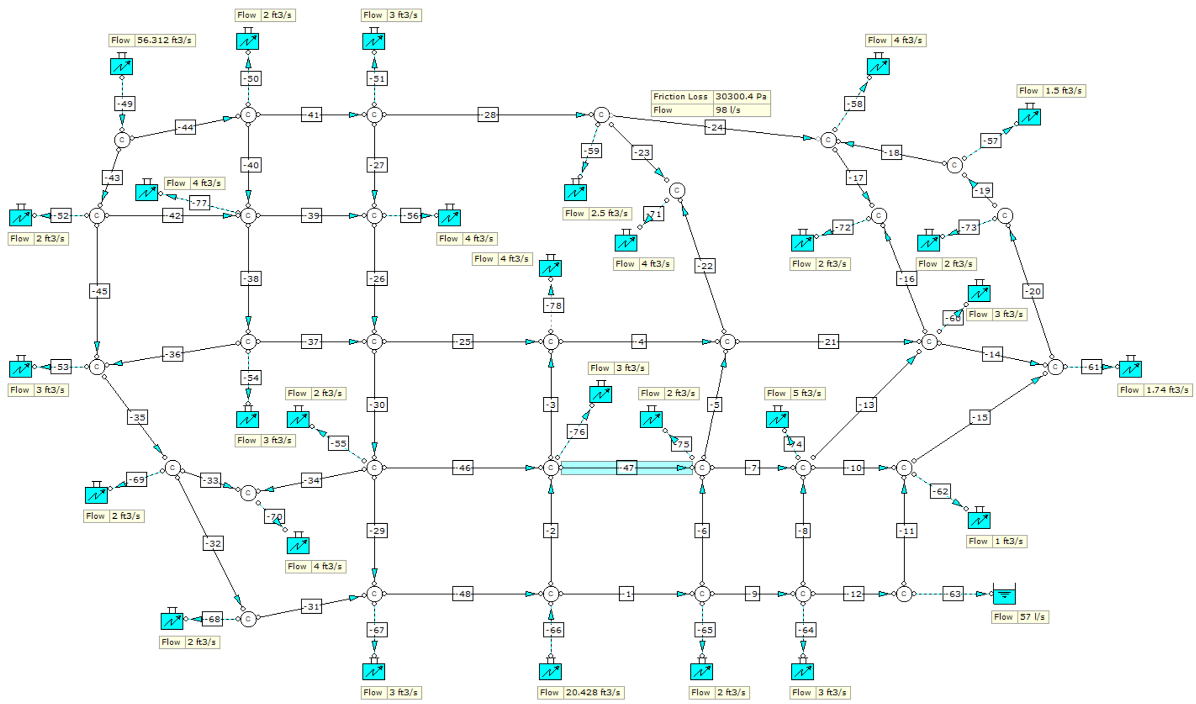
Commentary:

The software results are a close exact match with the calculation from the book. Note, when building the model in FluidFlow additional pipework was required to connect the flow boundary nodes whereas these link pipes are overlooked/ignored in the published calculation. There are some subtle differences in the results which can be attributed to the additional pipes described above as well as the fluid physical properties (density) etc which haven't been clearly defined in the text literature.

2.12 Case 12: 25 km Pipe Network.

Reference: Steady Flow Analysis of Pipe Networks: An Instructional Manual, Roland W. Jeppson, Pg 72.

Description: Determine the flow in ft^3/s and pressure loss in ft fluid in each branch pipe in the water distribution pipe network. The network is made up of over 25km of pipework. The pipelines will be solved using the Hazen-Williams Relationships using a C Factor of 120.



FluidFlow Model

Result Comparison:

Pipe Number	Published Data (ft^3/s)	FluidFlow Results (ft^3/s)	Published Data (ft fluid)	FluidFlow Results (ft fluid)
Pipe 1	19.65	19.03	11.44	14.21
Pipe 2	10.25	10.01	3.42	4.32
Pipe 3	4.79	4.59	0.84	1.02
Pipe 4	3.93	4.06	25.51	27.32
Pipe 5	2.60	2.53	0.27	0.34
Pipe 6	4.06	4.04	18.06	18.12
Pipe 7	4.42	4.63	10.53	11.63
Pipe 8	4.58	4.29	16.87	15.17
Pipe 9	13.59	12.99	11.72	14.58

Pipe 10	2.39	2.35	3.37	3.31
Pipe 11	4.01	3.69	17.64	15.31
Pipe 12	6.01	5.70	2.59	3.17
Pipe 13	1.61	1.57	3.23	3.14
Pipe 14	1.09	1.18	1.78	1.39
Pipe 15	5.40	5.04	1.05	1.21
Pipe 16	1.57	1.56	4.67	4.68
Pipe 17	0.43	0.44	0.14	0.15
Pipe 18	1.25	0.98	1.52	0.99
Pipe 19	2.75	2.48	0.61	0.68
Pipe 20	4.75	4.48	1.23	1.47
Pipe 21	4.06	4.18	13.49	14.43
Pipe 22	2.48	2.41	10.88	10.42
Pipe 23	1.52	1.59	1.46	1.61
Pipe 24	3.18	3.45	8.60	10.15
Pipe 25	3.14	3.46	16.83	20.41
Pipe 26	3.04	3.33	7.93	9.49
Pipe 27	2.47	2.56	5.39	5.84
Pipe 28	7.20	7.54	65.07	71.87
Pipe 29	2.41	2.08	0.95	0.98
Pipe 30	7.94	7.60	8.66	10.81
Pipe 31	10.07	9.53	1.66	1.97
Pipe 32	12.07	11.53	5.79	7.02
Pipe 33	2.97	3.18	7.57	8.71
Pipe 34	1.03	0.82	1.07	0.71
Pipe 35	17.04	16.71	8.78	11.16
Pipe 36	0.41	0.24	0.03	0.01
Pipe 37	8.04	7.73	6.65	8.37
Pipe 38	11.44	10.98	3.15	3.85

Pipe 39	4.57	4.77	1.87	2.73
Pipe 40	11.93	11.67	13.81	17.94
Pipe 41	12.67	13.11	10.29	14.83
Pipe 42	8.09	8.07	5.38	7.25
Pipe 43	29.72	29.54	18.45	24.06
Pipe 44	26.60	26.77	10.02	13.37
Pipe 45	19.63	19.47	8.56	11.11
Pipe 46	2.50	2.70	7.33	8.57
Pipe 47	4.96	5.12	26.07	28.00
Pipe 48	9.47	8.61	2.96	3.27

Commentary:

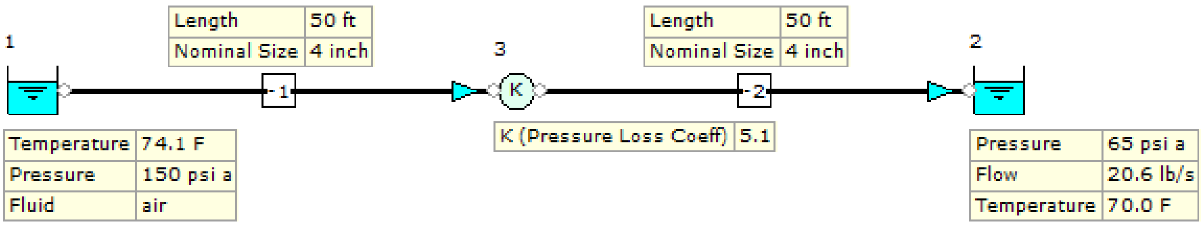
The software results are a close exact match with the calculation from the book. Note, when building the model in FluidFlow additional pipework was required to connect the flow boundary nodes whereas these link pipes are overlooked/ignored in the published calculation. There are some subtle differences in the results which can be attributed to the additional pipes described above as well as the fluid physical properties (density) etc which haven't been clearly defined in the text literature.

3 Compressible Flow

3.1 Case 1: Piped Gas Flow Between Two Known Pressures.

Reference: Fluid Flow Handbook, 2002, McGraw-Hill, Jamal Saleh, Pg 9.12, Example 9.3

Description: Find the air flow rate in a 4 inch I.D. pipe with an upstream pressure of 150 psia and downstream pressure of 65 psia. The flow mis assumed adiabatic at an average temperature of 70ºF. The pipe length is 100 ft.



FluidFlow Model

User Number	2	
Element Type	Known Pressure Boundary	
Flow	20.6	lb/s
Flow at STP	966971.5	ft3/h
Flow at NTP	916442.3	ft3/h
In Fluid Phase	Gas or Vapor	
Stagnation Pressure	65.00	psi a
Static Pressure	42.18	psi a
Temperature	70.0	F
Density	0.33	lb/ft3
Viscosity	0.018	cP
Specific Heat Capacity	1007.41	J/kg C
Composition Mass %	air	100.0%

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Flow Rate (lb/s)	20.6	20.6

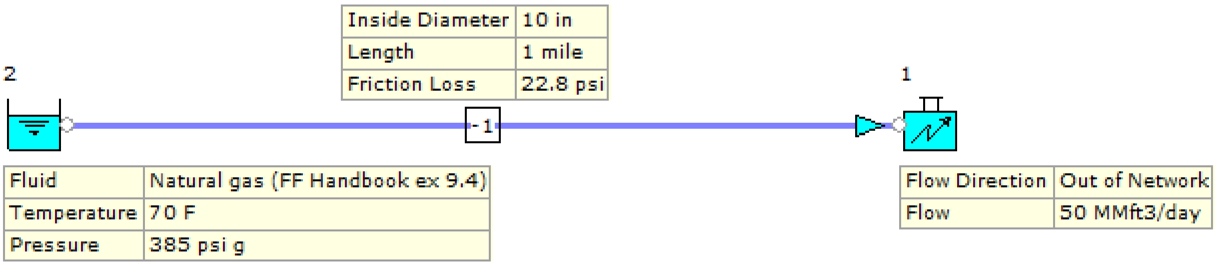
Commentary:

The software results are an exact match with the hand calculation. Note, FluidFlow does not assume gas ideality as the software solves for real gas conditions using an equation of state for incremental pipe lengths. This ensures the highest level of accuracy. We would therefore expect some level of difference in calculated results.

3.2 Case 2: Piped gas flow with known flow and inlet conditions

Reference: Fluid Flow Handbook, 2002, McGraw-Hill, Jamal Saleh, Pg 9.13, Example 9.4.

Description: Calculate the pressure drop for natural gas pipe with 50 MMSCFD (75% Methane, 20% Ethane, 5% Propane). The pipe is 1 mile long, with an I.D. of 10 inches. The gas inlet conditions are 185 psig and 70 °F.



FluidFlow Model

User Number	-1	
Element Type	Steel Pipe, Duct or Tube	
Flow	2150.2	m3/h
Flow at STP	62262	m3/h
Flow at NTP	58986	m3/h
Friction Loss	22.75	psi
Pressure Gradient	0.0141	psi/m
Loss Correlation	Duxbury	
Economic Velocity	15.56	ft/s
Exact Economic Size	15.76	in
Size	10.00	in
In Fluid Phase	Gas or Vapor	
In Stagnation Pressure	399.7	psi a
In Static Pressure	399.4	psi a
In Velocity	38.67	ft/s
In Mach Number	0.03	
In Stag. Temperature	70.0	F
In Static Temperature	69.9	F
In Density	1.55	lb/ft3
Out Fluid Phase	Gas or Vapor	
Out Stagnation Pressure	376.9	psi a
Out Static Pressure	376.7	psi a
Out Velocity	41.13	ft/s
Out Mach Number	0.03	
Out Stag. Temperature	69.8	F
Out Static Temperature	69.7	F
Out Density	1.46	lb/ft3

Calculated Results

Result Comparison:

Description	Published Data	FluidFlow Results
Pressure Loss (psi)	19.89	22.75

Commentary:

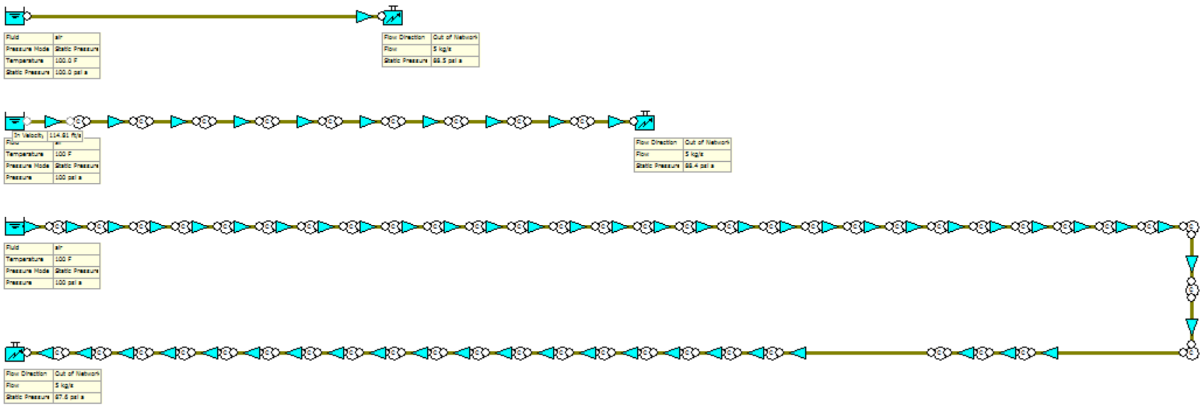
The textbook example uses a modified Darcy equation to generate a linear plot of pressure loss against flow rate, with 6 points. The published data result stated above has then been taken from that linear approximation. FluidFlow uses the Duxbury method and takes into account density changes of the gas as it flows along the pipeline. Considering this pipeline is 1 mile in length, the density changes will have an effect on the overall result. The software also takes into account the J-T effect.

Considering the above, we would expect the results to differ with FluidFlow returning a high level of accuracy.

3.3 Case 3: Pressure drop sensitivity to varying incremental pipe lengths

Reference: Fluid Flow Handbook, 2002, McGraw-Hill, Jamal Saleh, Pg 9.25, Example 9.9.

Description: 5 kg/s of gas flows in a pipe with 6 inches inside diameter. The pipe inlet pressure is 100 psia and the inlet temperature is 100 °F. The pipe length is 500 ft and the pipe roughness may be assumed to be 0.0018 in. Find the exit pressure and temperature using pipe incremental lengths of 1, 10 and 50.



FluidFlow Model

Unique Name	
Status	On
Length	500
Length Unit	ft
Geometry	Cylindrical
Use Database Size	No
Inside Diameter	6
Diameter Unit	in
Wall Thickness	3.9
Friction Model	Moody
Use Database Roughness	No
Roughness	0.0018
Roughness Unit	in
Use Database Scaling	No
Scaling (0 to 50%)	0
Sizing Model	Economic Velocity
Heat Loss Model	Ignore Heat Loss/Gain

Sample Pipe Input

Result Comparison:

Description	No of Nodes	Published Data	FluidFlow Results
Exit Pressure (psia)	1	N/A	88.45
Exit Pressure (psia)	10	87.47	88.44
Exit Pressure (psia)	50	87.40	87.51

Commentary:

The purpose of the text book exercise is to demonstrate an increase in accuracy when the pipeline is broken up into smaller segments for calculation purposes. The results comparison demonstrates that FluidFlow provides a good estimation of exit pressure with only one pipe used in the model, with increasing accuracy as more nodes are added. The designer can make an engineering decision on the number of nodes to be modelled to give satisfactory model accuracy. It is noted that there is a law of diminishing returns – indeed the text book example states that in this case, any further increase in nodes over 100 will yield negligible improvement.

For further comparison, values for pressure drop and velocity in the pipe broken down into 10 increments is tabulated below. It is noted that temperature has not been compared as only a very basic temperature calculation has been carried out in the handbook and insufficient data is available to complete an accurate calculation.

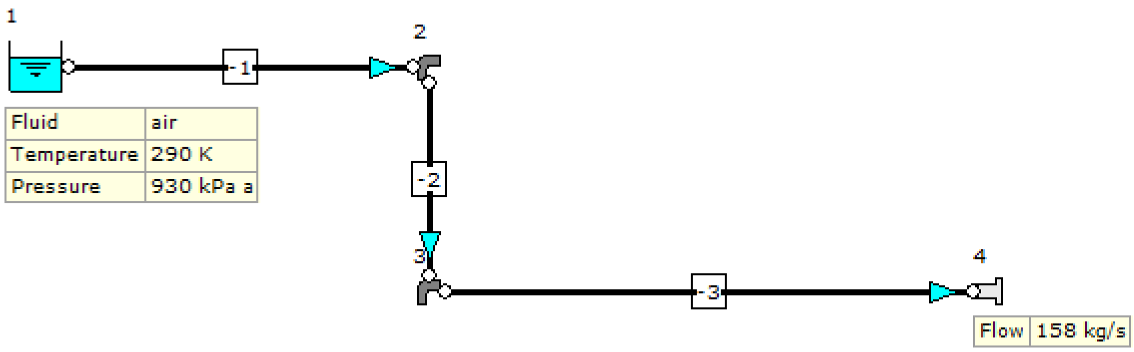
Result Comparison:

	Handbook			FluidFlow		
Pipe Increment	**Inlet Pressure (psia)**	**Pressure Drop (psi)**	**Velocity (ft/s)**	**Inlet Pressure (psia)**	**Pressure Drop (psi)**	**Velocity (ft/s)**
1	100	1.1808	114.008	100	1.0881	115.865
2	98.82	1.2069	115.096	98.90	1.0994	117.017
3	97.61	1.2194	116.232	97.80	1.1117	117.320
4	96.39	1.232	117.405	96.68	1.1244	119.667
5	95.16	1.2451	118.617	95.54	1.1376	121.062
6	93.92	1.2586	119.87	94.40	1.1513	122.507
7	92.66	1.2727	121.167	93.24	1.1654	124.004
8	91.38	1.2872	122.51	92.06	1.1801	125.558
9	90.1	1.3023	123.903	90.87	1.1967	127.172
10	88.79	1.318	125.348	89.66	1.2147	129.159
Total	87.47	12.52		88.44	11.47	

3.4 Case 4: Flow Through a Broken Pipe.

Reference: Internal Flow Systems, 2nd Ed., 1996, BHR Group, D.S.Miller, Pg 175, Example 1.

Description: A safety assessment indicates that the most likely impact induced failure will occur at a certain point of a 0.1m^2 CSA pipe carrying air from a pressure vessel. Assuming a double ended failure occurs (i.e. a complete and clean break) find the initial flow rate from the vessel for the following air conditions in the vessel; P = 930 kPa a, T = 290 K, and pipe friction coefficient of 0.012.



FluidFlow Model

Unique Name	
Status	On
Elevation	0
Elevation Unit	m
Pressure Model	Stagnation Pressure
Pressure	930
Pressure Unit	kPa a
Temperature	290
Temperature Unit	K
Fluid	air
Fluid Type	Newtonian/NN-NonSettling

System Inlet Data

Result Comparison:

Description	Published Data	FluidFlow Results
Exit Flow (kg/s)	152	158

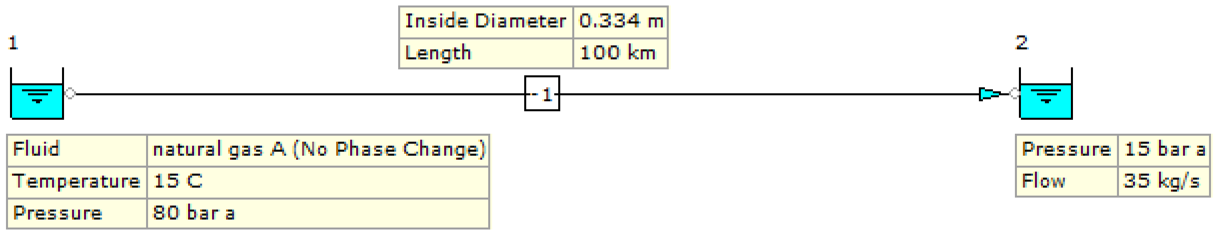
Commentary:

The results compare reasonably well. The calculation procedure carried out in the text book is described as "reasonably accurate". We would expect FluidFlow to yield a more accurate result due to the method and rounding up of values in the text book.

3.5 Case 5: Calculating Gas Flowrate given a Known Pressure Drop across a Pipe.

Reference: Internal Flow Systems, 2nd Ed., 1996, BHR Group, D.S.Miller, Pg 183, Example 7.

Description: A natural gas pipeline of 0.334 m internal diameter, 100 km long, operates with a pressure drop of 65 bar. If the inlet pressure is 80 bar, estimate the flow rate in kg/s.



FluidFlow Model

Unique Name	
Status	On
Elevation	0
Elevation Unit	m
Pressure Model	Static Pressure
Pressure	80
Pressure Unit	bar a
Temperature	15
Temperature Unit	C
Fluid	natural gas A (No Phase Change)
Fluid Type	Newtonian/NN-NonSettling

System Inlet Data

Result Comparison:

Description	Published Data	FluidFlow Results
Flow (kg/s)	33.2	35.3

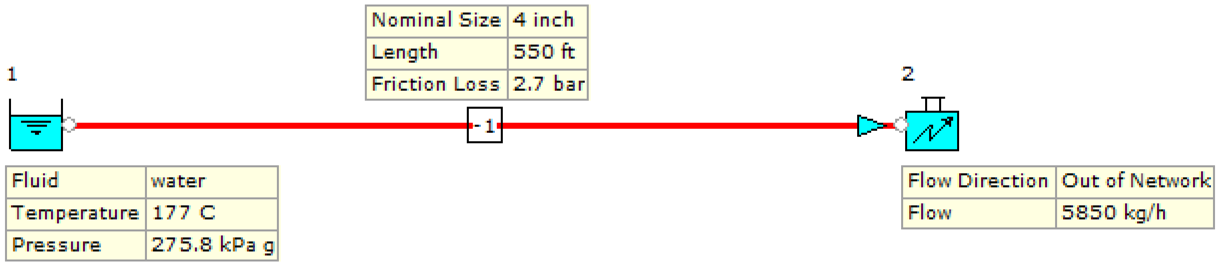
Commentary:

The results compare well. The discrepancy in the result can be explained in the value of viscosity used in the calculations. The text book proposes a value of 10^{-5} Pa s, while FluidFlow uses an extrapolated value of 12.5×10^{-5} Pa s.

3.6 Case 6: Estimating Pressure Drop along a Pipe Transporting Superheated Steam.

Reference: Handbook of mechanical engineering calculations, 2^{nd} Ed., 2006, McGraw-Hill, Tyler G Hicks, Pg 8.15.

Description: Determine the pressure loss in 510 ft of 4in steel pipe containing fittings of equivalent length 40ft. The schedule 40 piping conveys 5850 kg/h of superheated steam at 275.8 kPa & 177 °C.



FluidFlow Model

Unique Name	
Status	On
Elevation	0
Elevation Unit	m
Pressure Model	Static Pressure
Pressure	275.8
Pressure Unit	kPa g
Temperature	177
Temperature Unit	C
Fluid	water
Fluid Type	Newtonian/NN-NonSettling

System Inlet Data

Result Comparison:

Description	Published Data	FluidFlow Results
Pressure Loss (kPa)	274.9	274.1

Commentary:

The results correlate extremely well. The text book used published steam tables to arrive at the result, while FluidFlow calculated the value from the design inputs. In fact, the fluid is defined as water in FluidFlow however, the software automatically determines that it is in gas phase based on the design pressure and temperature conditions and applies the appropriate correlations.

3.7 Case 7: 100 kM Buried Seabed Pipe Heat Transfer Calculation.

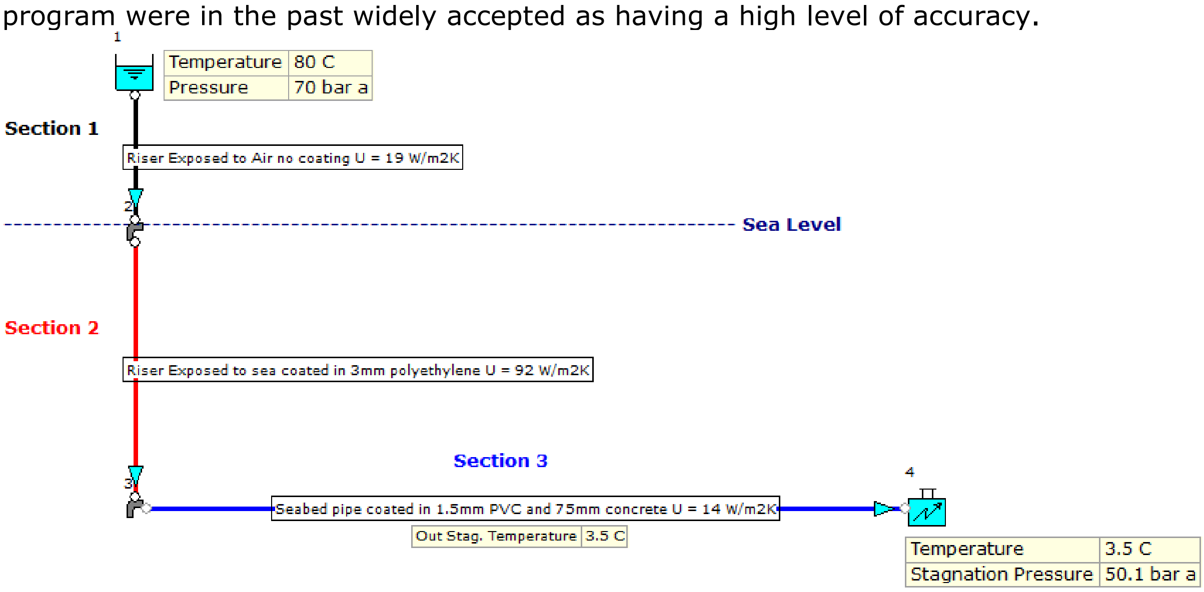
Reference: Gas/dp Software.

Description: In this example system, we have an offshore natural gas production platform exporting gas at 80ºC via a 100km, 20" buried sea-bed pipeline. The pipeline is modelled in three sections as follows;

1) Pipe segment exposed to air (no coating).
2) Pipe segment exposed to sea coated in 3mm polyethylene.
3) Pipe segment running along the sea bed coated with 1.5mm PVC and 75mm concrete.

The overall heat transfer coefficients for each pipe segment have been established from the table of typical values. The air and sea temperatures used in the example are 10ºC and 5ºC degrees respectively.

This heat transfer example is one of many FluidFlow verification examples and the calculated results have been compared to those available from the software package known as "Gas/dp" which is discontinued. Note, the results produced by the "Gas/dp" program were in the past widely accepted as having a high level of accuracy.



FluidFlow Model

User Number	4	
Flow	57.3	kg/s
Flow at STP	250000.0	m3/h
Flow at NTP	236871.3	m3/h
Stagnation Pressure	50.1	bar a
Static Pressure	50.1	bar a
Temperature	3.5	C
Density	49	kg/m3
Viscosity	0.012	cP
Specific Heat Capacity	1928.55	J/kg C
Composition Mass %	tural gas - subs	100.0%

FluidFlow Results

System Design Data:

Volumetric Flow Rate: 6000000 m^3/day.
Upstream Pressure: 70 Bar a.
Upstream Temperature: 80°C.

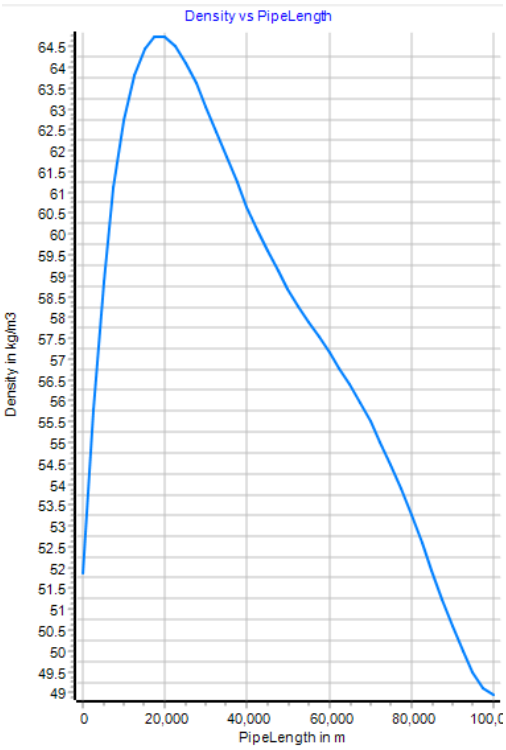
Result Comparison:

Software	In Temp (°C)	Out Temp (°C)	In Density (kg/m³)	Out Density (kg/m³)	In Pressure (bara)	Out Pressure (bara)	In Velocity (m/s)	Out Velocity (m/s)	Heat Transfer (kW)
FluidFlow	80	3.5	48.98	49.06	70	50.07	6.2	6.24	8980
Gas dp	80	4.16	50.18	50.9	70	50.99	6.1	5.97	9511

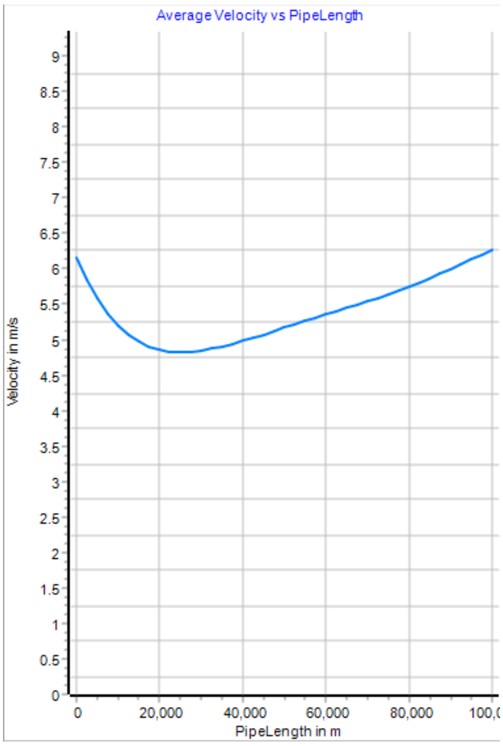
Commentary:

Considering this is an example of gas flow across a considerable length of pipework which include heat transfer, the results correlate extremely well. Note, FluidFlow does not assume gas ideality but calculates for real gas conditions providing a high level of accuracy.

Note, an illustration of the density and velocity profile of the gas as it flows along the pipe length are outlined below.



Profile of Density Results for 100km Pipeline.



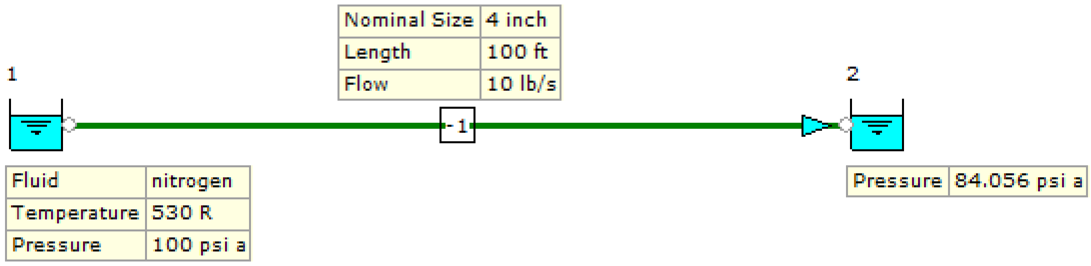
Profile of Gas Velocity Results for 100km Pipeline.

The above graphs provide a classic representation of a density and velocity profile along a gas pipeline. Note, how the gas velocity decreases initially as the gas cools before it then increases as the gas expands along the pipeline.

3.8 Case 8: Nitrogen Flow through a Pipeline.

Reference: Pipe Flow – A Practical & Comprehensive Guide (AIChE).

Description: In this example, the reference literature uses Turton's equations to determine the flow of nitrogen through a 4 inch schedule 40 pipeline over a distance of 100ft. The inlet pressure and temperature condition is 100 psia and 530 R and the outlet pressure is 84.056 psi a.



FluidFlow Model

User Number	-1	
Element Type	Steel Pipe, Duct or Tube	
Flow	9.9	lb/s
Flow at STP	13701.31	m3/h
Flow at NTP	12985.84	m3/h
Friction Loss	109.9	kPa
Pressure Gradient	3607	Pa/m
Loss Correlation	Duxbury	
Economic Velocity	6.51	m/s
Exact Economic Size	333.8	mm
Size	102.3	mm
In Fluid Phase	Gas or Vapor	
In Stagnation Pressure	689476	Pa a
In Static Pressure	670041	Pa a
In Velocity Pressure	19435	Pa a
In Velocity	70.82	m/s
In Mach Number	0.20	
In Stag. Temperature	21	C
In Static Temperature	19	C
In Density	8	kg/m3
In Viscosity	0.02	cP
Out Fluid Phase	Gas or Vapor	
Out Stagnation Pressure	579546	Pa a
Out Static Pressure	556219	Pa a
Out Velocity Pressure	23327	Pa a
Out Velocity	85.00	m/s
Out Mach Number	0.24	
Out Stag. Temperature	21	C
Out Static Temperature	17	C
Out Density	6	kg/m3

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Flow (lb/s)	10.00002	10

Commentary:

The results correlate extremely well, and with rounding applied can be considered to yield an identical result.

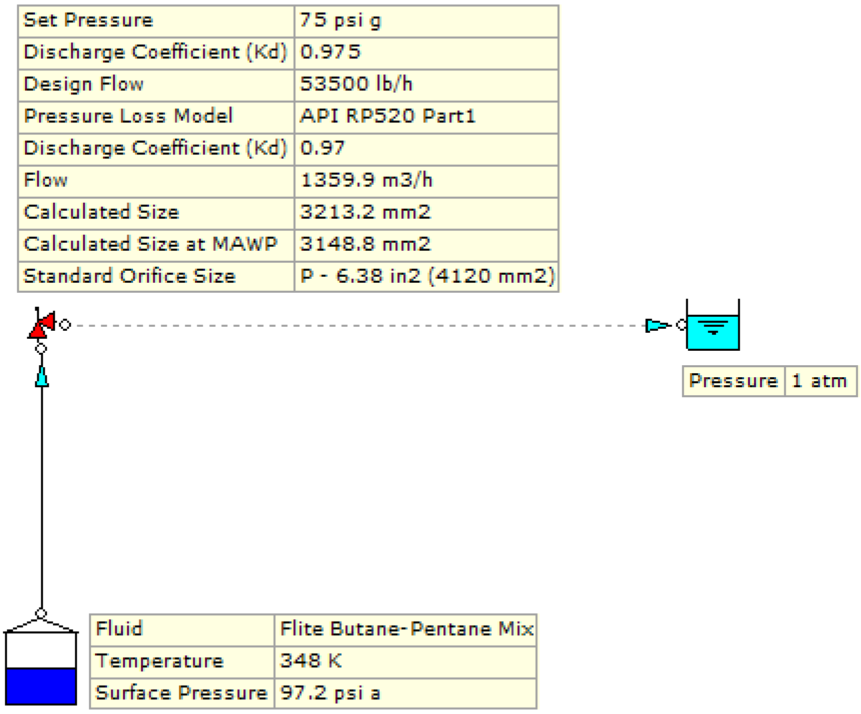
3.9 Case 9: Relief Valve Sizing (Hydrocarbon System).

Reference: API 520 RP, Example 3.6.2.2, Pg 44.

Description: As well as modelling specific manufacturer's relief valves in piping systems, FluidFlow allows you to automatically size relief valves and bursting disks for liquids, gases and two-phase systems to API & ISO standards.

This hand calculation for auto-sizing a relief valve is for a butane & pentane hydrocarbon system taken from the API standard. The design flow rate is given as 53500 lb/h, the relieving temperature and pressure is 348 Kelvin and 75 psi g respectively and the back pressure is given as 14.7 psi a (or 1 atm).

The permitted accumulation is 10 % and the relieving pressure is 97.2 psi a. A discharge coefficient of 0.975 has been used and the calculated relief orifice size is 3179mm2.



FluidFlow Model

User Number	2	
Flow	1359.9	m3/h
Flow at STP	8529	m3/h
Flow at NTP	8010	m3/h
Friction Loss	546042	Pa
Discharge Coefficient (Kd)	0.97	
Calculated Size	3213.3	mm2
Calculated Size at MAWP	3148.8	mm2
Standard Orifice Size	P - 6.38 in2 (4116 mm2)	
In Stagnation Pressure	670292	Pa a
In Static Pressure	666632	Pa a
In Velocity	20.25	m/s
In Mach Number	0.09	
In Stag. Temperature	74.8	C
In Static Temperature	74.7	C
Out Stagnation Pressure	124250	Pa a
Out Static Pressure	101332	Pa a
Out Velocity	126.82	m/s
Out Mach Number	0.58	
Out Stag. Temperature	74.1	C
Out Static Temperature	69.9	C
Composition Mass %	Butane-Pentan	100.0%

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Relief Valve Size (mm^2)	3179	3148.8

Commentary:

The results correlate extremely well. The size is just slightly different and this can be attributed to a number of reasons;

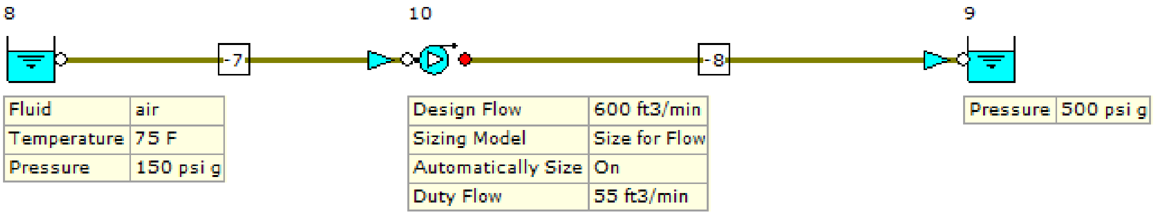
- The physical properties (molecular weight etc) of the FluidFlow gas mixture is slightly different to that used in the API standard as the FluidFlow mixture is based on a mixture ratio of 50-50. Note, the API standard doesn’t describe the % of butane or pentane in the mixture.
- FluidFlow does not assume gas ideality but solves for real gas conditions using an equation of state (and you can choose from three).
- The API standard considers the RV in isolation whereas it has been solved in this system with two pipes connected.

Note that, when using the API pressure loss model, FluidFlow suggests the next standard size orifice available which you can then consider in your system design.

3.10 Case 10: Compressor System.

Reference: Piping Calculations Manual, Example 5.3, Pg 262.

Description: A compressor is used to pump air through a pipeline at 150 psig and a flow temperature of 75 °F. The compressor is rated at 600 standard ft^3/min (SCFM). Calculate the airflow rate under actual conditions in actual ft^3/min (ACFM).



FluidFlow Model

User Number	10	
Element Type	Centrifugal Compressor,	
Duty Flow	55	ft3/min
Flow at STP	600	ft3/min
Flow at NTP	569	ft3/min
Duty Pressure Rise	60263.3	ft Fluid
Duty NPSH Available	28357.2	ft Fluid
In Fluid Phase	Gas or Vapor	
In Stagnation Pressure	165	psi a
In Static Pressure	165	psi a
In Velocity Pressure	0	psi a
In Velocity	4.557	ft/s
In Mach Number	0.00	
In Stag. Temperature	75.0	F
In Static Temperature	75.0	F
In Density	0.84	lb/ft3
In Viscosity	0.018	cP
Out Fluid Phase	Gas or Vapor	
Out Stagnation Pressure	515	psi a
Out Static Pressure	515	psi a
Out Velocity Pressure	0	psi a
Out Velocity	1.493	ft/s
Out Mach Number	0.00	
Out Stag. Temperature	91.6	F
Out Static Temperature	91.6	F
Out Density	2.55	lb/ft3
Out Viscosity	0.019	cP
Composition Mass %	air	100.0%

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Actual Flow Rate (ACFM)	55.1	55

Commentary:

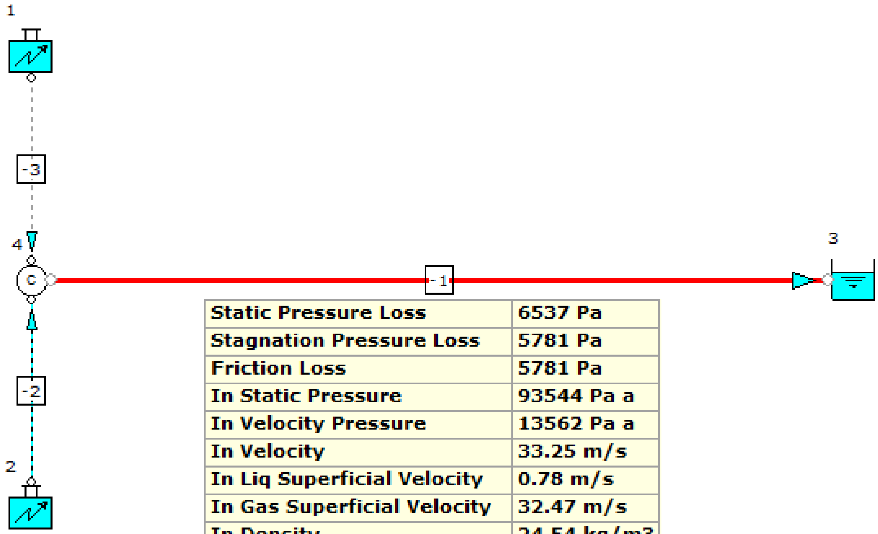
The results correlate extremely well.

4 Two-Phase (Liquid-Gas) Systems.

4.1 Case 1: System Pressure Loss Example

Reference: Fluid Flow Handbook, McGraw-Hill, Example 11.3.

Description: Calculate the pressure loss in a two-phase system pipeline (50.8mm diameter) which features an air input of 240.7 m^3/h at 26.6 °C and water at 5.677 m3/h at 26.6 °C.



Elevation	0 m
Flow Direction	Into Network
Flow	5.677 m3/h
Temperature	26.6 C
Fluid	water

Static Pressure Loss	6537 Pa
Stagnation Pressure Loss	5781 Pa
Friction Loss	5781 Pa
In Static Pressure	93544 Pa a
In Velocity Pressure	13562 Pa a
In Velocity	33.25 m/s
In Liq Superficial Velocity	0.78 m/s
In Gas Superficial Velocity	32.47 m/s
In Density	24.54 kg/m3
Out Static Pressure	87007 Pa a
Out Velocity Pressure	14318 Pa a
Out Velocity	35.10 m/s
Out Liq Superficial Velocity	0.78 m/s
Out Gas Superficial Velocity	34.32 m/s
Out Density	23.24 kg/m3
Reynolds No	2246333.0

Elevation	0 m
Flow Direction	Into Network
Flow	240.7 m3/h
Temperature	80 F
Fluid	air

FluidFlow Model

User Number	-1	
Element Type	Steel Pipe, Duct or Tube	
Flow	242.6	m3/h
Friction Loss	5781	Pa
Pressure Gradient	5780.52	Pa/m
Size	50.8	mm
In Fluid Phase	2 Phase	
In Vapor Quality	0.04956	
In Stagnation Pressure	107106	Pa a
In Static Pressure	93544	Pa a
In Velocity	33.25	m/s
In Liq Superficial Velocity	0.78	m/s
In Gas Superficial Velocity	32.47	m/s
In Stag. Temperature	26.6	C
In Static Temperature	26.4	C
In Density	24.54	kg/m3
In Viscosity	0.087	cP
Out Fluid Phase	2 Phase	
Out Vapor Quality	0.04956	
Out Stagnation Pressure	101325	Pa a
Out Static Pressure	87007	Pa a
Out Velocity	35.10	m/s
Out Liq Superficial Velocity	0.78	m/s
Out Gas Superficial Velocity	34.32	m/s
Out Stag. Temperature	26.6	C
Out Static Temperature	26.4	C
Out Density	23.24	kg/m3
Out Viscosity	0.084	cP
Composition Mass %	water	95.0%
	air	5.0%

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Pressure loss (kPa/m)	5.15	5.78

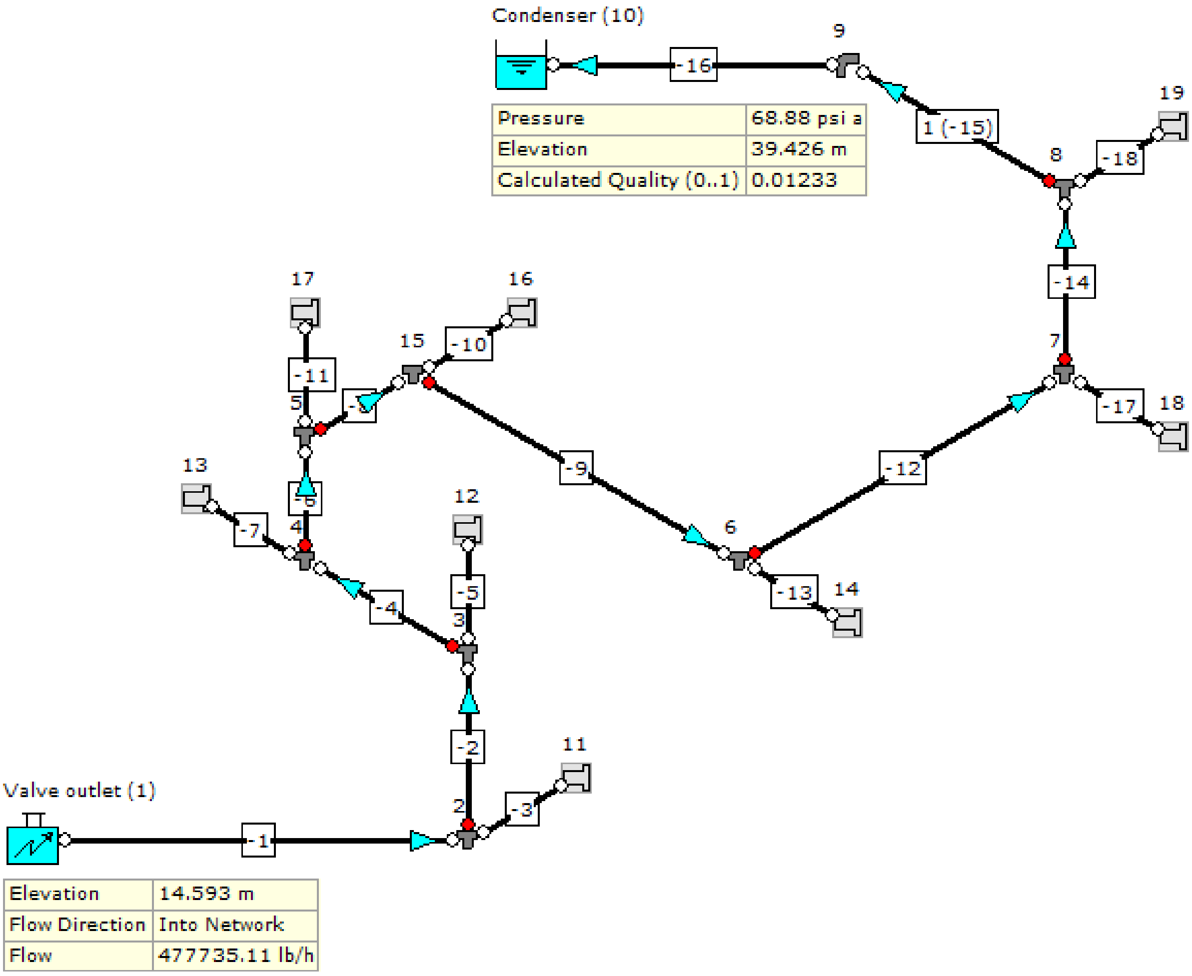
Commentary:

The FluidFlow results correlate extremely well with that provided by the Fluid Flow Handbook.

4.2 Case 2: Two-Phase Steam System.

Description: This system comprises of 121m of 10 inch Schedule 40 steel pipework. The system inlet condition is known to be 477735.11 lb/hr steam at 313.40 ° F and the outlet condition is 68.88 psi a with a vapor quality of 0.013143.

The task is to calculate the system and determine the inlet fluid pressure & temperature and outlet vapor quality using FluidFlow.



FluidFlow Model

User Number	10	
Flow	1278	m3/h
Stagnation Pressure	69.48	psi a
Static Pressure	68.94	psi a
Temperature	302.5	F
Density	10.58	lb/ft3
Viscosity	0.126	cP
Specific Heat Capacity	4265.29	J/kg C
Calculated Quality (0..1)	0.01233	
Composition Mass %	water	100.0%

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Inlet Pressure (psia)	84.78	83.39
Inlet Temperature (°F)	313.4	314.9
Outlet Vapor Quality	0.013143	0.0123

Commentary:

The results calculated by FluidFlow are extremely close to that provided by the customer for the operating system. Comparing the software result for that of a real-world two-phase operating system provides useful validation.

4.3 Case 3: Two-Phase Textbook Example (Constant Quality).

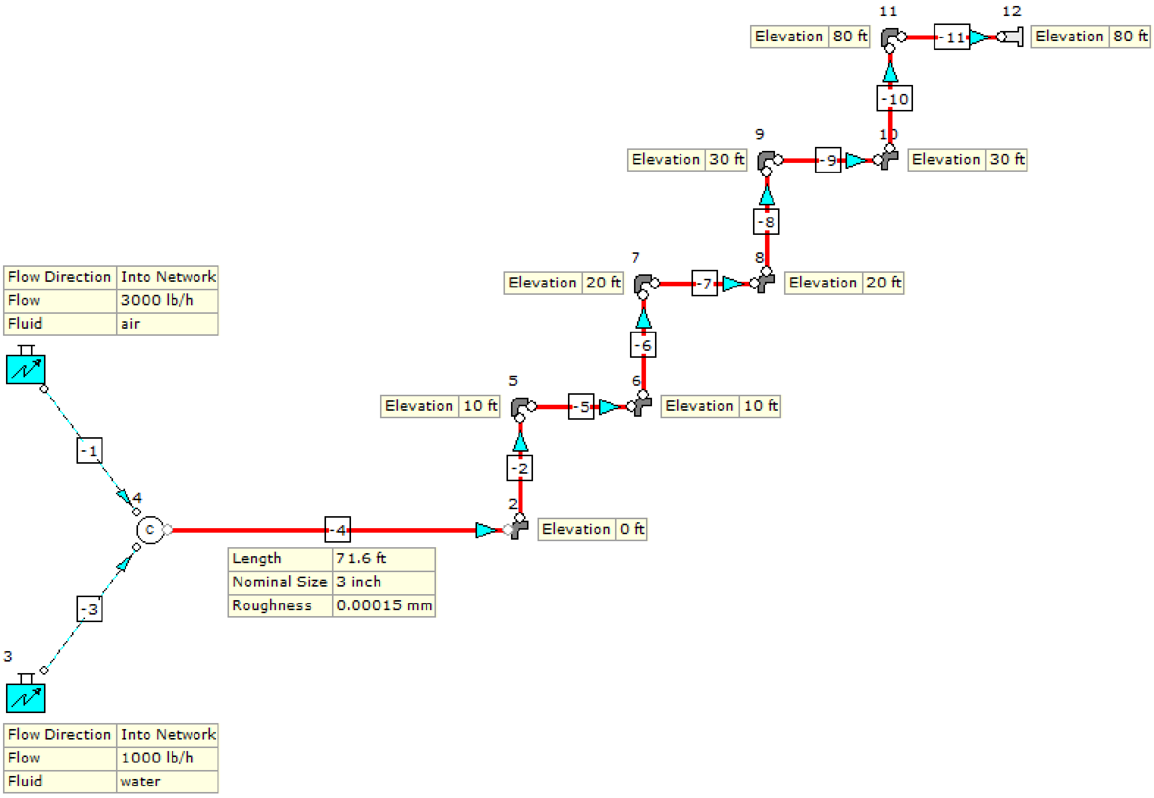
Description: A liquid-gas mixture is to flow in a line having a 358ft of level pipe and three vertical rises of 10ft each and one vertical rise of 50ft. evaluate the type of flow and expected pressure drop.

Fluid Data:

Description	Flow (lb/h)	Density (lb/ft³)	Density (kg/m³)	Viscosity (cP)
Liquid	1000	63.0	1009	1.0
Gas	3000	0.077	1.23	0.00127

Pipework: 3 Inch, Schedule 40 Stainless Steel (I.D. 3.068 in).
Relative Pipe Roughness: 0.000587.

Note: The literature calculation is based on the gas having a viscosity of 0.00127 cP and assumes gas ideality. For convenience, based on the gas having a density of 1.23 kg/m³, the model has been developed using air as the gas. It should therefore be noted that air has a viscosity of 0.018 cP and based on pressure and temperature in addition to the engineering conditions which apply, air density is 2.51 kg/m3 at the system inlet. Furthermore, FluidFlow does not assume gas ideality but calculates for real gas conditions.



FluidFlow Model

User Number	-11	
Flow	897	m3/h
Friction Loss	3.0294	psi
Pressure Gradient	0.1388	psi/m
Loss Correlation	Friedel	
Size	3.07	in
In Vapor Quality	0.75000	
In Stagnation Pressure	18.19	psi a
In Static Pressure	17.79	psi a
In Velocity	171.549	ft/s
In Liq Superficial Velocity	0.087	ft/s
In Gas Superficial Velocity	171.462	ft/s
In Stag. Temperature	59.0	F
In Static Temperature	57.0	F
Out Vapor Quality	0.75000	
Out Stagnation Pressure	15.17	psi a
Out Static Pressure	14.69	psi a
Out Velocity	205.676	ft/s
Out Liq Superficial Velocity	0.087	ft/s
Out Gas Superficial Velocity	205.589	ft/s
Out Stag. Temperature	59.0	F
Out Static Temperature	56.2	F
Composition Mass %	water	25.0%
	air	75.0%
Reynolds No	415471.2	
Friction Factor	0.013636	

FluidFlow Results

Result Comparison:

		FluidFlow Results						
Description	**Published Data**	Friedel	Chisholm Baroczy	Lockhart Martinelli	Drift Flux	Beggs & Brill	MSH	HEM
In Stag Pressure (psia)	**---**	30.06	29.44	25.92	25.71	30.05	29.45	21.48
Out Stag Pressure (psia)	**---**	14.7	14.7	14.7	14.7	14.7	14.7	14.7
Total System Pressure Drop (psi)	**15.8**	15.36	14.74	11.22	11.01	15.35	14.75	6.78
Liquid Velocity (ft/s)	**0.086**	0.087	0.087	0.087	0.087	0.087	0.087	0.087
Gas Velocity (ft/s)	**211**	205.5	205.5	205.5	205.5	205.5	205.5	205.5

Commentary:

The literature calculation is based on the gas having a viscosity of 0.00127 cP and assumes gas ideality. For simplicity, the model has been developed using air which has a viscosity of approx. 0.018 cP at 15 ^{o}C. The density of the air is also quite different as the hand calculation has assumed air density to be 1.23 kg/m^3 when its closer to 2.51 kg/m3. This will therefore have a slight effect on the calculated results.

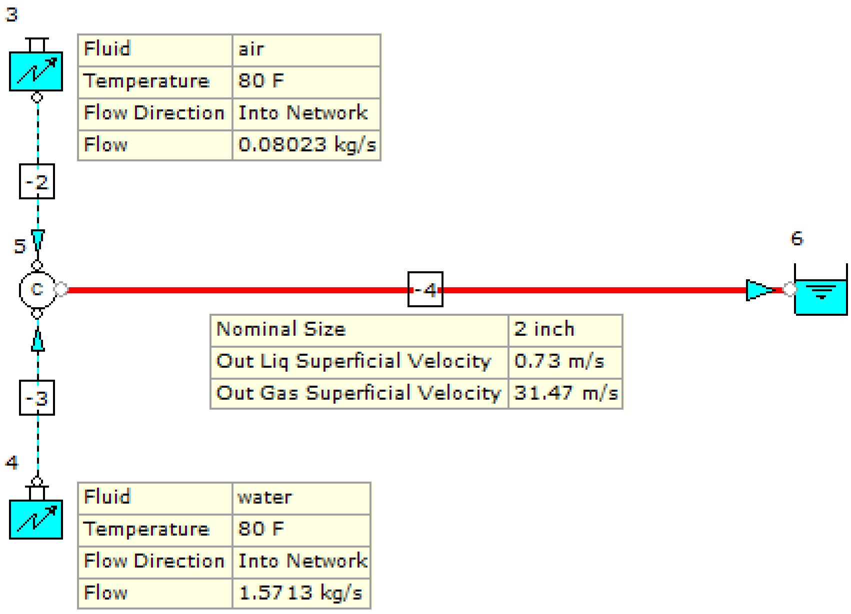
The "hand" calculation is based on ideal gas conditions. FluidFlow does not assume gas ideality but solves for **REAL** gas conditions and hence, provides more accurate results.

Based on the above, it is considered that the results provided by FluidFlow correlate well with the hand calculation and offers an accurate reflection of the system operating conditions. It is also considered that the Friedel correlation may be best suited for this particular application owing to the combination of both vertical and horizontal pipes.

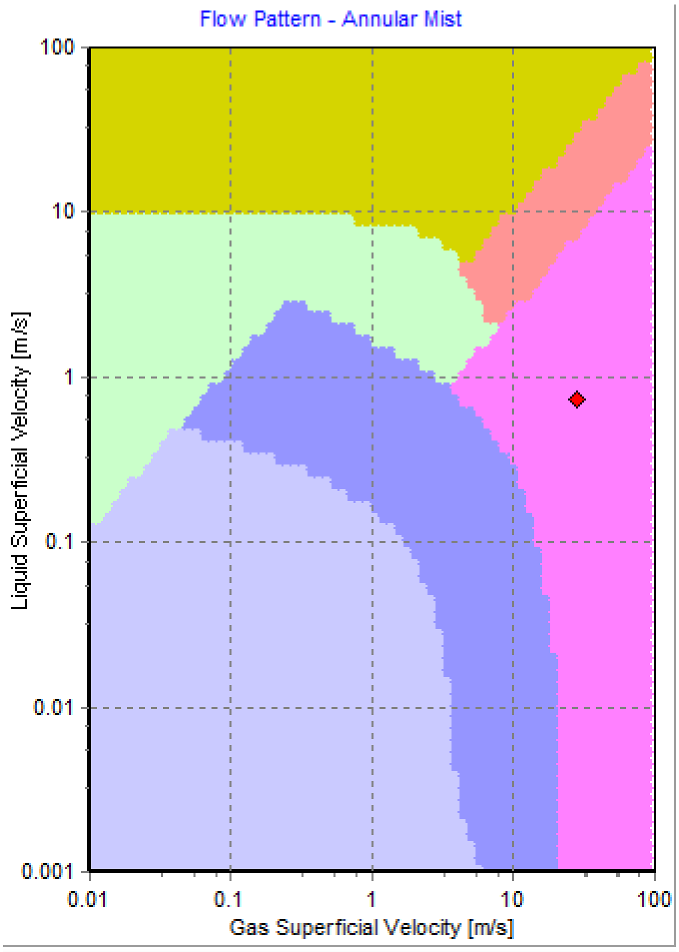
4.4 Case 4: Flow Pattern Map (Air-Water).

Reference: Fluid Flow Handbook, McGraw-Hill, Example 11.1.

Description: Determine the superficial liquid and gas velocities and the flow regime for a 2 inch pipeline transporting air & water at a flow rate of 0.08023 kg/s and 1.5713 kg/s respectively. The temperature of the air and water shall be 80 ^oF.



FluidFlow Model



FluidFlow Flow Pattern Map

Result Comparison:

Description	Published Data	FluidFlow Results
Flow Regime	Annular Mist	Annular Mist
Liquid Superficial Velocity (m/s)	33	31.47
Gas Superficial Velocity (m/s)	0.778	0.73

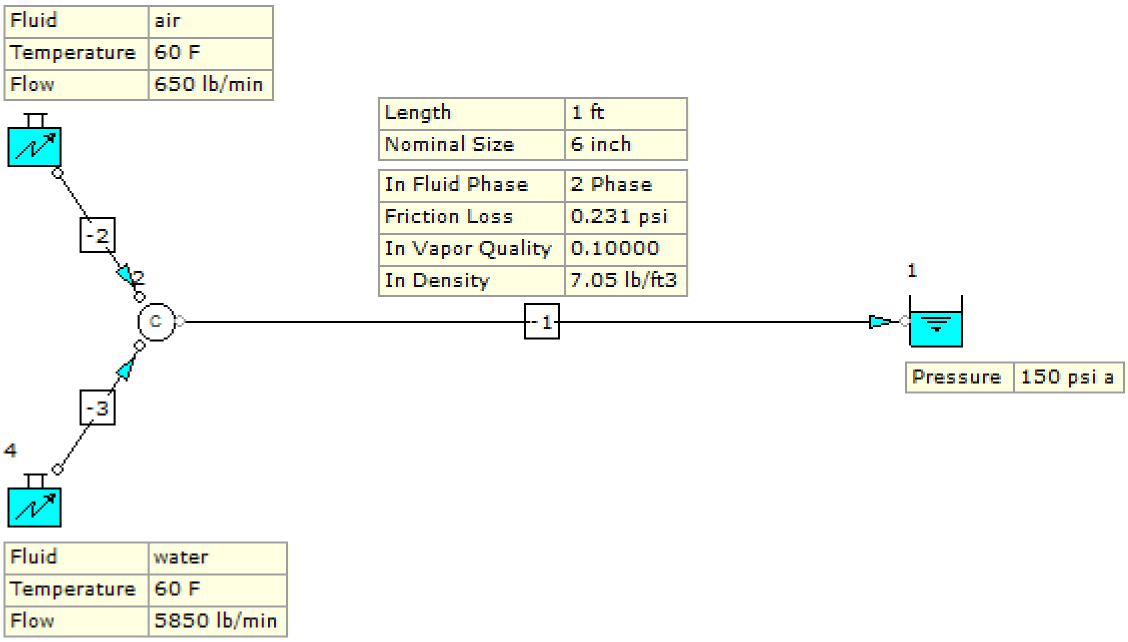
Commentary:

The FluidFlow results based on the Drift Flux Correlation correlate well with that provided by the Fluid Flow Handbook. The viscosity of water and air in the handbook are 0.81 and 0.01812 cP whereas FluidFlow uses 0.857 and 0.01845 cP. This will contribute to a slight difference in results.

4.5 Case 5: Lockhart Martinelli Example (Air-Water).

Reference: Chemical Engineering Fluid Mechanics, Ron Darby, Example 15.2.

Description: Estimate the pressure gradient in psi/ft using the Lockhart Martinelli relationship for a two-phase mixture of air and water entering a horizontal 6 in Sch 40 pipe at a total mass flow rate of 6500 lb/min. at 150 psia, 60 F with a vapor quality (x) of 0.1.



FluidFlow Model

Result Comparison:

Description	Published Data	FluidFlow Results
Vapor Quality	0.1	0.1
Friction Loss (psi/ft)	0.283	0.231
Density (lb/ft^3)	7.01	7.05

Commentary:

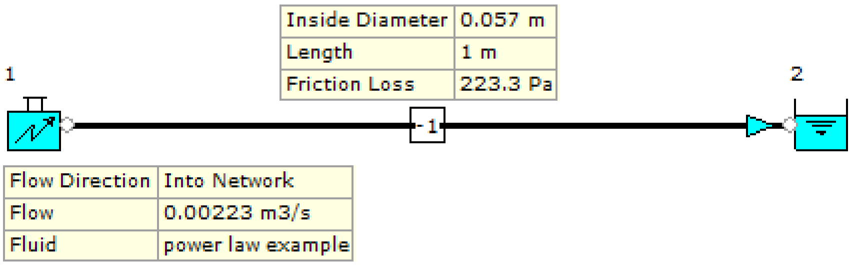
The results of the software are a very close match to the published data.

5 Non-Newtonian Slurries

5.1 Case 1: Pressure Gradient in a Pipeline Transporting Chalk Slurry.

Reference: Flow of Fluids in Piping Systems, 2002, Butterworth Heinemann, R.P King, Pg 141, Example 5.4.

Description: Calculate the pressure gradient due to friction along a 5.7 cm pipe when the chalk slurry flows at a rate of 2.23 x 10^{-3} m^3/s. Refer to the text book for slurry properties.



FluidFlow Model

User Number	-1	
Element Type	Steel Pipe, Duct or Tube	
Flow	3.2	kg/s
Friction Loss	223.33	Pa
Pressure Gradient	223	Pa/m
Size	57.0	mm
In Fluid Phase	Non-Newtonian	
In Stagnation Pressure	101548	Pa a
In Static Pressure	101003	Pa a
In Velocity Pressure	545	Pa a
In Velocity	0.87	m/s
In Stag. Temperature	15.0	C
In Static Temperature	15.0	C
In Density	1427.00	kg/m3
In Viscosity	7.148	cP
Out Fluid Phase	Non-Newtonian	
Out Stagnation Pressure	101325	Pa a
Out Static Pressure	100780	Pa a
Out Velocity Pressure	545	Pa a
Out Velocity	0.87	m/s
Out Stag. Temperature	15.0	C
Out Static Temperature	15.0	C
Out Density	1427.00	kg/m3
Out Viscosity	7.148	cP
Wall Shear Stress	3.18	Pa a
Fluid Shear Rate (in s-1)	123	
Composition Mass %	›wer law examp	100.0%
Reynolds No	9144.7	
Friction Factor	0.023362	

FluidFlow Results

Result Comparison:

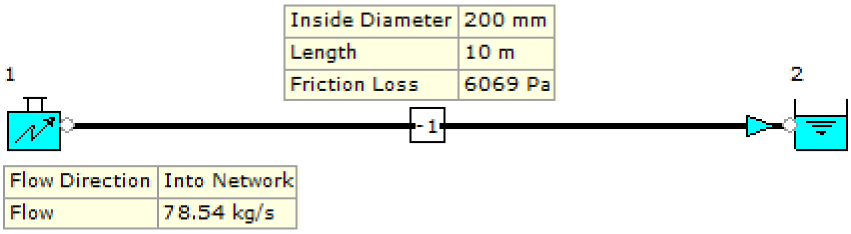
Description	Published Data	FluidFlow Results
Pressure Gradient (Pa/m)	215.8	223.3
Pipe Velocity (m/s)	0.874	0.874

Commentary:

The results compare well. Variations are to be expected when dealing with non-Newtonian slurries, due to the error element associated with best fitting a curve to the available data points.

5.2 Case 2: Sewage System Pressure loss

Description: Calculate the pressure loss along a 200mm pipe with a length of 10M when the sewage slurry flows at a rate of 78.54 kg/s.



FluidFlow Model

User Number	-1	
Element Type	Steel Pipe, Duct or Tube	
Flow	78.54	kg/s
Friction Loss	6068.6	Pa
Pressure Gradient	606.9	Pa/m
Size	200.0	mm
In Fluid Phase	Non-Newtonian	
In Stagnation Pressure	0.9	psi g
In Static Pressure	0.4	psi g
In Velocity	2.50	m/s
In Stag. Temperature	15.0	C
In Static Temperature	15.0	C
In Density	1000.00	kg/m3
In Viscosity	265.340	cP
Out Fluid Phase	Non-Newtonian	
Out Stagnation Pressure	0.0	psi g
Out Static Pressure	-0.5	psi g
Out Velocity	2.50	m/s
Out Stag. Temperature	15.0	C
Out Static Temperature	15.0	C
Out Density	1000.00	kg/m3
Out Viscosity	265.340	cP
Wall Shear Stress	30.34	Pa a
Fluid Shear Rate (in s-1)	100	
Composition Mass %	;ewage sludge /	100.0%
Reynolds No	1647.8	
Friction Factor	0.038839	

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Pressure Loss (Pa)	6061	6068.6

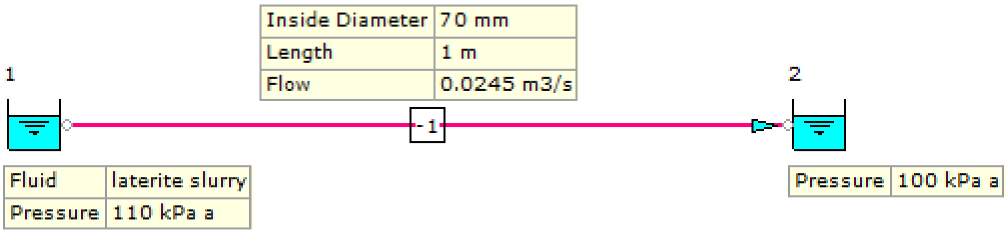
Commentary:

The results calculated by FluidFlow compare favourably with that provided by the Fluid Flow Handbook.

5.3 Case 3: Pressure Gradient for Herschel Bulkley Sewage Model.

Reference: Flow of Fluids in Piping Systems, 2002, Butterworth Heinemann, R.P King, Pg 134, Example 5.3.

Description: Calculate the flow rate of laterite slurry delivered in a 7cm diameter pipe line. System inlet pressure is 110 Kpa a and outlet pressure is 100 Kpa a. Refer to the text book for slurry properties.



FluidFlow Model

User Number	-1	
Element Type	Steel Pipe, Duct or Tube	
Flow	0.0245	m3/s
Friction Loss	10001	Pa
Pressure Gradient	10001	Pa/m
Size	70.0	mm
In Fluid Phase	Non-Newtonian	
In Stagnation Pressure	110000	Pa a
In Static Pressure	80976	Pa a
In Velocity	6.38	m/s
In Stag. Temperature	15.0	C
In Static Temperature	15.0	C
In Density	1427.00	kg/m3
In Viscosity	112.272	cP
Out Fluid Phase	Non-Newtonian	
Out Stagnation Pressure	99999	Pa a
Out Static Pressure	70975	Pa a
Out Velocity	6.38	m/s
Out Stag. Temperature	15.0	C
Out Static Temperature	15.0	C
Out Density	1427.00	kg/m3
Out Viscosity	112.272	cP
Wall Shear Stress	175.01	Pa a
Fluid Shear Rate (in s-1)	729	
Composition Mass %	laterite slurry	100.0%
Reynolds No	12066.6	
Friction Factor	0.024118	

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Flow Rate (m^3/s)	0.0226	0.0245

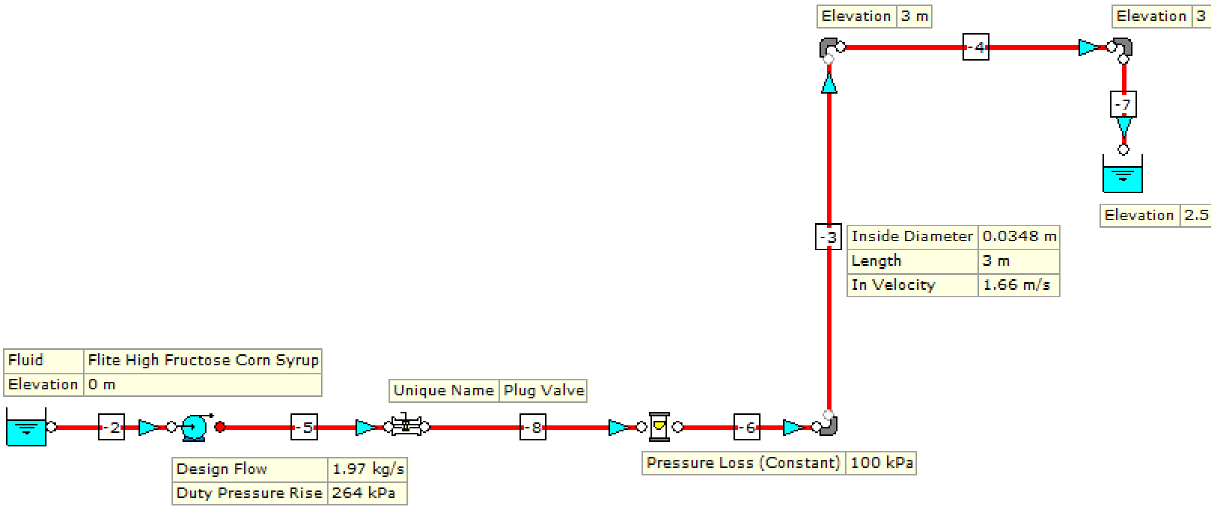
Commentary:

The results calculated by FluidFlow compare well with that provided by the Fluid Flow Handbook. The slight difference in results can be attributed to the subtle difference in Reynolds numbers.

5.4 Case 4: Food Process Plant – Power Law Fluid.

Reference: Rheological Methods in Food Process Engineering – James F. Steffe, Pg 152, Example 2.12.6.

Description: High fructose corn syrup (power law) shall be pumped from an input tank to an output tank at elevations of 0 & 2.5 m respectively. The system has a 0.0348 m diameter pipeline with a design flow rate of 1.97 kg/s resulting in an average velocity of 1.66 m/s. The fluid density is 1250 kg/m^3. The system includes a plug valve and a strainer which has a pressure drop of 100 kPa. Determine the friction losses in the system where K = 5.2 Pa s and n = 0.45.



FluidFlow Model

User Number	7	
Element Type	Centrifugal Pump	
Duty Flow	0.00158	m3/s
Duty Pressure Rise	264	kPa
Duty NPSH Available	7.3	m Fluid
In Fluid Phase	Non-Newtonian	
In Stagnation Pressure	91554	Pa a
In Static Pressure	89838	Pa a
In Velocity	1.66	m/s
In Stag. Temperature	15.0	C
In Static Temperature	15.0	C
In Density	1250.00	kg/m3
Out Fluid Phase	Non-Newtonian	
Out Stagnation Pressure	355662	Pa a
Out Static Pressure	353946	Pa a
Out Velocity	1.66	m/s
Out Stag. Temperature	15.0	C
Out Static Temperature	15.0	C
Out Density	1250.00	kg/m3
Composition Mass %	igh Fructose Corn	100.0%

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Velocity (m/s)	1.66	1.66
Pressure Drop (kPa)	265	264

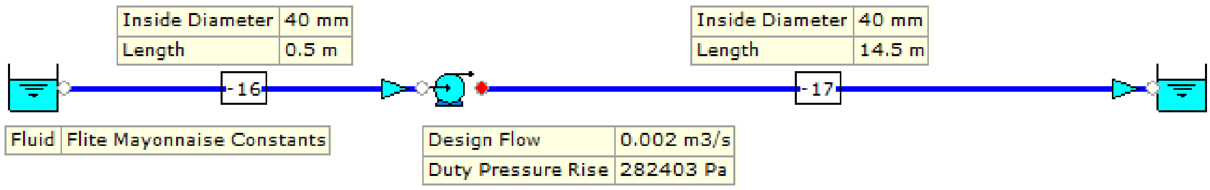
Commentary:

The results calculated by FluidFlow offer a high level of accuracy when compared with that provided by the Steffe Handbook.

5.5 Case 5: Mayonnaise Process Piping.

Reference: Introduction to Food Process Engineering – P.G. Smith, Pg 112, Example 6.15.

Description: Determine the pressure drop for a piping system transporting mayonnaise (power law fluid) at a flow rate of 0.002 m^3/s. The mayonnaise has a behaviour flow index of n = 0.31 and K = 27.5 Pa s.



FluidFlow Model

User Number	19	
Element Type	Centrifugal Pump	
Duty Flow	0.00200	m3/s
Duty Pressure Rise	282403	Pa
Duty NPSH Available	9.2	m Fluid
In Fluid Phase	Non-Newtonian	
In Stagnation Pressure	91912	Pa a
In Static Pressure	90645	Pa a
In Velocity	1.59	m/s
In Stag. Temperature	15.0	C
In Static Temperature	15.0	C
Out Fluid Phase	Non-Newtonian	
Out Stagnation Pressure	374315	Pa a
Out Static Pressure	373048	Pa a
Out Velocity	1.59	m/s
Out Stag. Temperature	15.0	C
Out Static Temperature	15.0	C
Composition Mass %	Mayonnaise Const	100.0%

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Pressure Drop (Pa)	282000	282403

Commentary:

The results calculated by FluidFlow offer a high level of accuracy when compared with that provided by the Food Process Engineering Handbook.

6 Settling Slurries

FluidFlow provides five correlations for settling slurry pipelines as follows;

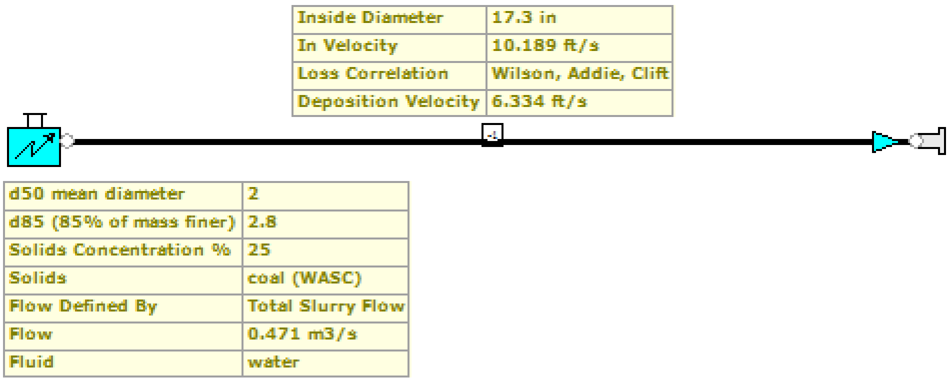
- Durand.
- WASC (Wilson, Addie, Sellgren, Clift).
- Wasp.
- Four-Component Model.
- Liu Dezhong.

The following section provides an outline of just some calculation verification examples completed using FluidFlow.

6.1 Case 1: Transport of Coal Slurry.

Reference: Slurry Transport Using Centrifugal Pumps 3rd Edition, 2006, Springer, Wilson, Addie, Sellman and Addie, Pg 404, Case Study 6.2.

Description: Coal is to be transported through a pipe with D = 17.3 inches and f_w = 0.013 mm at a solids concentration C_{vd} = 0.25. The coal has the following properties – Ss = 1.4, $\mu_S = 0.44$, and $C_{vb} = 0.60$. The particle sizes yield a d_{50} of 2.0mm and d_{85} of 2.8mm. Calculate the maximum limit of deposition velocity, V_{sm}.



FluidFlow Model

User Number	-1	
Flow	0.471	m3/s
Friction Loss	0.3123	ft Water
Pressure Gradient	306.3	Pa/m
Loss Correlation	Wilson, Addie, Clift	
Size	17.30	in
Cvd Deposition Velocity	2.966	ft/s
Deposition Velocity	6.334	ft/s
In Fluid Phase	Slurry	
In Stagnation Pressure	15.60	psi a
In Static Pressure	14.83	psi a
In Velocity	10.189	ft/s
In Stag. Temperature	59.00	F
In Static Temperature	59.00	F
In Density	68.63	lb/ft3
Out Fluid Phase	Slurry	
Out Stagnation Pressure	15.46	psi a
Out Static Pressure	14.70	psi a
Out Velocity	10.189	ft/s
Out Stag. Temperature	59.00	F
Out Static Temperature	59.00	F
Out Density	68.63	lb/ft3
Composition Mass %	water	68.2%
	coal	
	(WASC)	31.8%
Specific Energy	875.0	
Reynolds No	1198653	
Friction Factor	0.013449	

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Vsm (ft/s)	6.2	6.33
Friction Loss Gradient (ft water/ft pipe)	0.0313	0.03123

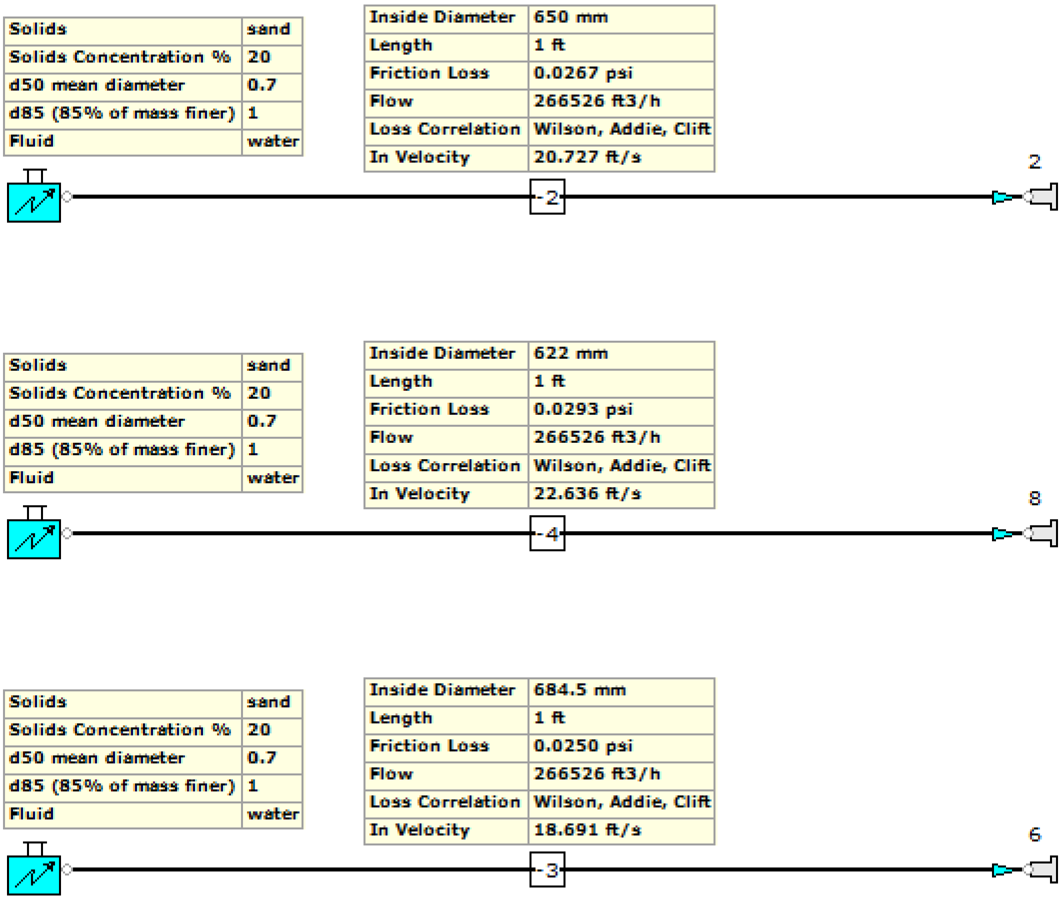
Commentary:

The results correlate extremely well, and with rounding applied can be considered to yield the same answer.

6.2 Case 2: Effect of Particle Size and Grading on Sand Transport.

Reference: Slurry Transport Using Centrifugal Pumps 3rd Edition, 2006, Springer, Wilson, Addie, Sellgren and Clift, Pg 401, Case Study 6.1.

Description: This study investigates the accuracy of FluidFlow with varying particle size distributions. The slurry is pumped through a pipe with D = 25.6 inches at 20% solids concentration by volume. D50 is 0.70mm and D85 is 1.00mm. The slurry is assumed to be travelling at a velocity of 20.7 ft/s in the pipe.



FluidFlow Model

Unique Name	
Status	On
Length	1
Length Unit	ft
Geometry	Cylindrical
Use Database Size	No
Inside Diameter	650
Diameter Unit	mm
Wall Thickness	9.25
Friction Model	Moody
Use Database Roughness	Yes
Roughness Description	Clean or new
Use Database Scaling	No
Scaling (0 to 50%)	0
Sizing Model	Economic Velocity
Heat Loss Model	Ignore Heat Loss/Gain

Pipe Input Data

Result Comparison:

Description	Published Data	FluidFlow Results
Friction Loss Gradient (ft water/ft pipe) Case 1	0.0612	0.0630
Friction Loss Gradient (ft water/ft pipe) Case 2	0.0653	0.0691
Friction Loss Gradient (ft water/ft pipe) Case 3	0.0589	0.0589

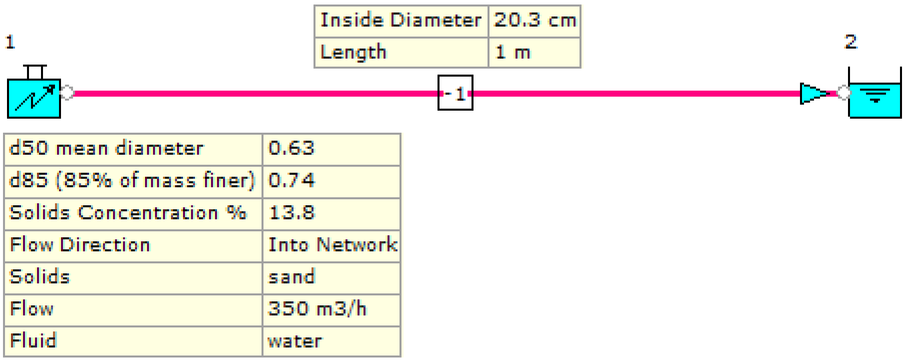
Commentary:

The results compare favourably, with variation between the two results sets attributed to rounding up of values in the published data.

6.3 Case 3: Heterogeneous Slurry Flow.

Reference: Flow of Fluids in Piping Systems, 2002, Butterworth Heinemann, R.P King, Pg 106, Example 4.7.

Description: Calculate the pressure gradient due to friction when a slurry of sand in water having D_{50} = 0.63 mm and D_{85} = 0.74 mm is transported through a 20.3 cm horizontal pipe with a solids fraction of 0.138. The density of the sand is 2650 kg/m^3 and the slurry flows at 3 m/s. The coefficient of friction between the settled solids and the pipe wall is 0.44.



FluidFlow Model

User Number	-1	
Element Type	Steel Pipe, Duct or Tube	
Flow	0.0972	m3/s
Friction Loss	1095	Pa
Pressure Gradient	1094.7	Pa/m
Loss Correlation	Wilson, Addie, Clift	
Size	203.0	mm
Cvd Deposition Velocity	2.411	m/s
Deposition Velocity	2.664	m/s
In Fluid Phase	Slurry	
In Stagnation Pressure	0.2	psi g
In Static Pressure	-0.6	psi g
In Velocity	3.004	m/s
In Stag. Temperature	20.0	C
In Static Temperature	20.0	C
In Density	1226.15	kg/m3
In Viscosity	1.566	cP
Out Fluid Phase	Slurry	
Out Stagnation Pressure	0.0	psi g
Out Static Pressure	-0.8	psi g
Out Velocity	3.004	m/s
Out Stag. Temperature	20.0	C
Out Static Temperature	20.0	C
Out Density	1226.15	kg/m3
Out Viscosity	1.566	cP
Composition Mass %	water	70.2%
	sand	29.8%
Specific Energy	2993.5	
Reynolds No	611223	
Friction Factor	0.013444	

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Reynolds Number	6.09×10^5	6.11×10^5
Friction Loss (kPa/m)	1.14	1.094

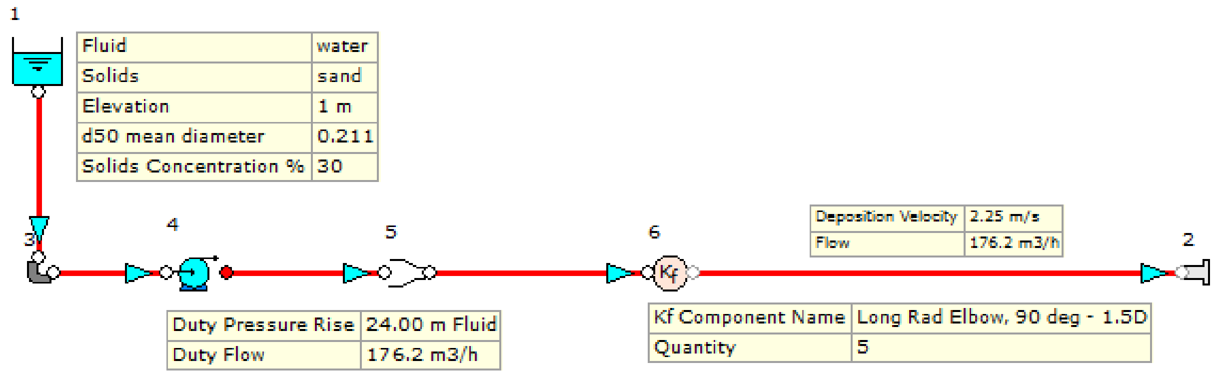
Commentary:

The results compare favourably. The text book example uses a water viscosity value of 0.001 Pa s while FluidFlow extrapolates a viscosity value based on the temperature of the water in the slurry. A temperature of 20°C has been assumed, which gives a viscosity value (0.0015 Pa s) close to that used in the text book.

6.4 Case 4: Pump Sizing for Heterogeneous Slurry.

Reference: Warman Slurry Handbook, 2009, Pg 32.

Description: A heavy duty slurry pipe is required to transport 65 tph of sand (d_{50} of 0.211 mm) with a S.G. of 2.65 in a slurry with 30% concentration by weight of solids. The pipeline is 100 M long, 6 inches in diameter, and has an elevation difference of 20 M. The pipeline also includes 5 x 90° long radius bends.



FluidFlow Model

User Number	**4**	
Duty Flow	**176.2**	m3/h
Duty Pressure Rise	**29.49**	m Water
Duty NPSH Available	**9.1**	m Fluid
In Stagnation Pressure	**1.5**	psi g
In Static Pressure	**0.9**	psi g
In Velocity	**2.62**	m/s
In Stag. Temperature	**15.0**	C
In Static Temperature	**15.0**	C
Out Stagnation Pressure	**43.4**	psi g
Out Static Pressure	**40.2**	psi g
Out Velocity	**6.04**	m/s
Out Stag. Temperature	**15.0**	C
Out Static Temperature	**15.0**	C
Composition Mass %	**water**	70.0%
	sand	30.0%

FluidFlow Results

Result Comparison:

Description	Published Data	FluidFlow Results
Pump Duty	176.2m^3/h @ 28.53 m water	176.2m^3/h @ 29.49 m water
Deposition Velocity (m/s)	2.3	2.3

Commentary:

The results correlate extremely well, with negligible difference between the two results. In both cases, the Durand method has been used due to the available solids data.

6.5 Case 5: Mica Case Study.

Reference: BHR Group.

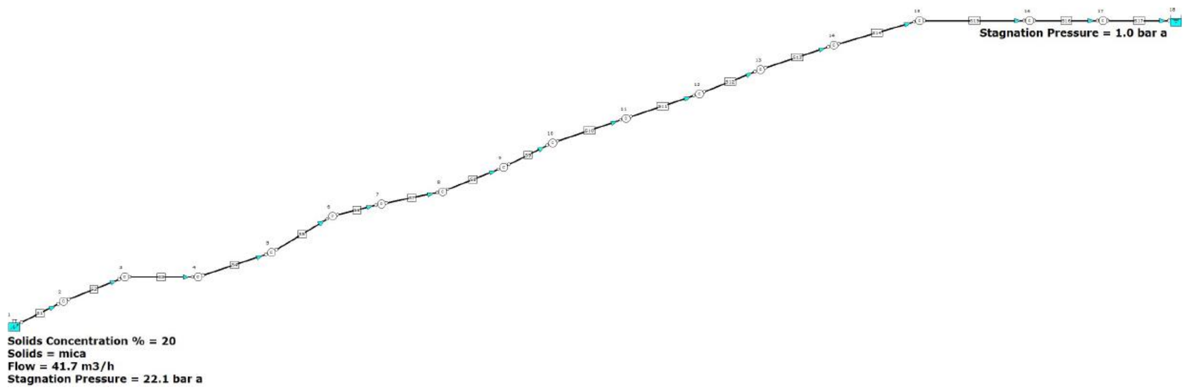
Description: This is an example of an existing mica slurry transportation system which when originally constructed had a total length of 1800m of 80mm ID pipework and a throughput of 5.2t/h of mica solids (density 2650 kg/m^3).

It was intended to extend the pipeline by 250m resulting in a new total length of 2050m. The corresponding increase in net elevation change was +66.2m to 80m. The throughput was also to increase to approximately 9.53 t/h.

The new pipe length was divided into 17 sections of known length and elevation change as set out in the Table below.

Pipe Section	Length (m)	Elevation Change
S1	137.5	+6.3
S2	87.5	+2.5
S3	62.5	0
S4	137.5	+8.2
S5	225	+15.1
S6	75	+1.9
S7	100	+2.8
S8	50	+2.2
S9	100	+6.8
S10	50	+1.5
S11	62.5	+6
S12	112.5	+10
S13	100	+4.9
S14	50	13.8
S15	50	0
S16	400	0
S17	250	0
Total	2050	+80

Using this data, a model was developed in FluidFlow.



FluidFlow Model

Required Information:

- Total System Pressure Differential.
- Ensure pipeline velocity > deposition velocity.

A study had previously been completed on this system by Engineering Consultants using the SRC Two-Layer Model approach. Based on historical test data available and the results of the SRC analysis, a model of the system was developed. Using the Liu Dezhong method, FluidFlow was used to analyse the system and the calculated results correlated with the SRC approach. The system was solved for a known particle distribution on the basis of a slurry concentration of 20% by weight and a total system volumetric flow rate of 41.7 m^3/h. Details of the findings are outlined in the table below.

Result Comparison:

Description	Published Data	FluidFlow Results
Pipe Velocity (m/s)	2.31	2.3
Deposition Velocity (m/s)	1.6	1.53
Total Differential Pressure (bar)	21.9	20.3
Solids Delivered (t/h)	9.53	9.51

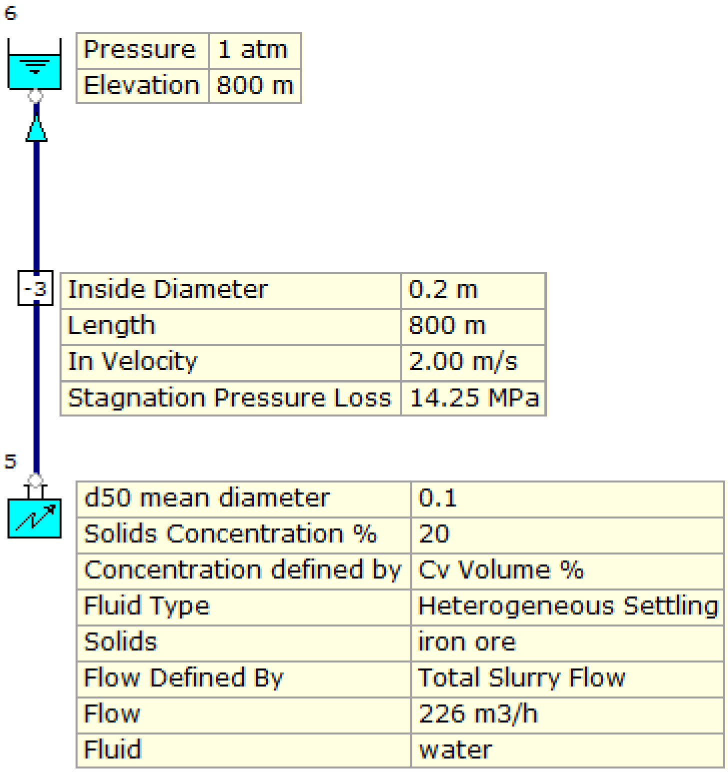
Commentary:

The results correlate extremely well, with negligible difference between the two results. The FluidFlow results are a very close match to that of the data for the actual system.

6.6 Case 6: 800M Vertical Pipe - Heterogeneous Slurry.

Reference: Warman Slurry Handbook, 2009, Pg 32.

Description: In an iron-ore mine the ore is ground to 100 μm (0.1mm) in a sub-surface facility and then pumped vertically 800m to the surface. The pipe has a diameter of 0.2m. The concentration by volume is 20% and the specific gravity of the solids is 4.9. Determine the pressure requirement to pump the slurry to the surface at a velocity of 2m/s.



FluidFlow Model

Unique Name	
Status	On
Length	800
Length Unit	m
Geometry	Cylindrical
Use Database Size	No
Inside Diameter	0.2
Diameter Unit	m
Wall Thickness	3.9
Friction Model	Moody
Use Database Roughness	Yes
Roughness Description	Clean or new
Use Database Scaling	No
Scaling (0 to 50%)	0
Sizing Model	Economic Velocity
Heat Loss Model	Ignore Heat Loss/Gain

Pipe Data Entry

Result Comparison:

Description	Published Data	FluidFlow Results
Pressure Requirement (MPa)	14.2	14.25

Commentary:

The results correlate extremely well, with negligible difference between the two results.

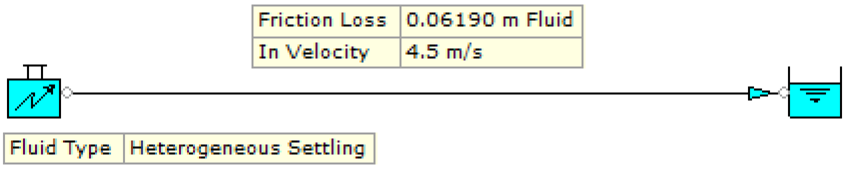
6.7 Case 7: Heterogeneous Slurry Loop Testing & Application of the Four-Component Model.

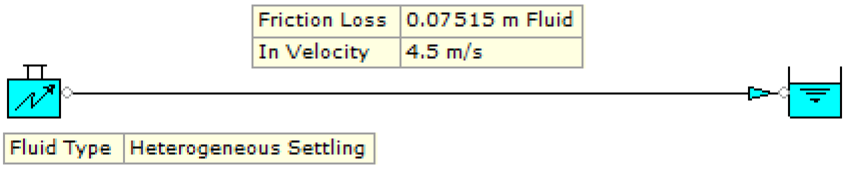
Reference: Slurry Transport Using Centrifugal Pumps 3rd Edition, 2006, Springer, Wilson, Addie, Sellgren and Clift.

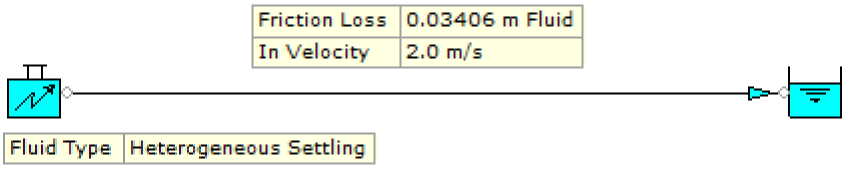
Description: A loop-testing study was carried out to assess the validity of the Four-Component model. The slurries were developed by combining four particles of a size which fell within the four component particle size limits. The table below summarises the simulated conditions and the measured friction losses for each tested case.

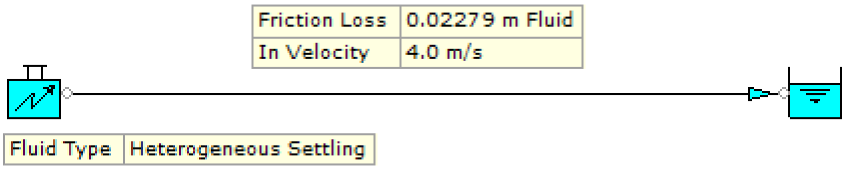
Test No.	Pipe Dia. (mm)	Velocity (m/s)	Solids SG	d_{50}	Cv %	Measured Friction Loss (m slurry/m pipe)
1	305	4.5	2.65	0.7	15	0.060
2	305	4.5	3	0.85	27	0.075
3	100	2	2.65	0.085	13	0.034
4	438	4	2.65	0.2	38	0.029
5	263	3.1	2.65	0.17	26	0.026
6	206	2	2.65	0.085	30	0.016
7	206	3	2.65	0.2	32	0.030

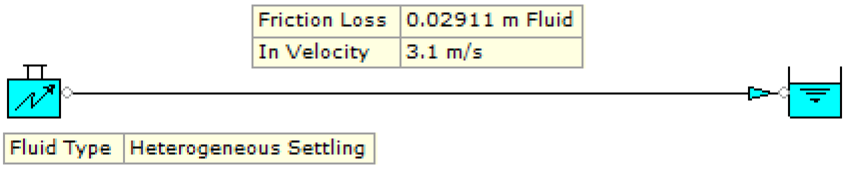
A model of each scenario above was developed and solved in FluidFlow using Particle Size Distribution (PSD) data. The model results are shown as follows:

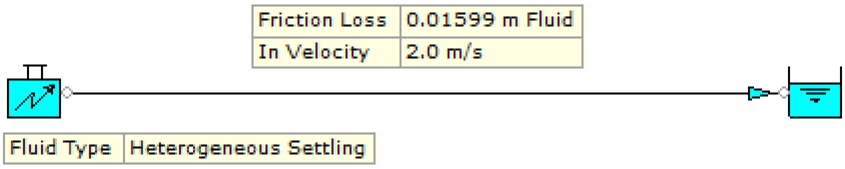


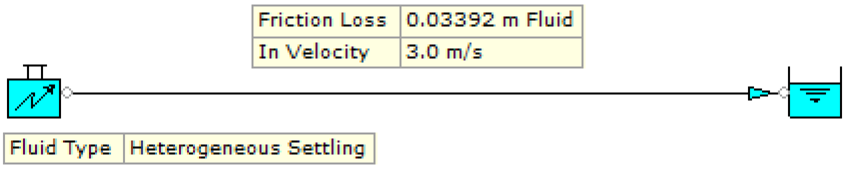












FluidFlow Models

Result Comparison:

Test	Pipe Dia. (mm)	Measured Friction Loss (m slurry/m pipe)	FluidFlow Results
1	305	0.060	0.061
2	305	0.075	0.075
3	100	0.034	0.034
4	438	0.029	0.023
5	263	0.026	0.029
6	206	0.016	0.016
7	206	0.030	0.033

Commentary:

The results correlate extremely well with published and measured loop test data.

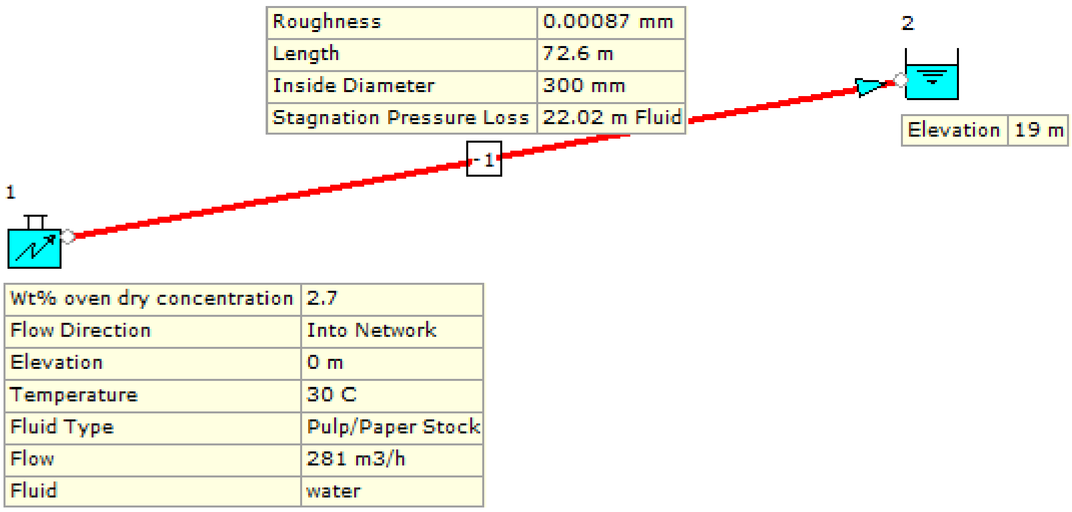
7 Pulp & Paper

7.1 Case 1: Pulp & Paper System (Chemical Pulp).

Reference: ScanPump Brochure, Example 2.4.

Description: A pipeline transports pulp/paper stock with a wt% oven dry concentration of 2.7 %. The pipeline has a length of 72.6 M (approx. 238 ft), an I.D. of 300mm and the pipe absolute roughness is 0.00087mm. The system flow rate is 281 m^3/h and the water temperature is 30°C. The pipe also experiences a change in elevation from 0 m to 19 M. The aspect ratio is 60 and the pulp has a freeness of 500 Csf.

Determine the overall pressure loss in the pipeline.



FluidFlow Model

Status	On
Length	72.6
Length Unit	m
Geometry	Cylindrical
Use Database Size	No
Inside Diameter	300
Diameter Unit	mm
Wall Thickness	0.62
Friction Model	Moody
Use Database Roughness	No
Roughness	0.00087

Pipe Data Entry

Result Comparison:

Description	Published Data	FluidFlow Results
Pressure Loss (m fluid)	22	22.02

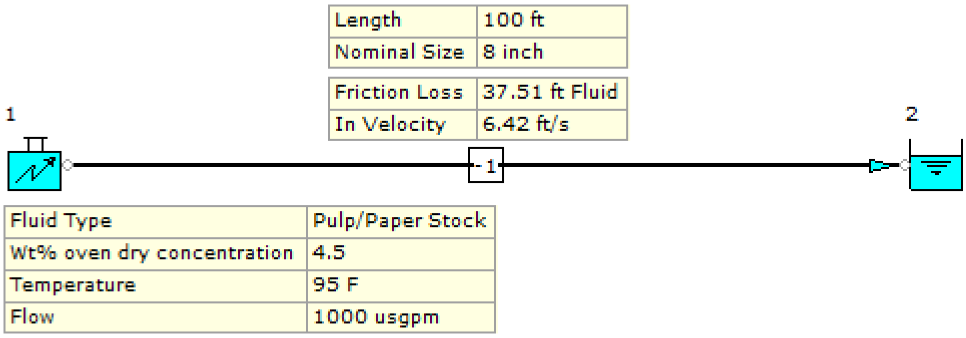
Commentary:

The results correlate extremely well with negligible difference between the two results. This system has been solved using the TAPPI approach.

7.2 Case 2: Pulp & Paper System (4.5% oven-dried unbeaten aspen sulfite stock, never dried).

Reference: Tech-E Paper Stock, Example 1.

Description: Determine the friction loss (per 100 ft of pipe) for 1000 U.S. GPM of 4.5% oven-dried unbeaten aspen sulfite stock, never dried, in 8 inch schedule 40 stainless steel pipe (pipe inside diameter = 7.981 in). Assume the pulp temperature to be 95° F.



FluidFlow Model

User Number	-1	
Flow	1000.00	usgpm
Friction Loss	37.51	ft Fluid
Pressure Gradient	3657.6	Pa/m
Loss Correlation	TAPPI(TIS) 408-4	
Size	8.0	in
In Fluid Phase	Pulp/Paper Stock	
In Stagnation Pressure	212807.45	Pa a
In Static Pressure	210903.98	Pa a
In Velocity	6.4194	ft/s
In Stag. Temperature	95.0	F
In Static Temperature	95.0	F
In Density	994.35	kg/m3
Out Fluid Phase	Pulp/Paper Stock	
Out Stagnation Pressure	101325.00	Pa a
Out Static Pressure	99421.45	Pa a
Out Velocity	6.4197	ft/s
Out Stag. Temperature	95.0	F
Out Static Temperature	95.0	F
Out Density	994.31	kg/m3
Composition Mass %	water	95.5%
	Pulp/Paper	4.5%
Reynolds No	481897.0	
Friction Factor	0.015889	

Pipe Results

Result Comparison:

Description	Published Data (ft/100ft)	FluidFlow Results (ft/100ft)
Pressure Loss (ft fluid)	37.28	37.51

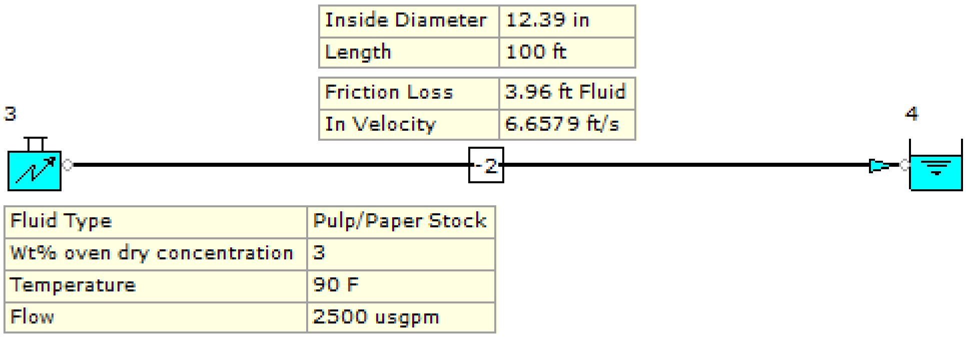
Commentary:

The results correlate extremely well, with negligible difference between the two results. This system has been solved using the TAPPI approach.

7.3 Case 3: Pulp & Paper System (3% oven-dried bleached kraft pine, dried and reslurried).

Reference: Tech-E Paper Stock, Example 2.

Description: Determine the friction loss (per 100 ft of pipe) of 2500 U.S. GPM of 3% oven-dried bleached kraft pine, dried and reslurried, in 12 inch schedule 10 stainless steel pipe (pipe inside diameter = 12.39 in).



FluidFlow Model

Result Comparison:

Description	Published Data (ft/100ft)	FluidFlow Results (ft/100ft)
Pressure Loss (ft fluid)	3.19	3.96

Commentary:

The results correlate extremely well, with negligible difference between the two results. This system has been solved using the TAPPI approach.