PSIG 09A1

Pipeline Modeling: Getting the right data and getting the data right.

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This tutorial differentiates between the important and the superfluous in the construction of pipeline models. The effects of data variation and selection of equations are discussed, and "universal" parameters are investigated.

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ABSTRACT

Data Gathering Exercises

Data used in simulation is researched, derived, calculated, estimated, measured, or simply guessed at for the majority of pipeline physical parameters.

In pipeline simulation, first-time users often find themselves in a quagmire of data gathering exercises. They spend many valuable hours researching 'as built' documentation and performing laborious calculations with the expectation of constructing a highly accurate pipeline model.

This paper is intended to help the new, and perhaps, the experienced modeler cut through what is important and what is superfluous.

Data Requirements

What is frequently not clear is how much of the collected and collated data is actually necessary and what level of accuracy. Additionally, how data quality will affect the simulation is often not recognized early in the process.

At the initial stage of data gathering, other important decisions must also be made; these decisions can affect, or be affected by, the practice of simulation within an organization. Examples are the selection of the equation of state, the friction factor equation, or the reference conditions.

Data Sensitivity

This paper discusses these issues by describing an approach that allows model sensitivity to be performed at an early enough stage in the modeling process to ensure that the key parameters are well understood.

This process is demonstrated through examples of both gas and liquid pipeline simulations. Various "universal" parameters are presented.

INTRODUCTION

Data required for pipeline simulation can be categorized in general types.

1. The physical geometry of the pipeline, such as leg lengths, diameters and elevation profile.
2. Fluids properties, for example gas compositions or liquid physical properties such as density and viscosity
3. Material properties of the pipeline and its environment, such as thermal coefficients and yield stresses.

The data required for each of these types may be further differentiated.

In some cases small data variation leads to large discrepancies, whilst in other large differences yield smaller variations.

During this tutorial generic forms of pipeline simulation equations will be presented, Data variations are examined and discussed.

In some cases filtering data with the aim of simplifying the output may be appropriate.

During this tutorial we will primarily be looking at data requirements for offline simulation. For real time simulation where detailed model hydraulics may be necessary, particularly for leak location applications, a different and more detailed set of data is required.

PIPELINE CONFIGURATION

Pipeline simulation software normally uses a node/equipment description to configure the model of the pipeline. A node is simply the connection point between pieces of equipment. Nodes have no physical dimension, although set-points or constraints may be configured at a node.

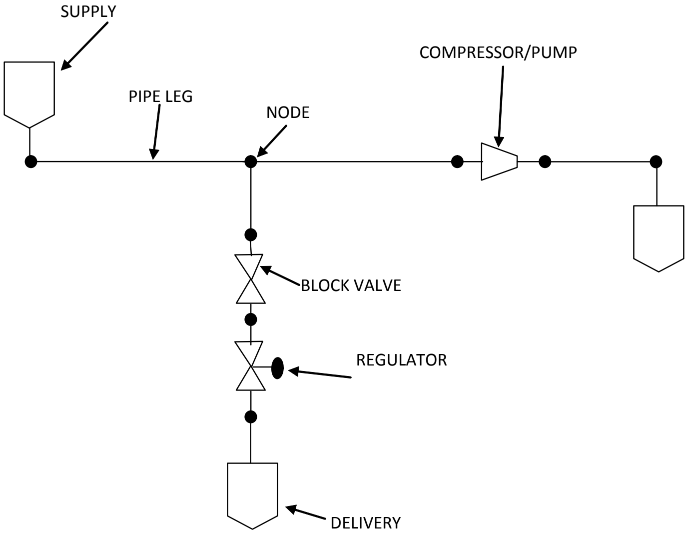


Figure 1, Showing some common pipeline simulation components

GENERAL DATA REQUIREMENTS

This section describes the data required for each element in the pipeline network. This should be considered as the minimum to acquire realistic results. This list is not exhaustive

Naming Convention

The first consideration should not be about equipment or elements, but a simple, concise and extensible device naming convention.

This is commonly overlooked in the early stages of model construction. Often the mistake is made to use a simple numerical scheme. Whilst simple and concise a numerical scheme is not easily extensible nor understandable. Most simulation software allows for multiple character entry in the naming convention, and so this should also permit the use of full or abbreviated location names to produce a better understanding of the pipeline network.

The naming convention should be used for all objects in a consistent fashion.

Units

Many different unit conventions are used in pipeline simulations.

A variation on the Imperial scheme is used in the USA and some parts of Asia, whilst a variation on the Metric scheme is used in Latin America, Europe and Africa.

Some company standards use a combination of both Metric and Imperial.

The units set chosen should be compatible with the corporate unit set.

An important consideration is not the units system that are being used, but ensuring consistency in the units used where possible. For example where possible try to stick with a single unit for type of measurement such as length, mass, temperature.

This advice has limitations, for example it may be impractical to use “feet” for pipeline length, as very large or very small numbers are no so easily parsed by the human mind scanning results. Similarly using miles for diameter may not be so easily understood.

Node

Nodes are connection points between two elements, and they have no physical properties.

A node requires a name, and if elevation is being considered this may often be associated with nodes.

Pipe Leg

A pipe leg has a number of physical properties that must be considered.

Firstly a pipe leg is normally has a constant set of physical properties, so if any of the properties change, a new leg is required.

Connectivity must be established by using the pipe name, upstream node and downstream node names.

Physical properties required for the pipe are internal or external diameter, length, wall thickness, roughness and thermal properties of the pipe. Also a known ambient temperature for the pipe, or table of temperatures, for transient simulation may be required.

The length of the leg considered should be the point to point, or isometric, length. The isometric length differs from the planar length by taking into account the elevation change between points on the pipeline.

Valves (Block, Check etc.)

Valves are connected between an upstream and downstream node. Depending on the method of expressing flow dependent pressure drop across a valve a valve co-efficient (CV) or table of co-efficients versus percentage open will be required.

A fully open orifice diameter may also be required.

Regulator (control) valve

A regulator valve is connected between two nodes, an upstream node and a downstream node.

As with most valves a valve co-efficient will be required, as well as orifice diameter.

Depending on how the regulator is being constrained, either the controlling flow or pressure drop, or up/down stream pressures will need to be known.

Delivery

A delivery is only connected to a single node.

Deliveries are controlled by pressure or flow setpoints.

Supply

A supply is used to control the flow entering the system.

A fluid or list of fluid batches will be configured at the supply, and supplies are controlled by pressure or flow setpoints. Normally a fluid temperature is also input at a supply point.

Compressors/pump

Compressors and pumps are normally connected between two nodes.

There are many types of models, and data requirements vary. However at the most basic level should permit power calculations based on pressure difference and fluid properties.

To achieve this result a knowledge of the set points and constraint(s) that will be simulated will be required. This will be up or down stream pressure, flow rate, compression ration or available power.

There will commonly be some associated efficiencies such as polytropic / adiabatic efficiency or mechanical efficiency which may also be taken into account.

Centrifugal or reciprocating models require a higher degree of information. In the case of centrifugal units “wheel” curves which describe the ratio of head, speed and flow for a given fluid are required. In addition curves describing the polytropic / adiabatic efficiency, speed and flow are also needed; and also normally surge and stonewall values.

Reciprocating models also require input of information relating to cylinder size, stroke length, slippage factors and available compression within the each cylinder.

A simulator which provides compressor drivers to calculate fuel gas or electric power usage will have further inputs based on the compressor driver used. At a simple level a relationship of energy usage to amount of available power in use is used in conjunction with a usage efficiency figure to determine how much energy is consumed for a given lift. At a more complex level a set of curves representing the heat rate of a turbine at differing speeds and powers is used to determine fuel usage.

Equipment

Many other equipment elements are used in pipeline simulation. These elements can include heat exchangers, resistances causing a flow dependent pressure drop, flow regulators for DRA etc.

In these cases ensuring that the correct data is collected is important, however discussing every element is beyond the scope of this tutorial.

Fluid

For a gaseous pipeline a fluid may be described either by its composition or certain equations can determine fluid properties from Specific Gravity.

For liquids the composition may be used as an input, however it may be better to provide a detailed set of properties, which includes the gravity range of the liquid, the viscosity range, and if correlations are not available you may also need to provide bulk modulus, thermal expansion and heat capacity of the fluid.

The API (American Petroleum Institute) offers some very good correlations for bulk modulus, thermal expansion and heat capacity for most products transported by pipeline in liquid phase.

Fluid properties are very important, however further discussion will be limited in this tutorial.

DATA SENSITIVITY

During the process of data gathering the sensitivity of the model results to variations in the collected and collated data to variations should be understood.

In the next section an investigation into the model sensitivity of pipe leg input data will be investigated using pipeline simulation software.

An exhaustive analysis of data sensitivity is beyond the scope of this tutorial however the most common areas of variance in pipe physical properties are presented.

There are several variables which affect the flow of fluids through pipes.

The selection of appropriate friction factor equation and the importance of data selection, filtering and validation are of significant importance to getting the best out of any simulator.

In this section we will consider the following:

- Diameter
- Length
- Frictional losses
- Heat Transfer Properties
- Elevation

Compressible fluids

A common form of the general pipeline compressible flow equation may be shown thus:

$$Q = C_1 \frac{T_b}{P_b} D^{2.5} E \left(\frac{P_1^2 - P_2^2 - \frac{C_2 g (H_2 - H_1) {P_a}^2}{Z_a T_a}}{L G T_a Z_a f} \right)^{0.5}$$

The constants C1 and C2 will vary depending on the units used. For the units presented in this paper C1 = 77.54 and C2 = 0.375.

Compressible fluid flow differs from incompressible flow in that a factor for the compressibility of the fluid is taken into account. This is normally determined by an “equation of state” and these are discussed in the fluids section of this paper. The friction factor, f, may be determined by a number of methods, some of which are discussed.

“in”-compressible fluids

All fluids are slightly compressible. There are methods of determining this compressibility. However to a good approximation it may be assumed that liquids are essentially incompressible in a line. Whilst this is inaccurate a common form of the incompressible fluid flow equation, based on the Colebrook-White friction factor, thus:

$$Q = \sqrt{\frac{\Delta P_f d^5}{C_3 \rho}} \left[-2log\left(\frac{\varepsilon}{3.7d} + \frac{2.51\nu}{C_1} + \sqrt{\frac{C_3 \rho}{\Delta P_f d^3}} \right) \right]$$

Where:

C1=9.224123
C2=2.647271x10-2
C3=1.1476269x10-2

NB the units differ slightly for this equation than rest of this tutorial

P_f = pressure loss in psi/000 ft of pipe
Q = barrels per day
d = inches
u=centistokes
r = density lb/ft^3

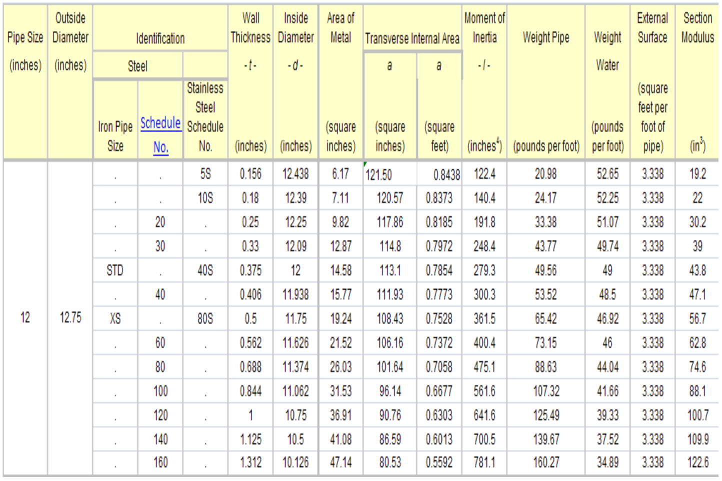
Diameter and Wall Thickness

This may be specified as either an external diameter or an internal diameter. A wall thickness is specified in addition for the purpose of calculating the correct diameter to use, possibly for pipewall stress, pipewall expansion and also for thermal conductivity or maximum pressure calculations.

There are many standards which cover pipe sizes. Nominal Pipe Size (NPS) is commonly used in the USA and Asia, and Diametre Nominel (DN) is Europe and the Middle East.

The aim of these standards is to produce a “schedule” of pipe. The schedule is measure of the working pressure of the pipe and is defined the standards ASME/ANSI B 36.10 Welded and Seamless Wrought Steel Pipe and ASME/ANSI B36.19 Stainless Steel Pipe.

For example let us take a table of data for a 12 “ pipe.



Pipe Size (inches)	Outside Diameter (inches)	Identification			Wall Thickness -t-	Inside Diameter -d-	Area of Metal	Transverse Internal Area		Moment of Inertia -I-	Weight Pipe	Weight Water	External Surface	Section Modulus
		Steel						a	a					
		Iron Pipe Size	Schedule No.	Stainless Steel Schedule No.	(inches)	(inches)	(square inches)	(square inches)	(square feet)	(inches^4)	(pounds per foot)	(pounds per foot)	(square feet per foot of pipe)	(in^3)
12	12.75	.	.	5S	0.156	12.438	6.17	121.50	0.8438	122.4	20.98	52.65	3.338	19.2
		.	.	10S	0.18	12.39	7.11	120.57	0.8373	140.4	24.17	52.25	3.338	22
		.	20	.	0.25	12.25	9.82	117.86	0.8185	191.8	33.38	51.07	3.338	30.2
		.	30	.	0.33	12.09	12.87	114.8	0.7972	248.4	43.77	49.74	3.338	39
		STD	.	40S	0.375	12	14.58	113.1	0.7854	279.3	49.56	49	3.338	43.8
		.	40	.	0.406	11.938	15.77	111.93	0.7773	300.3	53.52	48.5	3.338	47.1
		XS	.	80S	0.5	11.75	19.24	108.43	0.7528	361.5	65.42	46.92	3.338	56.7
		.	60	.	0.562	11.626	21.52	106.16	0.7372	400.4	73.15	46	3.338	62.8
		.	80	.	0.688	11.374	26.03	101.64	0.7058	475.1	88.63	44.04	3.338	74.6
		.	100	.	0.844	11.062	31.53	96.14	0.6677	561.6	107.32	41.66	3.338	88.1
		.	120	.	1	10.75	36.91	90.76	0.6303	641.6	125.49	39.33	3.338	100.7
		.	140	.	1.125	10.5	41.08	86.59	0.6013	700.5	139.67	37.52	3.338	109.9
		.	160	.	1.312	10.126	47.14	80.53	0.5592	781.1	160.27	34.89	3.338	122.6

Table 1

This table shows that for an NPS pipe size of 12”, a nominal outside diameter of 12.75” would be expected. Just as the actual outside diameter is not 12” it should be made clear that not all 12” pipes are actually 12” on the inside either. For example, if were working to Schedule 55 the internal diameter would be 12.438 “, but if you working to Schedule 150 your internal diameter would be 10.125”.

A worked example of how diameter sensitivity affects fluid flow is illustrated below.

Using a pipe configuration 100 miles long with a flat elevation, and taking a compressible fluid in gaseous phase (C1=75%; C2=15%; C3=4%; IC4=4%; CO2=2%), let us examine the range of NPS for a 12” line at the maximum diameter and the minimum diameters. For this example we shall assume the fluid inlet temperature 60 F, and ambient temperature 60 F. We are not currently investigating thermal properties, but to be able to do “like for like” comparison later on we need to start with a thermal case.

A PP model will be used (pressure control upstream and downstream), and the flow calculated. The pressure setpoints for this case is 1000 psig upstream and 200 psig downstream.

With an internal diameter of 12.438”, we can determine a flow rate of 78.6 MMSFCD.

If we were to reduce the diameter to the minimal NPS diameter of 10.125”, a change of nearly 20%, we get a value of 45.9 MMSCFD; i.e. a change of 58.4%.

This shows simulation results are very sensitive to changes in the diameter in the nominal range. As such care must be taken to ensure a good selection of diameter is chosen for the pipeline model.

Length

Previously it has been indicated that the length used for pipeline simulation should be the isometric length of the pipe. Whilst using a planar length versus isometric will introduce a small but predictable error, it will not examined in detail in this tutorial.

Keeping a consistent percentage change in physical property will allow us to be able compare and contrast some of these physical properties, and to further allow “like for like”. In keeping with the diameter case let us compare 100 mile pipe versus 80 mile pipe.

Using the previous configuration and a 12.438” line a comparison of effect of length can be performed.

The baseline model used 100 miles of pipe and the flow rate calculated 78.6 MMSCFD. Changing the mileages to 80 results in a flow rate is calculated as 88.3 MMSCFD. This represents an increase in flow of approximately 12% for a reduction in length of 20%.

We can see therefore that length does significantly affect flow rate, however not as much as pipe diameter.

Friction Factor

The friction factor, f, is a parameter about which there is much literature.

The friction factor is dependant normally on the Reynolds Number and roughness.

The Reynolds number is dimensionless and is determined from the dynamic pressure and shear stress. It is calculated from

$$Re = \frac{dv\rho}{\mu}$$

Roughness is normally an “unknown” parameter. It is a measurement of the resistance to flow encountered at the pipe's wall. This roughness arises in the pipe due to natural irregularities in the material of the wall, as well as corrosion or deposits on the wall.

The roughness may be entered as an absolute roughness (more likely) or a relative roughness.

The relationship of relative roughness, R, to absolute roughness, ε, is:

$$R = \frac{\varepsilon}{D}$$

There are many sources which discuss the pipeline friction factors, and as such further discussion shall not be made. However drawing from the conclusions of others, one recommendation would be to generally use the Colebrook-White as errors do not increase unbounded and it is applicable across a wide range of flow. . For laminar flow the following function is used to determine the friction factor.

$$f = \frac{N_{re}}{64}$$

The simulator should have a method of handling the transitional zone (either by a function or by interpolation), and for turbulent flow should use some function of the Moody diagram to determine friction factor.

$$\frac{1}{\sqrt{f}} = -2log\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right)$$

Calculation of the friction factor is can give a good ‘shape’ to the flow function, however it should not the only tuning parameter used.

Pipe efficiency can be used at a local pipe level to tune the pipe flow.

Let us take a worked example of tuning the roughness to give our 20% reduction comparison figure.

So going back to the configuration 100 miles long, 12.438” diameter pipe and 800 psig pressure drop with a compressible fluid. An initial absolute roughness of 0.001 inches is used to give a flow rate of 71.6 MMSFCD. If the absolute roughness is reduced to 0.0008 inches, the resulting flow rate is 80.1 MMSCFD.

So for a 20% reduction in roughness we see a 2% increase in flow.

Errors in roughness doe not, therefore, have a large impact on simulation accuracy.

Heat transfer co-efficient

The energy balance within a pipeline consists of five main parts.

- Energy transfers due to friction as fluid flows
- Energy transfers due to viscous forces within fluid
- Change in energy due to expansion of fluid (J-T)
- Energy transfer of energy across the pipeline wall
- Elevation changes

In this comparison of energy transfer we will investigate the transfer of heat energy across the pipeline wall, as the other four effects on the hydraulics are outside the scope of this tutorial.

At the more complex level energy transfer may be expressed using a concentric ring thermal model. However for this analysis we will use a simplified model.

Energy transfer across a pipe wall may be expressed by:

$$\frac{4U_w}{D}(T - T_g)$$

Using the same case we have been working with up until now let us investigate the overall heat transfer co-efficient.

An initial value of 0.2 BTU/h.ft2F gives us the flow rate 78.6 MMSFCD.

Keeping with our reduction of 20%, a revised value of 0.18 BTU/h.ft2.F gives a resulting flow rate of 78.7 MMSCFD, an increase of 0.1 %.

Errors in heat transfer co-efficient have a small effect on simulation accuracy, however at larger values of heat transfer co-efficient the effect will be much greater.

Elevation

The final discussion regarding pipes is in relation to the pipeline geometry. There are two main geometric properties that affect fluid flow in pipelines; firstly the layout of the line can impart an effect on the fluid flow. Bends in the pipe affects fluid flow, and elevation affects available head.

Whilst the effect of bends is noticeable locally, and is an important consideration in areas of shorter pipes, such as plant or stations; for the purpose of transportation or distribution the effect may be insignificant and is not considered in this tutorial. When bends are important resistance elements are often used to represent their effects on the pipeline.

A more important geometrical change to consider is elevation.

Survey data for built and even designed pipelines can be very detailed.

For a compressible fluid pipeline simulation elevation is less critical; and small variations along the pipeline are lost in the overall noise of other factors.

A survey may be filtered to minimize the data complexities of an elevation profile. In a “real” survey there may be tens of thousands of data points, so for the sake illustration we will examine a much reduced data set of 20 points.

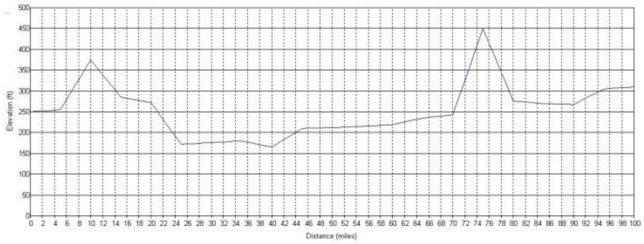


Chart 1

If we crudely filter it thus, a reduction in points from 20 to 8 is obtained.

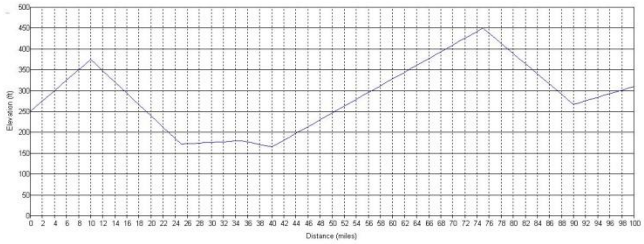


Chart 2

Lets us now run a simulation using a liquid and a natural gas and compare pressures at the key points.

Elevation Change for Liquid Pipeline

Using the configuration used previously, 100 mile, 12.438 inch pipeline; but reducing the pressure to 250 psig inlet and 15 psig outlet; and using a liquid (in this case a model of jet fuel) the filtered versus non filtered elevation profile can be compared and contrasted.

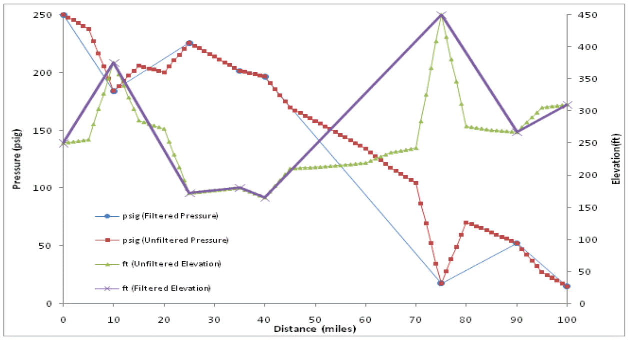


Chart 3

Chart 3 shows the pressure and elevation for both cases using filtered and unfitered surveys, with data taken at 5 mile intervals.

It is seen that with the crudely filtered profile that pressure profiles are reasonably close fitting to the more detailed profile, grasping all of the peaks and troughs in the line.

Length (miles)	Elevation (ft)	Pressure unfiltered (psig)	Pressure filtered (psig)
0	250	250	250
10	375	184	184
25	172	226	226
35	180	204	204
40	165	196	196
75	450	18	18
90	267	52	52
100	310	15	15

Table 2 Comparison of elevation and pressure data at key points

With some refinement the elevation for this case could produce an even better profile match to the data, even grasping the key difference areas at 18 miles and 70 miles with the addition of 2-3 more points, still proving a 50% reduction in data requirements for the model, which will reduce computational load and data management of the system.

Elevation Change for a Compressible Fluid Pipeline

Again, using a 100 mile, 12.428” pipeline with a pressure drop from 250 psig to 150 psig, but this time with a compressible fluid model, in this a natural gas, we can compare and contrast the elevation profile change.

It is widely recognized that whilst the elevation affects the calculation at the head and tail of the pipe, in a gas line intermediate maxima and minima are not normally required unless there is a very significant elevation change.

The following chart shows an example of crudely filtering the elevation profile for a compressible fluid versus a more detailed profile.

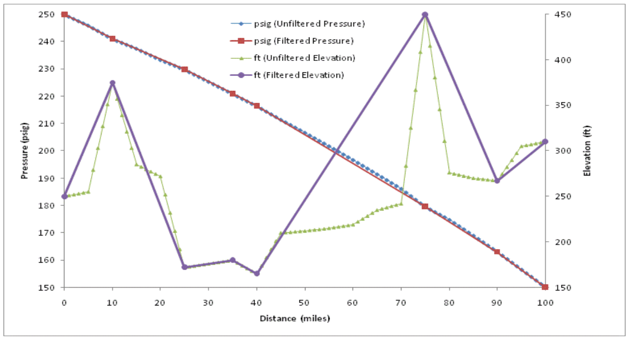


Chart 4

For a liquid pipeline it may be observed that the elevation profile is more important. Since this is the case, using survey data directly without any kind of filtering approach will lead to several issues. Firstly as the pipeline has more discrete intervals the increase in calculation will slow simulation process. Secondly the user will almost certainly run into an input or output file limitation in terms of computer storage space.

Discussion and Conclusions

Leaving elevation aside for one moment, as a direct comparison of effect is not possible in this case, let us look at a table of results to comparing the resulting flow rate for the pipeline configuration under our investigation.

Variable	Initial Value	Calculated flow rate	Value reduced by 20%	Resulting flow rate	Percentage difference (%)
Internal Diameter	12.438 inches	78.6	10.125 inches	45.9	- 58.4
Length	100 miles	78.6	80 miles	88.3	+12.3
Roughness	0.001 inches	78.6	0.0008 inches	80.1	+1.9
Heat Transfer Coefficient	0.2 BTU/h.ft2.F	78.6	0.18 inches	78.7	+0.1

Thumbnail of table 3, table comparing the percentage change in flow rate for a 20% change in a pipeline physical property.

Table 3 compares and contrasts the sensitivity to relatively large changes in variables.

We can see from this table that the most sensitive piece of data is the pipes internal diameter, From this we can conclude that it is very important to ensure that this piece of data is well represented in simulations.

The least sensitive piece of data we can see is the heat transfer co-efficient.

The heat transfer co-efficient is a value that again should be well understood by the user, but is less important than others.

A percentage change in length produces a noticeable increase in flow, due to the same pressure drop over even short lengths. This effect should be very well understood by the user, as surveys will have very accurate pipe lengths.

Finally the roughness is a value that cannot easily measured or gathered, and indeed has to be often “guesstimated”. As a rule of thumb, it is normal to use a value of about 0.001 inches or 25 microns for unlined pipe, and 0.0005 or 13 microns for lined pipe during the design phase. Once the pipeline is built a better estimation can be made.

Roughness also changes over time as the pipe wall changes due to corrosion and wearing of the surface. The actions of scrapers in the pipe can also greatly changed the effective roughness in a pipe.

As such, the roughness becomes a very effective “tuning” variable to better match pressures and flows in the line.

We cannot directly compare the elevation profiles with the other cases but we can discuss the finding of the simulations.

It could be proposed that a filtering of global maxima and minim in the pipeline would be the correct course of action, and whilst this may be the case for the most part it could perhaps be enhanced by also adding local maxim and minima.

The conclusions we can draw from this are that whilst maxima and minima in the elevation profiles are very important; to minimise the amount of data required in model construction filtering of this data would be a recommended practice.

Appendix A. Nomenclature and Units

Symbol	Definition	English Unit	Metric Unit	Factor
D	Pipe diameter	inches	*mm*	.03937
e	Pipe efficiency	Dimensionless		
f	Darcy-Weisbach friction factor	Dimensionless		
S.G.	Gas specific gravity	Dimensionless		
H_c	Elevation correction	$PSIA^2$	*Kpa*$_2$	.021034
H_1	Inlet elevation	feet	*meters*	3.2808
H_2	Outlet elevation	feet	*meters*	3.2808
L	Pipe length	miles	*Km*	.62137
Nre	Reynolds' number	Dimensionless		
P_{av}	Average pressure	PSIA	*KPaa*	.14503
P_b	Pressure base	PSIA	*KPaa*	.14503
P_1	Inlet pressure	psig	*KPag*	.14503
P_2	Outlet pressure	psig	*KPag*	.14503
Q	Standard Flow rate	ft_3/day	m^3/*day*	35.315
T_a	Average temperature	°R	*°K*	1.8
T_b	Temperature base	°R	*°K*	1.8
v	fluid velocity	ft/sec	*m/sec*	3.2808
Z_a	compressibility factor	Dimensionless		
Z_1	compressibility factor at inlet conditions	Dimensionless		
Z_2	compressibility factor at outlet conditions	Dimensionless		
e	Pipe roughness roughness	inches	*mm*	.03937
m	Viscosity	lb_f-sec/ft^2	*pascal-sec*	.0020886
r	fluid density	lb/ft^3	kg/m^3	.062417
U_w	overall heat transfer co-efficient	btu/h.ft^2. °R	*W/*m^2*. °K*	26.269
D	diameter	inches	*mm*	.03937
T	temperature at the inside of the pipe wall	°R	*°K*	1.8
T_g	Temperatrue of ambient medium	°R	*°K*	1.8

The stated factor multiplies the Metric unit value to reach the English unit value. For example:
1 meter X 3.2808 = 3.2808 feet

Appendix B. Tables and Figures

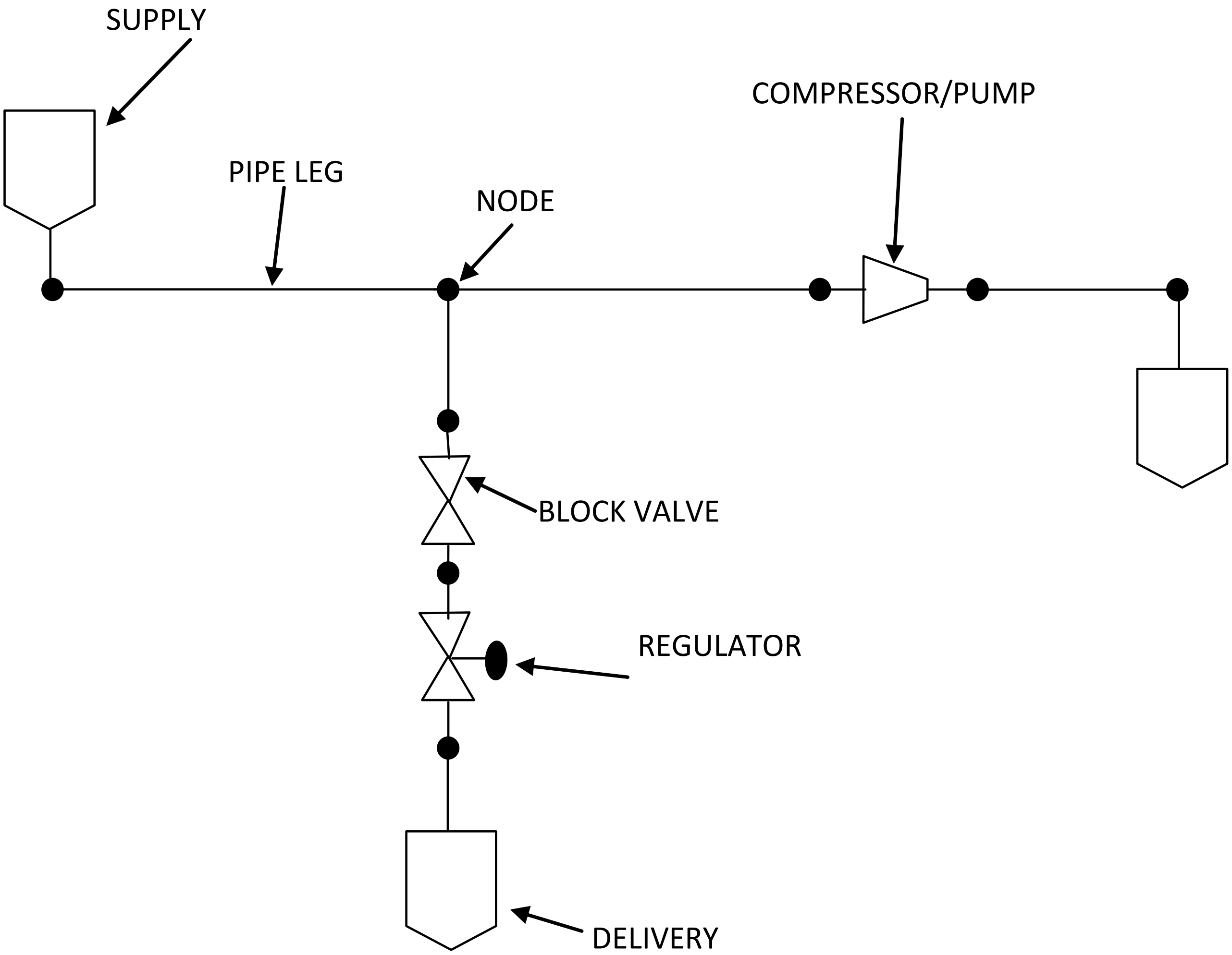
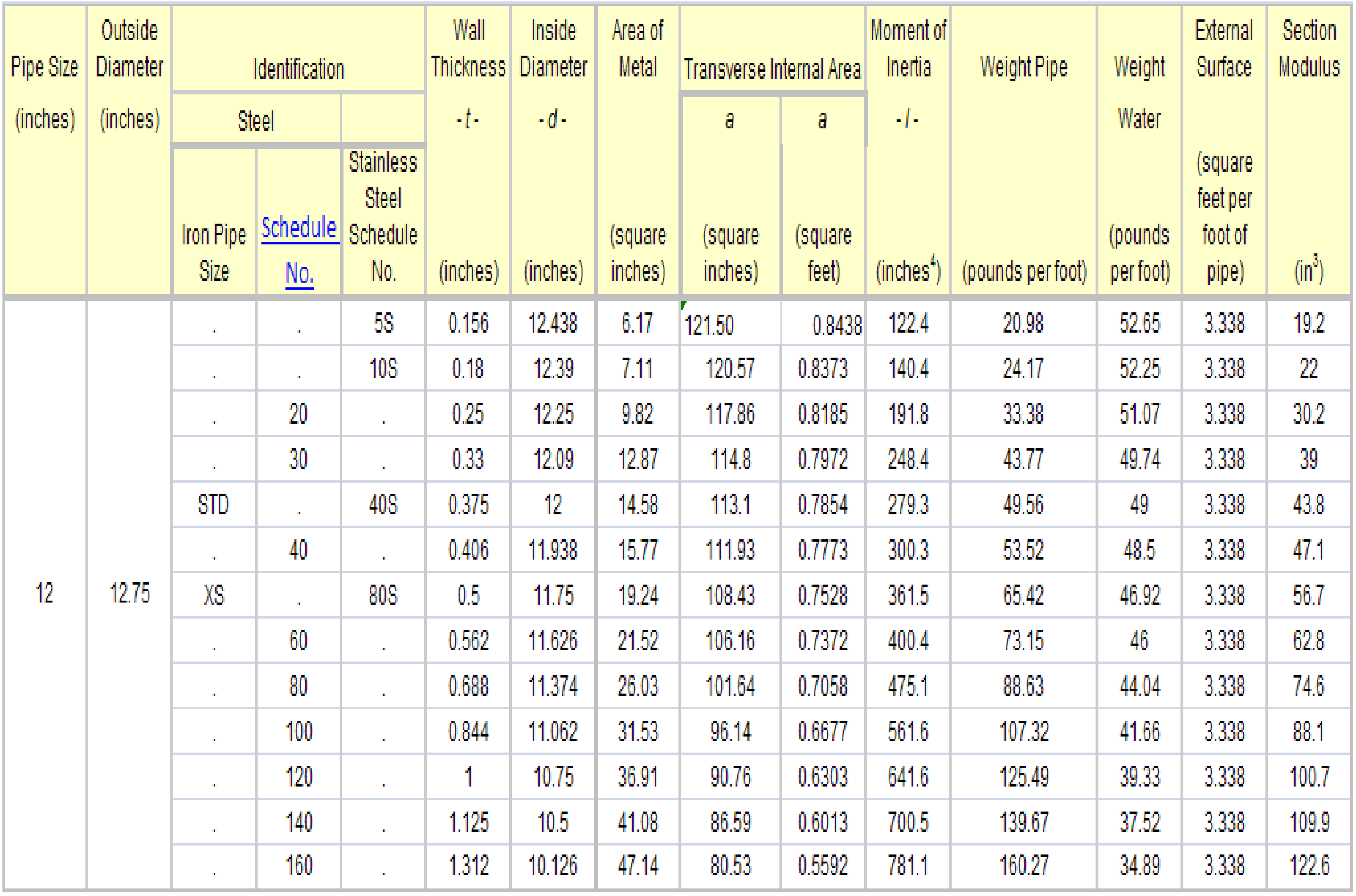


Figure 1: showing some common pipeline simulation components



Pipe Size (inches)	Outside Diameter (inches)	Identification			Wall Thickness -t- (inches)	Inside Diameter -d- (inches)	Area of Metal (square inches)	Transverse Internal Area		Moment of Inertia -I- (inches^4)	Weight Pipe (pounds per foot)	Weight Water (pounds per foot)	External Surface (square feet per foot of pipe)	Section Modulus (in^3)
		Steel						a	a					
		Iron Pipe Size	Schedule No.	Stainless Steel Schedule No.				(square inches)	(square feet)					
12	12.75	.	.	5S	0.156	12.438	6.17	121.50	0.8438	122.4	20.98	52.65	3.338	19.2
		.	.	10S	0.18	12.39	7.11	120.57	0.8373	140.4	24.17	52.25	3.338	22
		.	20	.	0.25	12.25	9.82	117.86	0.8185	191.8	33.38	51.07	3.338	30.2
		.	30	.	0.33	12.09	12.87	114.8	0.7972	248.4	43.77	49.74	3.338	39
		STD	.	40S	0.375	12	14.58	113.1	0.7854	279.3	49.56	49	3.338	43.8
		.	40	.	0.406	11.938	15.77	111.93	0.7773	300.3	53.52	48.5	3.338	47.1
		XS	.	80S	0.5	11.75	19.24	108.43	0.7528	361.5	65.42	46.92	3.338	56.7
		.	60	.	0.562	11.626	21.52	106.16	0.7372	400.4	73.15	46	3.338	62.8
		.	80	.	0.688	11.374	26.03	101.64	0.7058	475.1	88.63	44.04	3.338	74.6
		.	100	.	0.844	11.062	31.53	96.14	0.6677	561.6	107.32	41.66	3.338	88.1
		.	120	.	1	10.75	36.91	90.76	0.6303	641.6	125.49	39.33	3.338	100.7
		.	140	.	1.125	10.5	41.08	86.59	0.6013	700.5	139.67	37.52	3.338	109.9
		.	160	.	1.312	10.126	47.14	80.53	0.5592	781.1	160.27	34.89	3.338	122.6

table 1, showing NPS pipe properties for 12” pipe

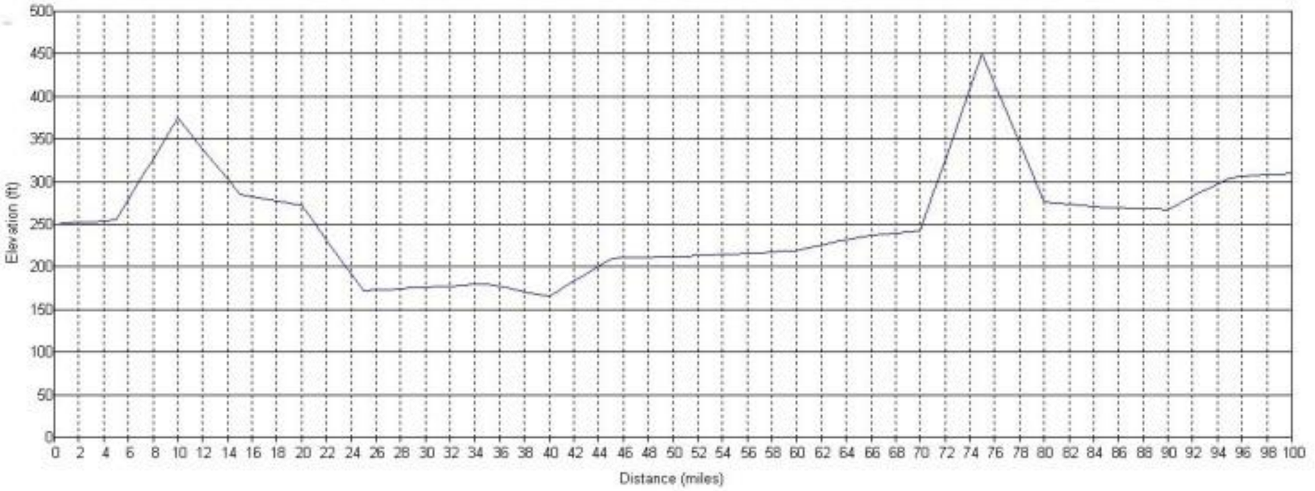


Chart 1, showing a crude survey profile

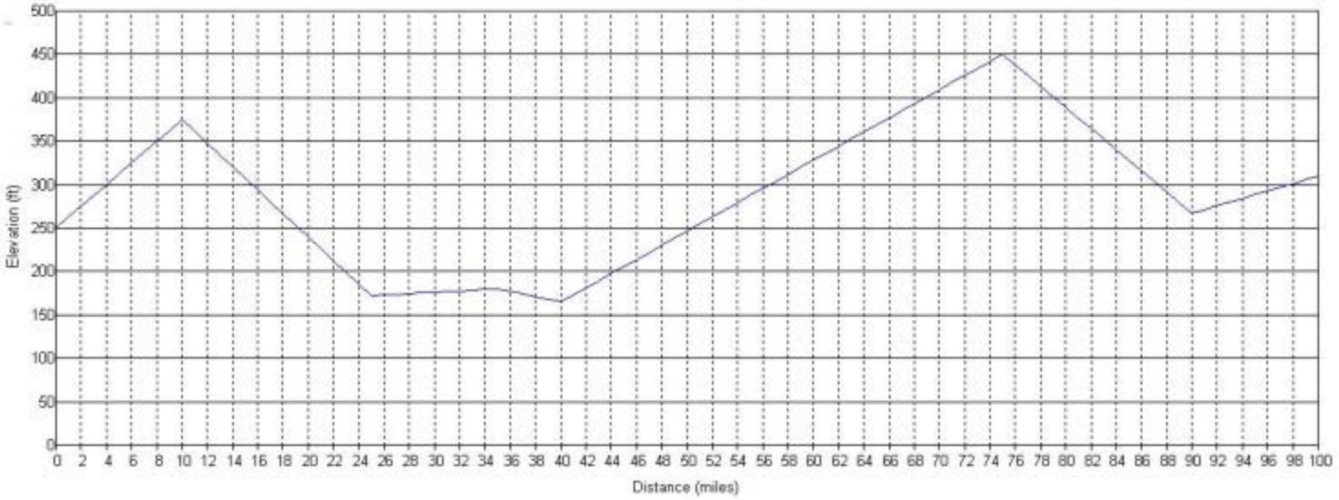


Chart 2, showing the filtered survey profile

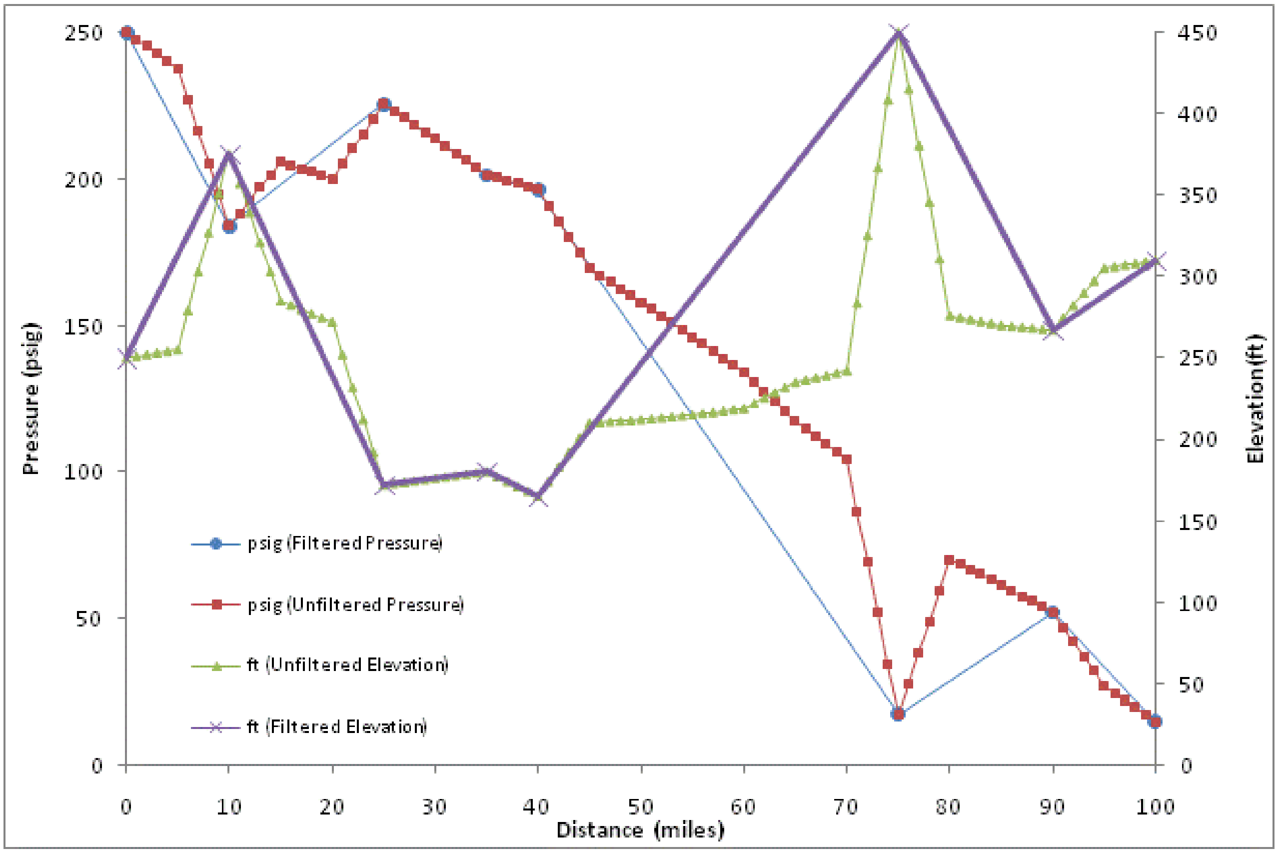


Chart 3 showing filtered and unfiltered surveys and corresponding pressure profiles for a liquid pipeline

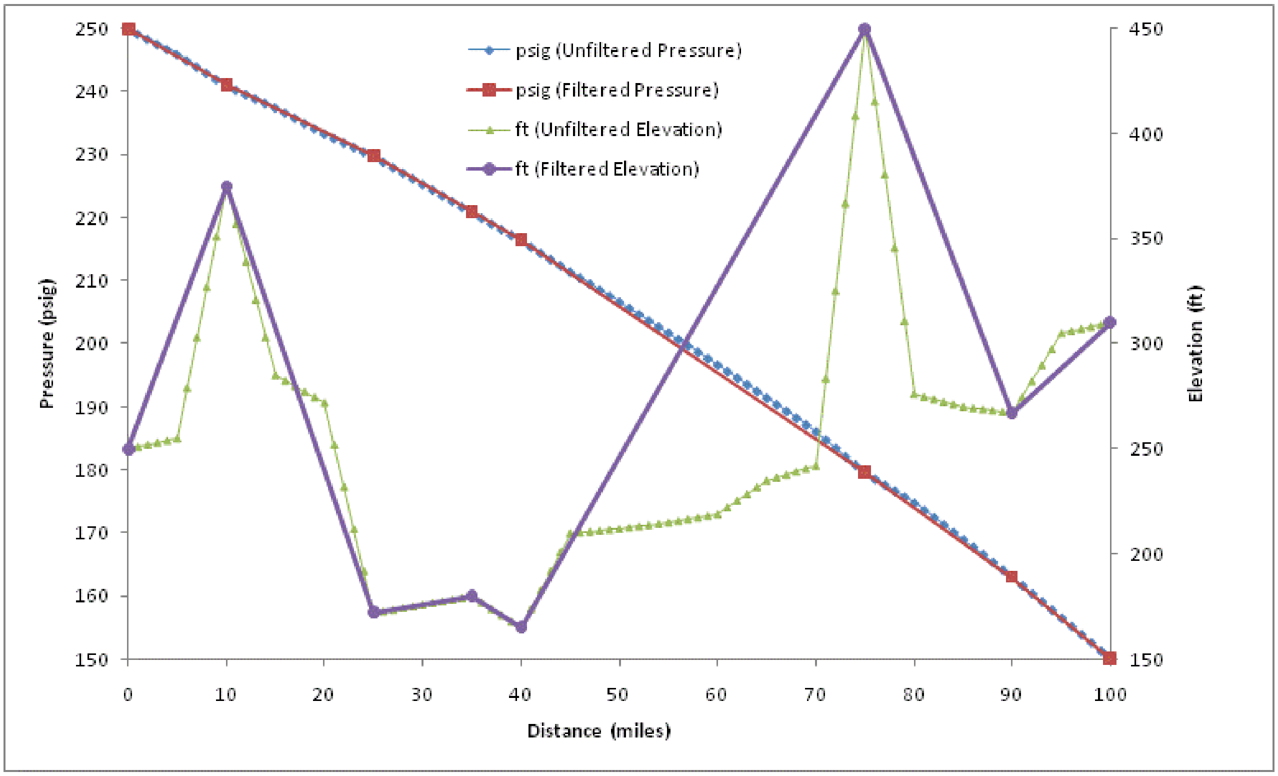


Chart 4 showing filtered and unfiltered surveys and corresponding pressure profiles for a natural gas pipeline

Variable	Initial Value	Calculated flow rate	Value reduced by 20%	Resulting flow rate	Percentage difference (%)
Internal Diameter	12.438 inches	78.6	10.125 inches	45.9	- 58.4
Length	100 miles	78.6	80 miles	88.3	+12.3
Roughness	0.001 inches	78.6	0.0008 inches	80.1	+1.9
Heat Transfer Coefficient	0.2 BTU/h.ft2.F	78.6	0.18 inches	78.7	+0.1

table 3, table comparing the percentage change in flow rate for a 20% change in a pipeline physical property

Appendix C. References

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