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Simulation of Bidirectional Flows in a Complex Pipeline Network

Vadim Shapiro¹, Daniel Theis¹ John Hooker¹

¹ Statistics & Control, Inc

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ABSTRACT

Recently, precise pipeline network modeling, simulation, and production planning have become critical factors for successful dispatching in the oil and gas transportation industry. Simulation technology has significantly progressed, demonstrating advancements in accuracy and reliability. Individual pipeline components are now simulated with different industrial software packages that provide satisfactory results. Challenges arise when a project requires simulating an entire network, especially when this network contains looping, interconnections, and circular routes. The most significant simulation challenge is determining flow direction and dynamically simulating flow reversing within pipeline segments. System complexity creates difficulties predicting the system's reaction to a regime change. A single change in one of the inputs initiates changes throughout the whole system and can reverse flow in pipeline looping and interconnections. This paper introduces a proposed simulation method to be used in such situations to calculate system dynamics and to model transient behavior of reversing flow.

INTRODUCTION

With the enhancement of computer processing power simulation has become easier to solve complex solutions. When trying to simulate a complex network that contains loops interconnections, and circular routes it is difficult to understand which way the flow is going. When flow reverses itself in a

pipeline network the company loses time and energy to deliver a product. This paper discusses how flow can reverse itself in a network and the amount of travel time a fluid takes to get from one point to end consumption. When the algorithms for flow reversal and travel time are implemented, the paper will talk about a case study where it's happening and discuss the results found when applied to a live transportation network.

THEORETICAL BACKGROUND

In principle the fundamental equations that govern the flow of oil/gas through a pipeline do not impose a bias to the direction of the fluid's movement. Instead, the hurdles that must be overcome to simulate the flow of the fluid in a bidirectional manner are introduced by the approximations and procedures that are used to solve those equations.^[1] This section of the paper discusses the formulas are used to generate accurate, unbiased implementations of the conservation equations.

It also discusses the procedure that was developed to overcome the additional problems that are introduced by the existence of pipe-junctions. Pipe-junctions are areas in the pipeline where three pipes intersect. At those points one of two things will happen: either two incoming streams of fluid will be merged into one outgoing stream; or one incoming stream will be split into two outgoing streams. To allow for the possibility of bidirectional flow, a common set of formulas must be used for both types of junctions.^[2]

Finally, the last part of this section describes the procedure that is used to predict the amount of time that is required to transport fluid from one of its producers (i.e., an oil well, steam generator, or supply station) to a consumer (i.e., refinery, factory, or terminal station).

Solving the Conservation Equations

The changes that occur to the velocity, temperature, and pressure of the fluid at each point of the pipeline are determined using the differential equations that enforce the conservation of mass, momentum, and energy. Mathematical expressions of the conservation laws are shown in Eq. 1 ^[1]

$$\begin{cases} \frac{\partial \rho}{\partial t} + \frac{\partial \rho v}{\partial x} = 0 \\ \rho \cdot \frac{\partial v}{\partial t} + \rho v \cdot \frac{\partial v}{\partial x} = -\frac{\partial P}{\partial x} - \frac{f \rho v \cdot |v|}{2D} - g \rho \sin \theta \\ \rho C_p \cdot \frac{\partial T}{\partial t} + \rho v C_p \cdot \frac{\partial T}{\partial x} = \frac{f \rho v^3}{2D} - \frac{4h \cdot \{T - T_{amb}\}}{D} \end{cases} \quad (1)$$

where:

- x and t specify the position and time of all the properties (density, velocity, etc.) that appear in Eq. 1
- ρ , C_p , v , P , and T denote the density, specific heat capacity, velocity, pressure, and temperature of the fluid
- D , θ , and g denote the pipe's diameter, angle of elevation, and gravitational constant
- T_{amb} denotes the ambient temperature of the environment that surrounds the pipe
- and f and h denote the values of the friction factor and heat transfer coefficient

To obtain an accurate, directionally unbiased solution to the coupled set of differential equations shown in Eq. 1, the time (Δt) between each set of calculations is set to a fixed value and the pipeline is broken into segments of size $\Delta x = c_0 \Delta t$, where c_0 specifies the acoustic velocity of the fluid.

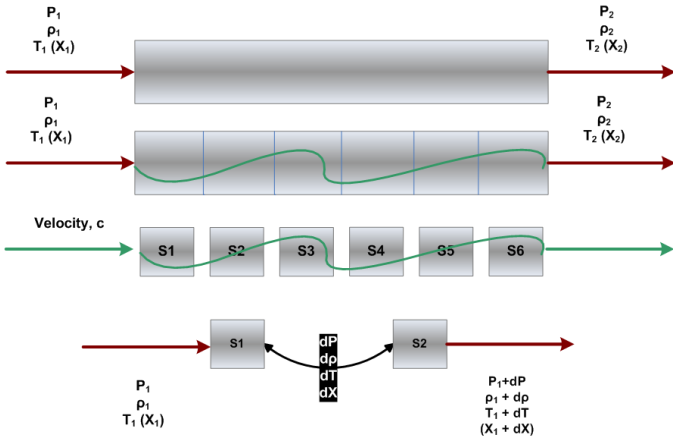


Figure 1 – Pipe Segmentation

Then, the previous values that were computed for the velocities, pressures, temperatures, and other fluid properties are used in Eqs. 2 – 5 to compute new velocities and pressures [3],[1]

$$P_{n,k} = \frac{1}{2} \{P_{n,k}^- + P_{n,k}^+\} + \frac{1}{2} b_{n,k} \cdot \{v_{n-1,k-1} - v_{n+1,k-1}\} \quad (2)$$

$$v_{n,k} = \frac{K_{n,k-1}^{f,ave} v_{n,k-1}^{ave} + b_{n,k} \cdot \{v_{n-1,k-1} + v_{n+1,k-1}\}}{K_{n,k-1}^{f,ave} + 2b_{n,k}} + \frac{\{P_{n,k}^- - P_{n,k}^+\} - \Delta P_{n,k-1}^{st,ave} - \Delta P_{n,k-1}^{elev}}{K_{n,k-1}^{f,ave} + 2b_{n,k}} \quad (3)$$

$$b_{n,k} = \frac{(\beta T)_{n,k-1} \Delta t}{\Delta x} \quad (4)$$

$$P_{n,k}^\pm = P_{n\pm 1,k-1} - (P_{n,k-1}^{dyn} - P_{n\pm 1,k-1}^{dyn}) \pm \frac{1}{2} \Delta P_{n\pm 1,k-1}^{st} \pm \frac{1}{2} \Delta P_{n\pm 1,k-1}^{elev} \quad (5)$$

where

- $v_{n,k}$ and $P_{n,k}$ denote the velocity and pressure of the fluid at position x_n and time t_k
- $\rho_{n,k}$ and $(\beta T)_{n,k}$ denote the density and elasticity of the fluid at position x_n and time t_k
- D_n and θ_n denote the pipe's diameter and angle of elevation at position x_n
- $f_{n,k}$ denotes friction factor at position x_n and time t_k
- g denotes the acceleration due to gravity
- $P_{n,k}^{dyn} = \frac{1}{2} \rho_{n,k} v_{n,k} \cdot |v_{n,k}|$ specifies the dynamic pressure of the fluid at position x_n and time t_k
- $\Delta P_{n,k}^{st} = \frac{f_{n,k} \rho_{n,k} v_{n,k} \cdot |v_{n,k}|}{2D_n} \cdot \Delta x$ specifies the change in pressure due to friction at position x_n and time t_k
- and $\Delta P_{n,k}^{elev} = g \rho_{n,k} \sin \theta_n \cdot \Delta x$ specifies the change in pressure due to change in elevation at position x_n and time t_k

The remaining terms that appear in Eqs. 2 - 5 originate from an approximation that is used to compute the value of $\Delta P_{n,k}^{st}$ before the value of $v_{n,k}$ is known

$$\Delta P_{n,k}^{st} \approx \Delta P_{n,k}^{st,ave} + K_{n,k-1}^{f,ave} \cdot (v_{n,k} - v_{n,k}^{ave}) \quad (6)$$

In that approximation average values are used for the velocity and frictional pressure drop

$$v_{n,k-1}^{ave} = \frac{1}{2} v_{n,k-1} + \frac{1}{4} v_{n-1,k-1} + \frac{1}{4} v_{n+1,k-1} \quad (7)$$

$$\Delta P_{n,k-1}^{st,ave} = \frac{f_{n,k-1} \rho_{n,k-1} v_{n,k-1}^{ave} \cdot |v_{n,k-1}^{ave}|}{2D_n} \cdot \Delta x \quad (8)$$

and the term $K_{n,k-1}^{f,ave}$ represents the change in the average frictional pressure drop with respect to the average velocity

$$K_{n,k-1}^{f,ave} = \frac{2\Delta P_{n,k-1}^{st,ave}}{v_{n,k-1}^{ave}} \approx \left. \frac{\partial \Delta P_{st}}{\partial v} \right|_{v=v_{n,k-1}^{ave}} \quad (9)$$

Once new values have been determined for the velocity and pressure the following procedure is used to compute new values for the temperature. [3],[4]

1. A collection of temperatures is stored for each pipe segment. Those temperatures represent the temperature of the fluid at different positions within the pipe segment.
2. During each simulation step the values of those temperatures are changed to account for the temperature changes that result from friction and heat lost to the surrounds. The value of that temperature change is computed using the following equation

$$\Delta T_{n,k} = \frac{f_{n,k} \cdot \{v_{n,k}\}^3}{2D_n (C_P)_{n,k}} \cdot \Delta t - \frac{4h_{n,k} \cdot \{T_{n,k} - (T_{amb})_{n,k}\}}{\rho_{n,k} D_n (C_P)_{n,k}} \cdot \Delta t \quad (10)$$

where $(C_P)_{n,k}$ specifies the fluid's heat capacity at position x_n and time t_k , $h_{n,k}$ specifies the value of the heat transfer coefficient at position x_n and time t_k , and $(T_{amb})_{n,k}$ specifies the ambient temperature of the surrounding environment at position x_n and time t_k .

3. The positions of the temperatures are also changed using the new values that were computed for the velocities.
4. If the velocity is positive a new temperature will be added to the start of the pipe segment and an old temperature will be removed from the end of the pipe segment. Those temperatures represent the temperatures of the fluid that enters and exits pipe segment n from segments $n-1$ and $n+1$, respectively.
5. Alternatively, if the velocity is negative a new temperature will be added to the end of the pipe segment and an old temperature will be removed from the start of the pipe segment. Those temperatures represent the temperatures of the fluid that enters and exits pipe segment n from segments $n+1$ and $n-1$, respectively.

Simulating the Flow of Fluid through Pipe Junctions

If the pipeline that is being simulated includes pipe-junctions specialized procedures also need to be developed to determine the velocities, pressures, and temperatures of the fluid at those junctions. At pipe-junctions either two incoming streams will merge into one outgoing stream, or one incoming stream will split into two outgoing streams. When the pressures of the neighboring pipes change, the directions of any (or all) of those streams could change, which could cause a merging junction to become a splitting junction or vice-versa. This means that the procedure that is used to compute the velocities, pressure, and temperature of the fluid at a pipe-junction must work for both types of junctions.^[2]

One method that can be used to determine reasonable values for the velocities and pressure is to constrain the velocities and pressures to obey the following conditions ^[2]

$$P_{0,k} = P_{1,k-1} - \frac{f_{1,k-1} \rho_{1,k-1} v_{1,k} |v_{1,k}|}{2D_1} \cdot \Delta x_{junct} \quad (11)$$

$$P_{0,k} = P_{2,k-1} - \frac{f_{2,k-1} \rho_{2,k-1} v_{2,k} |v_{2,k}|}{2D_2} \cdot \Delta x_{junct} \quad (12)$$

$$P_{0,k} = P_{3,k-1} - \frac{f_{3,k-1} \rho_{3,k-1} v_{3,k} |v_{3,k}|}{2D_3} \cdot \Delta x_{junct} \quad (13)$$

$$\rho_{0,k} A_0 v_{1,k} + \rho_{0,k} A_0 v_{2,k} + \rho_{0,k} A_0 v_{3,k} = 0 \quad (14)$$

where

- $P_{0,k}$ denotes the pressure of the fluid at the center of the junction (at time t_k)

- $\rho_{0,k}$ denotes the density of the fluid at the center of the junction (at time t_k)
- Δx_{junct} and A_0 denote length and cross-sectional area of the junction pipe
- $v_{1,k}$, $v_{2,k}$, and $v_{3,k}$ denote the velocities of the fluid at the start of the 3 neighboring pipes (at time t_k)
- $P_{1,k-1}$, $P_{2,k-1}$, and $P_{3,k-1}$ denote the pressures of the fluid at the start of the 3 neighboring pipes (at time t_{k-1})
- $\rho_{1,k-1}$, $\rho_{2,k-1}$, and $\rho_{3,k-1}$ denote the densities of the fluid at the start of the 3 neighboring pipes (at time t_{k-1})
- D_1 , D_2 , and D_3 denote the diameters of the 3 neighboring pipes
- and $f_{1,k-1}$, $f_{2,k-1}$, and $f_{3,k-1}$ denote the friction factors at the start of the 3 neighboring pipes (at time t_{k-1})

Equations 11 – 13 arise from the assumption that the change in the pressure that occurs as the fluid moves from the start of the neighboring pipe to the center of the junction is equal to the drop in pressure due to friction. Eq. 14 represents a simplified expression for the conservation of mass.^{[1],[2]}

In Eqs. 11 - 14, the velocities have positive values when the fluid enters the junction and negative values when the fluid exits the junction. That sign convention was chosen to simplify the procedure that is used to solve those equations. However, it is important to remember that the sign conventions that are used in Eqs. 11 – 14 may not match the sign conventions used throughout the rest of the pipeline. This means that once new values are computed for the velocities it might be necessary to change the signs of those velocities to make them consistent with the sign conventions that are used in the neighboring pipes.

In the discussions that follow, pipe 1 ($P_{1,k-1}$) will correspond to the pipe with the largest pressure, pipe 2 ($P_{2,k-1}$) will correspond to the pipe with the middle pressure, and pipe 3 ($P_{3,k-1}$) will correspond to the pipe with the smallest pressure. When the indices (1, 2, 3) are ordered in that manner $v_{1,k}$ will have a positive value (because fluid will flow into junction away from the high-pressure pipe) and $v_{3,k}$ will have a negative value (because fluid will flow out of the junction towards the low-pressure pipe). Unlike the other velocities, $v_{2,k}$ could have either sign. If $v_{2,k}$ has a positive sign, the velocities can be determined using the following equations

$$v_{3,k}^{(case\ 1)} = -\sqrt{\frac{1}{5}A + \frac{1}{5}\sqrt{A^2 - B}} \quad (15)$$

$$v_{1,k}^{(case\ 1)} = \frac{K_{21,k}}{2v_{3,k}^{(case\ 1)}} - \frac{1}{2}v_{3,k}^{(case\ 1)} \quad (16)$$

$$v_{2,k}^{(case\ 1)} = -\left\{v_{1,k}^{(case\ 1)} + v_{3,k}^{(case\ 1)}\right\} \quad (17)$$

where $A = 2K_{23,k} - K_{21,k}$ and $B = 5K_{21,k}^2$.

Alternately, if $v_{2,k}$ has a negative sign the velocities will be determine using the Eqs. 18 – 20

$$v_{1,k}^{(case\ 2)} = \sqrt{\frac{1}{5}Y + \frac{1}{5}\sqrt{Y^2 - Z}} \quad (18)$$

$$v_{3,k}^{(case\ 2)} = -\frac{K_{23,k}}{2v_{1,k}^{(case\ 2)}} - \frac{1}{2}v_{1,k}^{(case\ 2)} \quad (19)$$

$$v_{2,k}^{(case\ 2)} = -\{v_{1,k}^{(case\ 2)} + v_{3,k}^{(case\ 2)}\} \quad (20)$$

where $Y = K_{23,k} - 2K_{21,k}$ and $Z = 5K_{23,k}^2$

In both sets of equations, the values of $K_{21,k}$ and $K_{23,k}$ are determined using the following expressions

$$K_{21,k} = \frac{2D_2\{P_{2,k-1} - P_{0,k-1}\}}{f_{2,k-1}\rho_{2,k-1}\Delta x_{junct}} - \frac{2D_1\{P_{1,k-1} - P_{0,k-1}\}}{f_{1,k-1}\rho_{1,k-1}\Delta x_{junct}} \quad (21)$$

$$K_{23,k} = \frac{2D_2\{P_{2,k-1} - P_{0,k-1}\}}{f_{2,k-1}\rho_{2,k-1}\Delta x_{junct}} - \frac{2D_3\{P_{3,k-1} - P_{0,k-1}\}}{f_{3,k-1}\rho_{3,k-1}\Delta x_{junct}} \quad (22)$$

It can be shown that Eqs. 15 – 17 can be solved if

$$K_{23,k}^2 - K_{21,k}^2 \geq K_{21,k}K_{23,k} \quad (23)$$

Similarly, Eqs. 18 – 20 can be solved if

$$K_{21,k}^2 - K_{23,k}^2 \geq K_{21,k}K_{23,k} \quad (24)$$

Now because $P_{1,k-1} \geq P_{2,k-1} \geq P_{3,k-1}$, the sign of $K_{21,k}K_{23,k}$ will always be negative. This fact insures that at least one of the two cases will produce values for $v_{1,k}$, $v_{2,k}$, and $v_{3,k}$. When more than one set of velocities are available, the set of velocities used for $v_{1,k}$, $v_{2,k}$, and $v_{3,k}$ will be the set that produces a value for $v_{2,k}$ which has the correct sign (i.e. velocities $v_{1,k}^{(case\ 1)}$, $v_{2,k}^{(case\ 1)}$, and $v_{3,k}^{(case\ 1)}$ will be used if $v_{2,k}^{(case\ 1)} > 0$ while velocities $v_{1,k}^{(case\ 2)}$, $v_{2,k}^{(case\ 2)}$, and $v_{3,k}^{(case\ 2)}$ will be used if $v_{2,k}^{(case\ 2)} < 0$).

Once new values have been computed for the velocities the temperature at the center of the pipe-junction can be computed using a weighted averaged of the temperatures of the fluid streams that enter the pipe-junction

$$T_{0,k} = \begin{cases} T_{3,k-1} & (v_{2,k} \geq 0) \\ \frac{v_{3,k}T_{3,k-1} + v_{2,k}T_{2,k-1}}{v_{3,k} + v_{2,k}} & (v_{2,k} < 0) \end{cases} \quad (25)$$

Finally, the pressure at the center of the pipe-junction is determined by averaging each of the values of $P_{0,k}$ that are computed by Eqs. 11 – 13.

$$P_{0,k} = \frac{1}{3}\{P_{1,k-1} + P_{2,k-1} + P_{3,k-1}\} - \frac{f_{1,k}\rho_{1,k-1}\{v_{1,k}\}^2}{6D_1} \cdot \Delta x - \frac{f_{2,k}\rho_{2,k-1}v_{2,k}|v_{2,k}|}{6D_2} \cdot \Delta x$$

$$+ \frac{f_{3,k}\rho_{3,k-1}\{v_{3,k}\}^2}{6D_1} \cdot \Delta x$$

Travel Time

The minimum amount of time that is needed to transport a fluid from a specific fluid source (i.e., an oil well, steam generator, or supply station) to a specified densitation (i.e., refinery, factory, or terminal station) is referred to as the travel time of the source-destination pair.

For simple pipelines (i.e., pipelines that do not have any branching) the travel time can be determined by separating the pipeline into smaller sections. The amount of time that it takes the fluid to pass through each section can then be determined by dividing the length of the section, $L_{section}$, by the velocity of the fluid, $v_{section}$,

$$t_{section} = \frac{L_{section}}{v_{section}} \quad (27)$$

The total travel time, t_{travel} , for the simple pipeline is then determined adding the amounts of time that it takes the fluid to travel through each section of the pipeline

$$t_{travel} = \sum_i^{all\ sections} t_i \quad (28)$$

For more complicated pipelines (pipelines that have significant amounts of branching), multiple paths can connect the producer to the consumer. Under those circumstances, it is necessary to compute separate travel times, t_{path} , for each path that connects the producer and consumer. Once those values are known the official travel time for the producer-consumer pair will be the travel time of the path with the minimum travel time

$$t_{travel} = \min(t_{path1}, t_{path2}, t_{path3}, \dots) \quad (29)$$

When running a simulation that allows for bidirectional flow, the path that produces the minimum travel time will depend on the pressures across the pipeline. As the pressures change merging junctions will become splitting junctions (and vice-versa). Those changes will open new pathways and close old pathways. Below is a figure of what travel time is with the red line being one travel math and the green line being the other travel path.

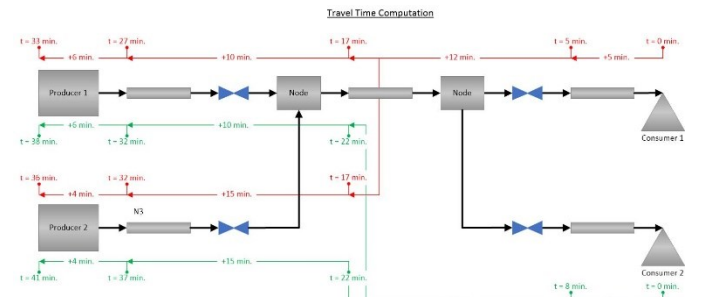


Figure 2 – Travel Time

For pipelines that transport liquid/gas mixtures, separate travel times are computed for the liquid and gas phases. The procedures that are used to compute the liquid and gas travel-times are identical to the procedure that is used to compute the travel-time of a single-phase liquid. The only difference is that separate liquid and gas velocities must be used in Eq. 27. Now that the reverse flow is added in with the constraints and a travel time algorithm has been added we can apply this to the simulation and compare it with a real-life example.

CASE STUDY

The proposed modeling and simulation techniques were applied to a pipeline network that had a main loop with two producers sending liquid and gas to 3 different consumers. The configuration is like the picture below:

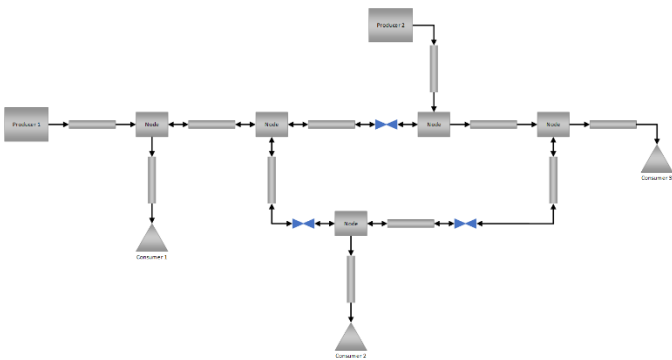


Figure 3 – Case Study of Pipeline

The two producers have inputs of oil properties:

Table 1 – Oil Properties for Producer 1 & 2

Parameters	Eng Unit	Prod 1	Prod 2	Prod 2
Oil Component	n/a	Oil AC10/121	Oil AC10-11	Paraffin
Molecular Weight	g/mol	318.41	326.388	373
Density	kg/m ³	873	879	900
Fraction	% Fluid	1	0.97	0.03
Temp 1	°C	15.6	15.6	15.6
Viscosity 1	Pa*s	0.02	0.02	0.02
Temp 2	°C	54.4	54.4	54.4
Viscosity 2	Pa*s	0.00612	0.00612	0.00612

For the two producers the gas input is given below:

Table 2 – Gas Properties for Producer 1

Mole fraction	Formula	Name	Cp/Cv	Cv
0.1048	CH ₄	Methane	1.31	1.7
0.0734	C ₂ H ₆	Ethane	1.19	1.48
0.1055	C ₃ H ₈	Propane	1.14	1.48
0.2035	C ₄ H ₁₀	i Butane (Isobutane)	1.1	1.53
0.0742	C ₄ H ₁₀	n Butane	1.09	1.53
0.0848	C ₅ H ₁₂	i Pentane	1.08	1.5259
0.045	C ₅ H ₁₂	n Pentane	1.08	1.5507
0.0963	C ₆ H ₁₄	N-Hexane	1.06	1.5491
0.2115	H ₂	Hydrogen	1.41	10.16
0.0002	H ₂ O	Water	1.33	1.46
0.0008	NH ₃	Ammonia	1.31	1.66

Table 3 – Gas Properties for Producer 2

Mole fraction	Formula	Name	Cp/Cv	Cv
0.0339	CH ₄	Methane	1.31	1.7
0.0755	C ₂ H ₆	Ethane	1.19	1.48
0.2114	C ₃ H ₈	Propane	1.14	1.48
0.1042	C ₄ H ₁₀	i Butane (Isobutane)	1.1	1.53
0.2795	C ₄ H ₁₀	n Butane	1.09	1.53
0.1242	C ₅ H ₁₂	i Pentane	1.08	1.5259
0.1	C ₅ H ₁₂	n Pentane	1.08	1.5507
0.0001	C ₆ H ₁₄	N-Hexane	1.06	1.5491
0.0489	H ₂ O	Water	1.33	1.46
0.0223	H ₂ S	Hydrogen Sulfide	1.33	

The first producer has an input where the liquid (oil properties) is 55% of the fluid and the gas is 45% of the fluid. The second producer has an input where the liquid is 59% of the fluid and the gas is 41% of the fluids. Now that inputs have been defined, we need the initial data from the scenario to match the simulation and be able to simulate reverse flow and calculate the travel time. Two scenarios exist for this case study. One where the producer 1 has more flow than producer 2 where it pushes the fluid to Consumer 3 and the customer doesn't lose energy within the loop. Scenario 2 where Producer 2 has more flow than Producer 1 and starts to recycle

fluid in the loop where it takes more time and energy to deliver the product.

Table 4 – Flow, Temperature, and Pressure Inputs for Scenario 1

Elements	Temp	Press	Flow
Eng Unit	°C	kPaa	Kg/sec
Producer 1	27.1	1721.6	22.7
Producer 2	27.4	1352.66	15.02
Consumer 1	23.3	1114	12.71
Consumer 2	20.5	1004	18.07
Consumer 3	20.8	1005	7.62

Table 5 – Flow, Temperature, and Pressure Inputs for Scenario 2

Elements	Temp	Press	Flow
Eng Unit	°C	kPaa	Kg/sec
Producer 1	27.1	1721.6	22.7
Producer 2	27.4	1891.13	25.02
Consumer 1	23.3	1114	12.71
Consumer 2	20.5	1004	25.82
Consumer 3	20.8	1005	15.43

Now we can run through the simulation and see the results.

RESULTS

The simulation ran with the inputs discussed in the case study. Since the producers will match the temperature and the flow as well as the consumer will match the pressure, the pressure at the producers as well as the flow and temperature at the consumer are only considered and ensure it's accurate. Below is the tuned model for accuracy.

Table 6 – Simulated Values for Flow, Temperature, and Pressure Inputs for Scenario 1

Elements	Temp	Press	Flow
Eng Unit	°C	kPaa	Kg/sec
Producer 1	27.1	1710	22.7
Producer 2	27.4	1348.96	15.02
Consumer 1	23.5	1114	12.59
Consumer 2	20.7	1004	18.17
Consumer 3	20.9	1005	7.7

Table 7 – Simulated Flow, Temperature, and Pressure Inputs for Scenario 2

Elements	Temp	Press	Flow
Eng Unit	°C	kPaa	Kg/sec
Producer 1	27.1	1706.6	22.7
Producer 2	27.4	1900.04	25.02
Consumer 1	23.3	1114	12.82
Consumer 2	21.0	1004	25.98
Consumer 3	21.2	1005	15.37

With the model being tuned we can start to see the transition from Producer 2 moving from 15 kg/s to 25 kg/s. Instead of the flow going from Producer 2 directly to consumer 3 the flow reverses itself and goes left and enters the loop on the left side of Consumer 2 and travels an extra 20 km to end up at Consumer 3 at the end.

Table 8 – Simulated Values for Travel Time for Scenario 1

Elements	Phase	Travel Time
Eng Unit	Gas/liquid	Hours
Consumer 1	Gas	0.22
Consumer 2	Gas	0.92
Consumer 3	Gas	1.04
Consumer 1	Liquid	1.05
Consumer 2	Liquid	1.25
Consumer 3	Liquid	1.55

When looking at Scenario 2 the travel time for Consumer 3 had quite a large increase for travel time.

Table 9 – Simulated Values for Travel Time for Scenario 2

Elements	Phase	Travel Time
Eng Unit	Gas/liquid	Hours
Consumer 1	Gas	0.22
Consumer 2	Gas	0.89
Consumer 3	Gas	1.65
Consumer 1	Liquid	1.05
Consumer 2	Liquid	1.15
Consumer 3	Liquid	2.98

CONCLUSIONS

With having the case study results, the algorithm can detect flow reversal and can show the change in travel time affected in the liquid. Future work can include adding optimization for travel time, especially if control valves are included in the pipeline as well as adding more complex pipeline networks to detect travel time and suggest the fastest or more economical route to a specific consumer or all consumers.

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AUTHOR BIOGRAPHY

Vadim Shapiro is co-founder and President of Statistics &

Control, Inc. He manages all aspects of engineering, including development of the company's *OptiRamp*[®] Advanced Process Control software. Vadim has over 25 years' leadership experience in systems and software engineering, project management, and product development in the field of turbo machinery control, advanced process control, and power management systems. He holds six patents in the areas of turbomachinery control and advanced process control, with several applications pending.

Dr. Daniel P. Theis is a software engineer working at Statistics & Control, Inc. He has a Bachelor of Science in Chemistry from Bethel College, a Master of Science in Physical Chemistry from the University of Minnesota, and a Doctorate in Computational Chemistry from the University of North Dakota. Daniel has over 15 years of experience in the development and use of computer software designed to predict the properties and behavior of complex chemical systems.

John Hooker is a controls engineer and the Engineering group manager at Statistics & Control, Inc. He has a Bachelor of Science in Aerospace Engineering from Iowa State University. Over the past 11 years, John has participated in several global projects in the oil & gas and power generation sectors and has implemented numerous applications for control solutions, equipment monitoring, design testing, data analysis, and brownfield optimization.

FIGURES

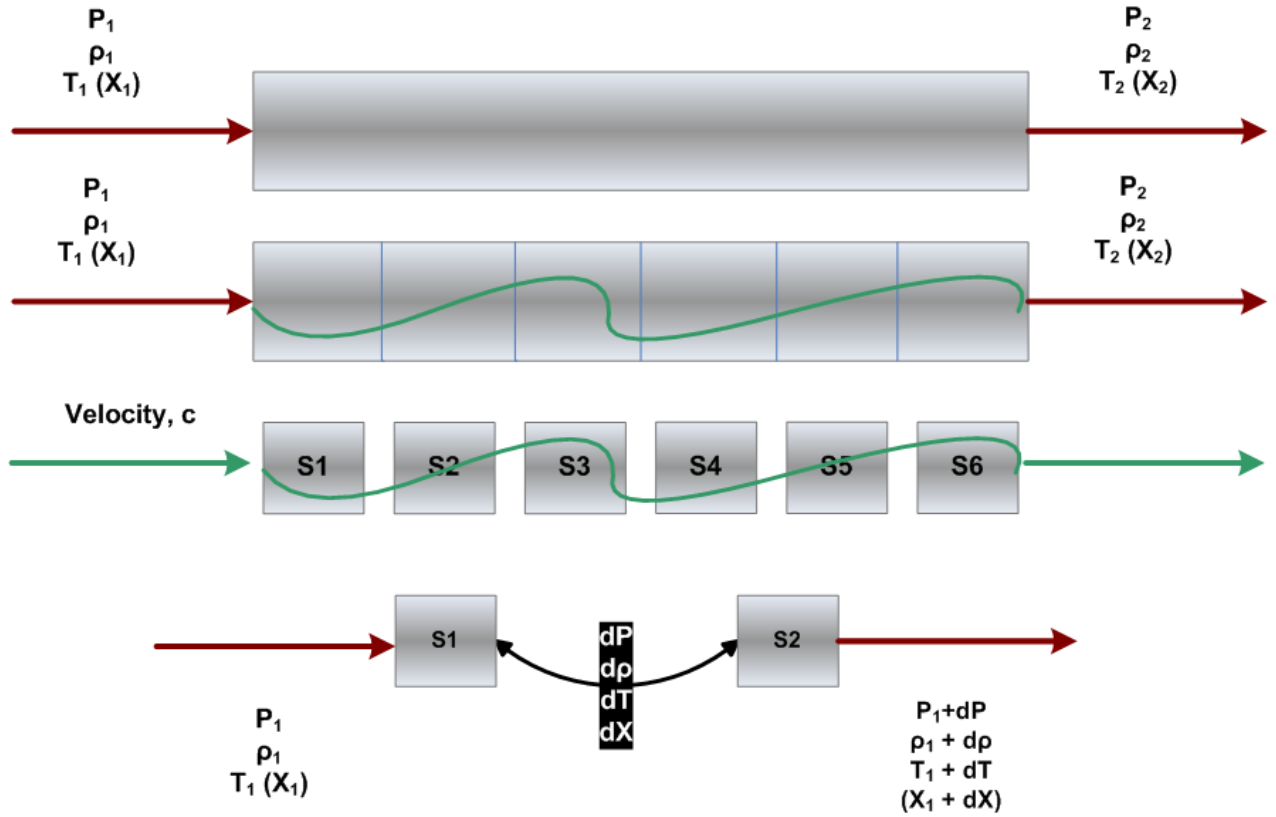


Figure 1 – Pipe Segmentation

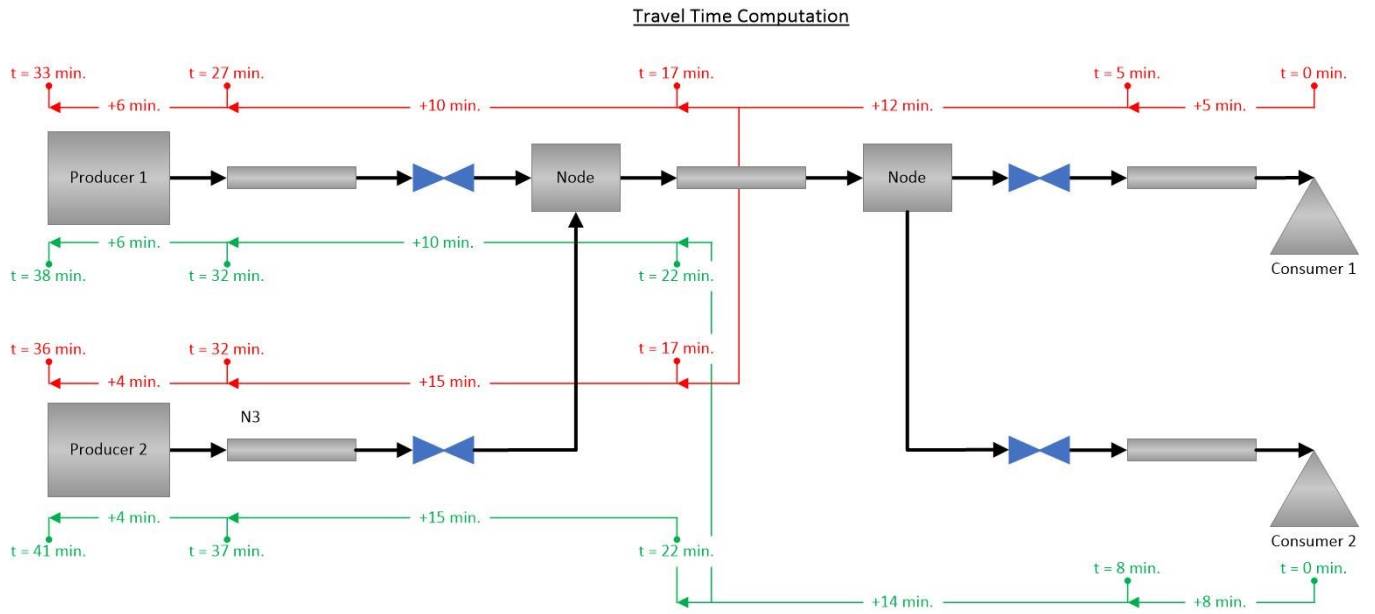


Figure 2 – Travel Time

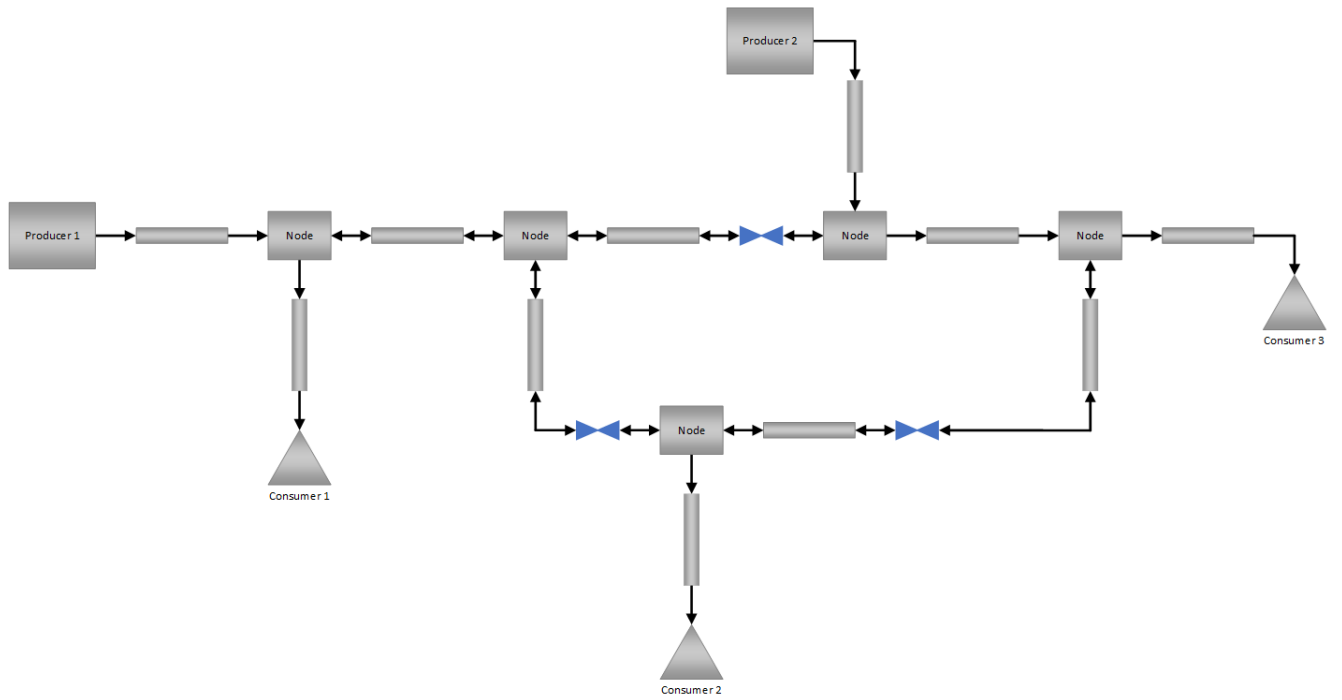


Figure 3 – Case Study of Pipeline