OPTIMIZATION OF GAS TRANSMISSION DESIGN

By
OLIVER MARCUS LIM

DISSERTATION

Submitted to the Petroleum Engineering Programme
In Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Petroleum Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

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TABLE OF CONTENTS

LIST OF FIGURES:

LIST OF TABLES:

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources or persons.

Oli

OLIVER MARCUS LIM

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to my Final Year Project (FYP) supervisor, Associate Professor Aung Kyaw for helping and assisting me throughout these two semesters by giving opinions, suggestions and advices as well as his continuous encouragement to me. I do believe without his supervising, this study would not have been successful. He was greatly inspired me to work in this project, and as much as I appreciate things, his determination in motivating me contributed tremendously in this project.

Besides, my coursemates have been a vey good company throughout my journey doing this project. Their help of finding the PIPESIM software was really helpful, especially when I was facing the difficulties in searching for this software. To some of the seniors, your help in giving me tutorials to use this software is highly appreciated, and I would like to thank for the manuals and some notes that really helped me in understanding the software.

Other than that, I would love to thank to all parties who contributed directly or indirectly for making this project a success.. Last but not least, I would like to thank to the course coordinators for giving me such opportunity to explore creativity and innovativeness through this course in UTP.

ABSTRACT

Pipelines were first built in the late 1800s to transport low-Btu coal gas through cast iron and lead pipes for street lighting. Long-distance, high-pressure pipelines began operating in the United States in 1891. Pipelines are the most common, and usually the most economic, delivery system to transport gas from the field to the consumer. Pipelines are a fixed, long-term investment that can be uneconomic for smaller and more remote gas fields. The volume of gas that can be transported in a pipeline depends on two main factors, which are the pipeline operating pressure and pipe diameter. The maximum diameter of pipelines continues to increase every few years. As diameters of 48 inch become common, the industry may be approaching the practical limit to onshore pipelines. In order to handle the increasing demand, it is likely that operating pressures will increase rather than the size of the pipe. Most transmission pipelines operate at pressures of more than 60 bar, and some operate as high as 125 bar. In order to maintain a high operating pressure, compressors maintain the pressure of gas, and depending on the length of the pipeline and the topography, may be installed at intervals of 150 km to 200 km. Increasing pressure requires larger and thicker pipes, larger compressors, and higher safety standards, all of which substantially increase the capital and operating expenses of a system. The gas industry uses an interesting unit to measure pipeline costs, dollars per inch per kilometer ($/in.-km), measuring the cost of 1-in. diameter per kilometer length. This cost has come down, more substantially in offshore pipes where larger diameter and longer distance pipelines are proposed. By some estimates, the cost of offshore lines has reduced from more than $100,000/in.-km to around $25,000 to $40,000/in.-km. Thus, a 400-km, 48-in. line would cost around $480 million to $770 million today, versus double that amount 20 years ago. The rising cost of steel, accounting for 45% of the cost of a typical pipeline, has offset some of the gains in pipe construction and fabrication costs.

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Design of offshore pipelines is usually carried out in three stages; conceptual engineering, preliminary engineering, and detail engineering. During the conceptual engineering stage, issues of technical feasibility and constraints on the system design and construction are addressed. Potential difficulties are revealed and non-viable options are eliminated. Required information for the forthcoming design and construction are identified. The outcome of the conceptual engineering allows for scheduling of development and a rough estimate of associate cost. The preliminary engineering defines system concept (pipeline size and grade), prepares authority application, and provides design details sufficient detail to define the technical input for all procurement and construction tendering. The materials covered in this book fit mostly into the preliminary engineering.

A complete pipeline design includes pipeline sizing (diameter and wall thickness) and material grade selection based on analyses of stress, hydrodynamic stability, span, thermal insulation, corrosion and stability coating, and riser specification. Smaller diameter pipes are often flowline with high design pressure leading to ratio of diameter to thickness (D/t) between 15 to 20. Depending upon types, some pipelines are bundled and others are thermal-coated or concrete-coated steel pipes to reduce heat loss and increase stability.

This paper is an approach to the design sensitivity analysis of diameter and thickness, as well as the differential pressure in the compressor to meet the requirements of the customer's need, such as the arrival pressure and temperature at the outlet end. Two different case studies were chosen; condensate pipeline and looped network gathering system.

1.2 PROBLEM STATEMENT

In gas pipeline transmission, there are several problems encountered when transport the gas from one place to another place. Mostly the problems of gas treatment are prior to long-distance transportation and hydrate control measurement in the operation of the liner part of gas pipelines.

Besides that, the process of designing the gas supply systems itself encounters several problems involved in the development in creating the field facilities of gas. They are the process of gathering, treatment, transportation and utilization of gas by various consumers and also taking care of fluctuations in gas consumption. More specific problems encountered in the processes mentioned before; rational distribution of field gas-gathering centers, and head trunk line installations, the choice of the configuration and characteristics of the gas-gathering net.

On the other hand, in spite of all the problems mentioned above, pipeline gas transmission is all about business. Therefore, in terms of business perspective, optimization of the cost is everything. When it comes to cost optimization, important parameters such as diameter, thickness and the grade of the pipe material must be taken into account, since they influence the cost directly. Problems encountered when it comes to optimization of the parameters itself, since it is involving specific details of some engineering analysis.

1.3 SIGNIFICANT OF PROJECT

Through the one-and-a-half century of pipeline operating practice, the petroleum industry has proven that pipelines are by far the most economical means of large scale overland transportation. Transporting petroleum fluids with pipelines is a continuous and reliable operation. Pipelines have demonstrated an ability to adapt to a wide variety of environments including remote areas and hostile environments.

On the basis of simple pipeline, internal diameter (ID) of the pipeline has significant effect on the arrival pressure at the outlet end. While on the other hand, the thickness of thermal insulation has a significant effect on the arrival temperature at the outlet end. These two parameters are crucial in order to meet the requirements of customer's need. Other parameter is the pressure differential that a compressor can maintain to increase the declining pressure towards the outlet end of a pipeline.

1.4 OBJECTIVES

The objective of this project is to optimize the design of constructing gas pipeline transmission, or to be more specific, to determine how the selected parameters vary in order to meet the requirements of customer's need, namely the arrival pressure and temperature. There are a lot of parameters that involved in the gas pipeline transmission, but this paper only emphasizes the sensitivity of three important parameters which are chosen to see how they vary along the selected case studies of gas pipeline transmission. Namely they are:

- Diameter
- Thickness of insulation material
- Pressure differential in the compressor

These are the most important parameters that will be varied to meet the requirements of customer's need. On the other hand, the selected case studies are the condensate pipeline and the looped gas gathering network.

1.5 SCOPE OF STUDY

The scope of study will evolved around the PIPESIM software for the design of the gas pipeline transmission based on the three selected parameters. Learning on the theories of gas pipeline transmission is also needed as the knowledge from the theories will be implemented in the PIPESIM software. Besides that, learning on the method and procedure of conducting the PIPESIM software is crucial, in order to get familiar with new software. At the same time, all the parameters involve in gas pipeline transmission must be studied, instead of the three selected parameters. This is because every parameter is crucial, and must be considered as a whole, which at the same time will help during the handling of the PIPESIM software later. Overall the project study can be divided into two stages, whereby the first stage is the studies of gas pipeline transmission theories, as well as the learning on the method and procedure in handling the PIPESIM software. The second stage is the operating and handling the PIPESIM software to design the gas pipeline transmission using all the parameters needed, but only three parameters are selected and to be manipulated, while the rest remain constant.

1.6 THE RELEVANCY OF THE PROJECT

Nowadays, manufacturers have come up with cost effective varieties as per the demands of the present market. The pipe variety can be customized as per its size, length, and thickness. As known, the larger the diameter, the larger the cost is. But on the other hand, the larger the diameter, the larger the material's high strength, rigidity and pressure tolerance. The same concept applies to the thickness. Therefore, optimum diameter and thickness must be determined in order to minimize the cost, but at the same time to optimize the performance of the pipeline.

This paper is aiming to optimize the pipe diameter, thickness of thermal insulation and the pressure differential in compressors to meet the requirements of customer's need, which is the arrival pressure and temperature at the outlet end of the pipeline.

1.7 FEASIBILITY STUDY

The Gantt chart prepared serves of how this study evolves and move through the end of project. Simulation of the condensate pipeline case study started from end of January, while the looped gas gathering network case study started from middle of February, and both simulations are completed in the middle of March. Documentation of results finished in March 2011.

CHAPTER 2

LITERATURE REVIEW / THEORY

2.1 NATURAL GAS

Natural gas is a gaseous fossil fuel consisting primarily of methane (CH_4) but including significant quantities of ethane, propane, butane, and pentane. Heavier hydrocarbons removed prior to use as a consumer fuel as well as carbon dioxide, nitrogen, helium and hydrogen sulfide. Before natural gas can be used as a fuel, it must undergo extensive processing to remove almost all materials other than methane. The by-products of that processing include ethane, propane, butanes, pentanes and higher molecular weight hydrocarbons, elemental sulfur, and sometimes helium and nitrogen. [1]

Natural gas is not only cheaper, but burns cleaner than other fossil fuels, such as oil and coal, and produces less carbon dioxide per unit energy released. For an equivalent amount of heat, burning natural gas produces about 30% less carbon dioxide than burning petroleum and about 45% less than burning coal.

The major difficulty in the use of natural gas is transportation and storage because of its low density. Natural gas conventional pipelines are economical, but they are impractical across oceans. For example, many existing pipelines in North America are close to reaching their capacity, prompting some politicians representing colder areas to speak publicly of potential shortages.

It is difficult to evaluate the cost of heating a home with natural gas compared to that of heating oil, because of differences of energy conversion efficiency, and the widely fluctuating price of crude oil. However, for illustration, one can calculate a representative cost per BTU. Assuming the following current values (2008):

i. Natural gas.
  - One cubic foot of natural gas produces about 1,030 BTU (38.4 MJ/m³).
  - The price of natural gas is \$9.00 per thousand cubic feet (\$0.32/m³).

ii. Heating oil.
  - One US gallon of heating oil produces about 138,500 BTU (38.6 MJ/l).
  - The price of heating oil is \$2.50 per US gallon (\$0.66/l).

This gives a cost of \$8.70 per million BTU (\$8.30/GJ) for natural gas, as compared to \$18 per million BTU (\$17/GJ) for fuel oil. Such comparisons fluctuate with time and vary from place to place dependent on the cost of the raw materials and local taxation. [2]

2.2 DIAMETER, WALL THICKNESS AND GRADE OF PIPE

With total pressure required in order to move various amounts of oil or natural gas in hand, pipeline designers have to determine the optimum pipe size and grade. They calculate the *hoop stress,* the force produced in the pipe wall by the fluid pressure inside the pipe pushing against the pipe wall. To do so, *Barlow's Formula* is used:

$$\boxed{S = \frac{2t}{D} \times P}$$

Where:

S = Hoop stress
t = Wall thickness
D = Pipe outside diameter
P = Internal Pressure

Barlow's formula figures in an important computational, albeit convoluted, procedure. Pressure inside the pipe pushes perpendicularly against the wall all around its circumference, trying to push it apart. Steel molecules making up the pipe desperately cling to each other circumferentially, trying to hold it together. Figure below shows on slice of that pipe. [3]

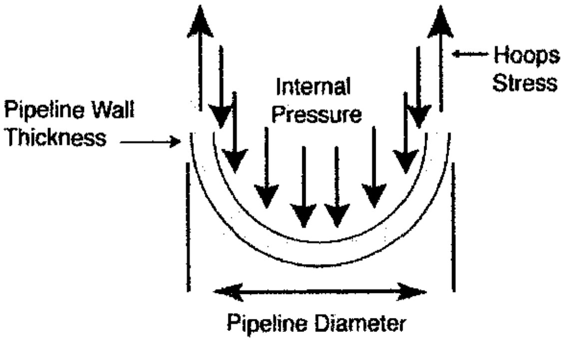


Figure 1: Free-body diagram of pipe under pressure.

The arrows of internal pressure represent the forces pushing out uniformly on the pipe. At a given pressure inside the pipe, each molecule of oil or natural gas pushes against the every other molecule and against the pipe wall, all around the pipe. The bigger the diameter of the pipe, the more area over which the pressure is applied, and the bigger the force on the pipe. The offsetting force holding the pipe together is a function of the strength of the steel and the thickness of the pipe.

Pipeline designer choose pipe diameter, wall thickness, and steel to safely contain the expected pressures on the line. The Maximum Allowable Operating Pressure (MAOP) of the pipe is calculated with a rearrangement of Barlow's formula: [1]

$$\boxed{\mathrm{MAOP} = \frac{2t}{D} \times \mathrm{SMYS} \times \mathrm{SF}}$$

Where:

MAOP = Maximum allowable operating pressure

t = wall thickness

D = Pipe outside diameter

SMYS = Specified minimum yield of the steel

SF = Safety factor as established by standards or regulations

As an example, the MAOP of a 30 inch piece of X-52 pipe, 0.25 inch thickness, assuming a safety factor of 0.72 is:

$$\boxed{(2 \text{ x } 0.25\text{in} / 30\text{in}) \text{ x } 52000 \text{ psi x } 0.72 = 624 \text{ psi}}$$

If the wall thickness is increased to 0.375 inch, the MAOP goes up to 936 psi. If the diameter is decreased to 28 inch, the MAOP increases further to 1002 psi. Of course, the maximum amount flowing through the 28 inch line at its MAOP is less than the amount flowing through a 30 inch line at its MAOP. Engineers work iteratively to get the wall thickness, diameter, and grade of steel that gives the best (least costly) combination to handle the planned volumes.

2.3 GAS PRODUCTION FACILITY (COMPRESSOR)

Compressors are used whenever it is necessary to flow gas from a lower pressure to a higher pressure system. Flash gas from low-pressure vessels used for multistage stabilization of liquids, often exists at too low a pressure to flow into the gas sales pipeline. Sometimes this gas is used as fuel and the remainder flared or vented. Often it is more economical or it is necessary for environmental reasons to compress the gas for sales. In a gas field, a compressor used in this service is normally called a "flash gas compressor." Flash gas compressors are normally characterized by low throughput rate and high differential pressure. [3]

The differential pressure is expressed in terms of overall compressor ratio, RT, which is defined as:

$$\boxed{R_T = \frac{P_d}{P_s}}$$

Where:

R_T = Overall compressor ratio

P_d = Discharge pressure, psia

P_s = Suction pressure, psia

Flash gas compressors typically have an overall compressor ratio in the range of 5 to 20.

In some marginal gas fields, and in many larger gas fields that experience a decline in flowing pressure with time, it may be economical to allow the wells to flow at surface pressures below that required for gas sales. In such cases a "booster compressor" may be installed. Booster compressors are typically characterized by low overall compressor ratio (on the order of 2 to 5) and relatively high throughput. Booster compressors are also used on long pipelines to restore pressure drop lost to friction. The design of a long pipeline requires trade-off studies between the size and distance between booster compressor stations and the diameter and operating pressure of the line.

CHAPTER 3

PROPOSED PROJECT METHODOLOGY

3.1 RESEARCH METHODOLOGY

A number of exercises and case studies have been run by using the Pipesim simulator. The research methodology is as follows:

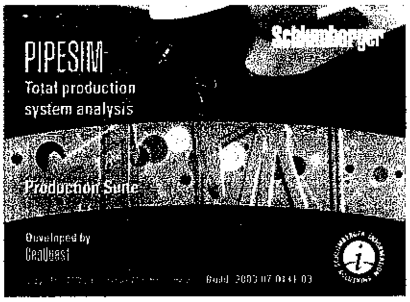


Figure 2: Schlumberger Pipesim Software

RESEARCH METHODOLOGY	
Exercise	❖ Single Phase Pipeline ✛ Build the Physical Model ✛ Gas Pipeline Sensitivity Study ✛ Calculate the gas flow rate for a given pressure drop ❖ Multiphase Pipeline ✛ Build a Multiphase pipeline model ❖ Network Modeling ✛ Looped Gathering Network ✛ Gas Transmission Network
Case Study	❖ Condensate Pipeline ✛ Sensitivity Analysis for Pipe Diameter ✛ Sensitivity Analysis for Insulation Thickness ❖ Gas Looped Gathering Network

Table 1: Research methodology in sequence.

3.2 PROJECT ACTIVITIES FLOW

The following table represents the activities, start date and end date.

ACTIVITIES	FROM	TO
Single Phase Introductory Exercise	24th Jan 2011	28th Jan 2011
Multiphase Pipeline Exercise	31st Jan 2011	4th Feb 2011
Network Modeling Exercise	7th Feb 2011	11th Feb 2011
Condensate Pipeline Case Study	14th Feb 2011	25th Feb 2011
Gas Looped Gathering Network Case study	28th Feb 2011	11th March 2011
Documentation of Result	12th March 2011	15th March 2011

Table 2: Project activities flow.

3.3 KEY MILESTONE (GANTT CHART)

		JAN	FEB				MAR					APR				MAY		
No	**Activities /Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17 - 19**
1	Pipesim Exercise	🟦	🟦	🟦				MID - SEM BREAK										EXAMINATION WEEK
2	Pipesim Case Study				🟦	🟦	🟦											
3	Progress Report Submission								🟦								STUDY WEEK	
4	Pre-EDX											🟦						
5	EDX												🟦					
6	Final Oral Presentation													🟦				
7	Delivery of Final Report to External Examiner														🟦			
8	Submission of Hardbound Copies															🟨		

🟦 Activities done 🟨 Incoming Activities

Table 3: Project Gantt chart.

3.4 PIPESIM

PIPESIM provides both, professors and students, a tool that is useful for studying, teaching and learning how pipelines work and how they can be scheduled in an easy and widespread way. *PIPESIM features both static and dynamic pipelines.*

Besides that, PIPESIM is a full interactive application that helps the user to master the knowledge about pipeline scheduling by means of a very simple interface and a very descriptive and didactic way. The simulator has a very comprehensive help system. Using this, users can even study the theoretical concepts of pipelining and pipeline scheduling. Besides, the application is completely flexible in the way of presenting the results. It is possible, for example, to see any of the stages of scheduling, whichever it is. Users can either walk through the complete simulation step by step, have a look at all the details and watch concrete steps of the scheduling or just study the final results of the simulation without presenting intermediate results. Besides that, users can check hand-solved problems after each completed step to obtain the final result. The ability of comparing the final scheduling results underlines the importance of simulator-supported learning in modern teaching techniques.

PIPESIM consists of the following modules:

- Pipeline & Facilities
- Well Performance Analysis
- Network Analysis
- Production Optimization (GOAL)
- Field Planning (FPT)
- Multi-lateral (HoSim)

i. Pipeline & Facilities

A comprehensive multiphase flow model with "System Analysis" capabilities. Typical applications of the module include:

- multiphase flow in flowlines and pipelines
- point by point generation of pressure and temperature profiles
- calculation of heat transfer coefficients
- flowline & equipment performance modeling (system analysis)

ii. Well Performance analysis

A comprehensive multiphase flow model with "Nodal & System Analysis" capabilities. Typical applications of the module includes:

- Well design
- Well optimization
- Well inflow performance modeling
- Gas Lift Design
- ESP Design
- Gas lift performance modeling
- ESP performance modeling
- Horizontal well modeling (including optimum horizontal completion length determination)
- Injection well design
- Annular and tubing flow

iii. Network analysis module

Features of the network model include:

- unique network solution algorithm to model wells in large networks
- rigorous thermal modeling of all network components
- multiple looped pipeline/flowline capability
- well inflow performance modeling capabilities

- *rigorous modeling of gas lifted wells in complex networks*
- comprehensive pipeline equipment models
- gathering and distribution networks

iv. Production Optimization (GOAL)

This module allows production optimization of an artificial lifted (gas lift or ESP) oil field to be performed given a number of practical constraints on the system. Full features of the model include:

- interfaces with the well Analysis module
- solves multi-well commingled scenarios
- allows well production performance modeling
- offers operator decision support functions
- Black Oil only

v. Field Planning (FPT)

Allows the network module to be coupled to a “reservoir model” to model reservoir behavior over time. In addition conditional logic decision can be taken into account. The reservoir may be described as either:

- Black oil tank model
- Compositional tank model
- look-up tables
- Commercial reservoir simulator
- Commercial material balance program

CHAPTER 4

RESULTS AND DISCUSSION

4.1. CASE STUDY 1: Condensate Pipeline

<table>
<tr><th colspan="6">DATA</th></tr>
<tr><td>Layout</td><td colspan="5">Condensate flows down a 400 ft x 10" ID riser from the satellite platform to the seabed, along a 5 mile pipeline, and up a 400 ft x 10" ID riser to the processing platform.</td></tr>
<tr><td rowspan="6">Boundary Condition</td><td colspan="4">Fluid inlet pressure at satellite platform</td><td>1,500 psia</td></tr>
<tr><td colspan="4">Fluid inlet temperature at satellite platform</td><td>176 °F</td></tr>
<tr><td colspan="4">Design liquid flowrate</td><td>10,000 STB/d</td></tr>
<tr><td colspan="4">Maximum turndown</td><td>5,000 STB/d</td></tr>
<tr><td colspan="4">Minimum arrival pressure at processing platform</td><td>1,000 psia</td></tr>
<tr><td colspan="4">Minimum arrival temperature at processing platform</td><td>75 °F</td></tr>
<tr><td rowspan="9">Pure Hydrocarbon Components</td><td colspan="2">Component</td><td colspan="3">Moles</td></tr>
<tr><td colspan="2">Methane</td><td colspan="3">75</td></tr>
<tr><td colspan="2">Ethane</td><td colspan="3">6</td></tr>
<tr><td colspan="2">Propane</td><td colspan="3">3</td></tr>
<tr><td colspan="2">Isobutane</td><td colspan="3">1</td></tr>
<tr><td colspan="2">Butane</td><td colspan="3">1</td></tr>
<tr><td colspan="2">Isopentane</td><td colspan="3">1</td></tr>
<tr><td colspan="2">Pentane</td><td colspan="3">0.5</td></tr>
<tr><td colspan="2">Hexane</td><td colspan="3">0.5</td></tr>
<tr><td rowspan="2">Petroleum Fraction</td><td>Name</td><td>Boiling Point (°F)</td><td>Molecular Weight</td><td>Specific Gravity</td><td>Moles</td></tr>
<tr><td>C7+</td><td>214</td><td>115</td><td>0.683</td><td>12</td></tr>
<tr><td rowspan="2">Aqueous Component</td><td colspan="2">Component</td><td colspan="3">Volume ratio (%bbl/bbl)</td></tr>
<tr><td colspan="2">Water</td><td colspan="3">10</td></tr>
<tr><td rowspan="6">Pipeline Sizes Available</td><td colspan="2">I.D.(")</td><td colspan="2">Wall thickness (")</td><td>Roughness (")</td></tr>
<tr><td colspan="2">6</td><td colspan="2">0.5</td><td>0.001</td></tr>
<tr><td colspan="2">8</td><td colspan="2">0.5</td><td>0.001</td></tr>
<tr><td colspan="2">10</td><td colspan="2">0.5</td><td>0.001</td></tr>
<tr><td colspan="2">12</td><td colspan="2">0.5</td><td>0.001</td></tr>
<tr><td colspan="2">14</td><td colspan="2">0.5</td><td>0.001</td></tr>
<tr><td rowspan="7">Pipeline Data</td><td colspan="3">Height of undulations</td><td colspan="2">10/1000</td></tr>
<tr><td colspan="3">Horizontal distance</td><td colspan="2">5 miles</td></tr>
<tr><td colspan="3">Elevation difference</td><td colspan="2">0</td></tr>
<tr><td colspan="3">Wall Thickness</td><td colspan="2">0.5”</td></tr>
<tr><td colspan="3">Roughness</td><td colspan="2">0.001”</td></tr>
<tr><td colspan="3">Ambient Temperature</td><td colspan="2">50°F</td></tr>
<tr><td colspan="3">Overall Heat Transfer Coefficient</td><td colspan="2">0.2 Btu/hr/ft2/°F</td></tr>
</table>

Pipeline Insulation Study Data	Pipe thermal conductivity	50 Btu/hr/ft/°F
	Insulation thermal conductivity	0.15 Btu/hr/ft/°F
	Insulation thickness available	0.6", 0.7", 0.8" or 0.9"
	Ambient fluid	water
	Ambient fluid velocity	1.64 ft/sec
	Burial depth	0 (half buried)
	Ground conductivity	1.5 Btu/hr/ft/°F
Data or Risers 1 & 2	Horizontal distance	0
	Elevation difference (Riser_1)	-400 ft
	Elevation difference (Riser_2)	+400 ft
	Inner diameter	10"
	Wall thickness	0.5"
	Roughness	0.001"
	Ambient temperature	50 °F
	Overall heat transfer coefficient	0.2 Btu/hr/ft2/°F

Table 4: Condensate pipeline data.

4.1.1. Pipeline Diameter Sensitivity Analysis

The smallest pipeline I.D. that will allow the design flowrate of 10,000 STB/d of condensate to be transported from the satellite platform whilst maintaining an arrival pressure of not lower than 1,000 psia at the processing platform is to be determined.

By using the wizard feature in the Pipesim, this condensate pipeline model is constructed.

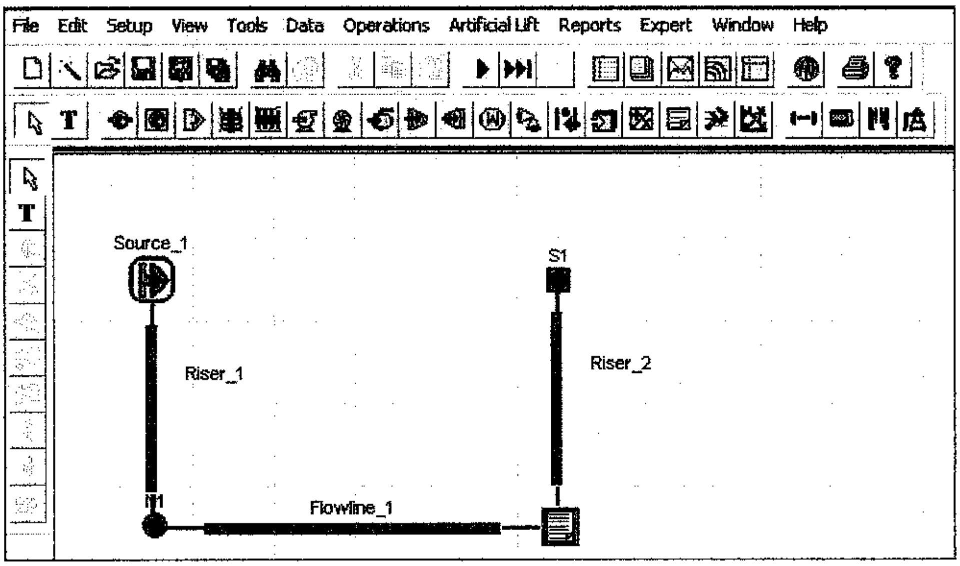
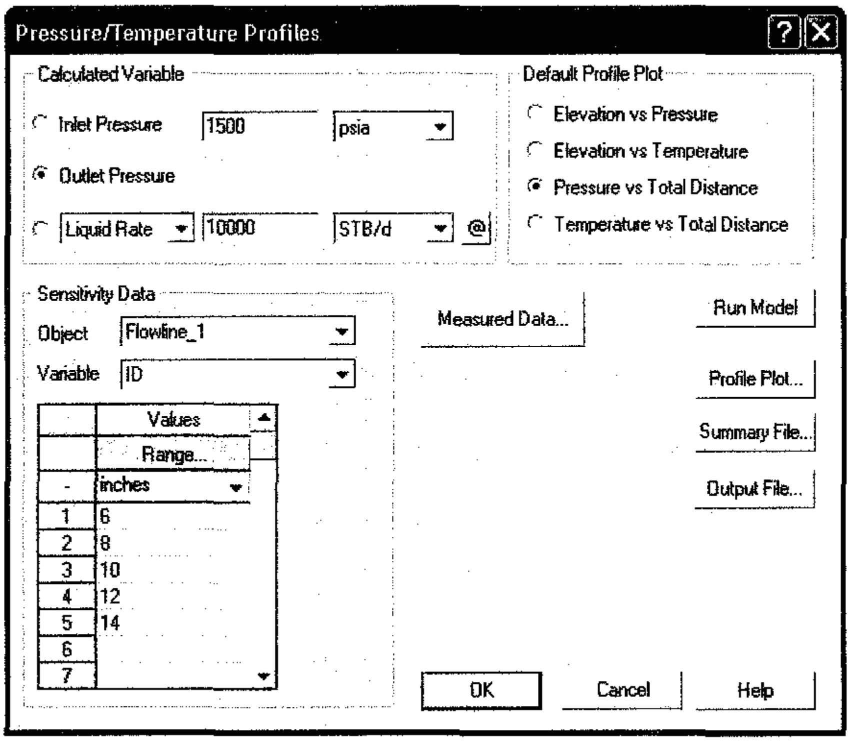


Figure 3: Constructed condensate pipeline model.

The pipeline sizes available are 6", 8", 10", 12" or 14" I.D. By using the pressure temperature profiles operation, the pipeline sizes are inserted and the pressure drop for each of the five pipeline size options is calculated.



Calculated Variable

○ Inlet Pressure 1500 psia

● Outlet Pressure

○ Liquid Rate 10000 STB/d

Default Profile Plot

○ Elevation vs Pressure

○ Elevation vs Temperature

● Pressure vs Total Distance

○ Temperature vs Total Distance

Sensitivity Data

Object Flowline_1

Variable ID

	Values
-	inches
1	6
2	8
3	10
4	12
5	14
6	
7	

Figure 4: Pressure / Temperature Profiles

- Calculated variable is outlet pressure.
- Inlet pressure 1,500 psia
- Liquid Rate is 10,000 STB/d.
- Default Profile Plot is "Pressure vs Total Distance"

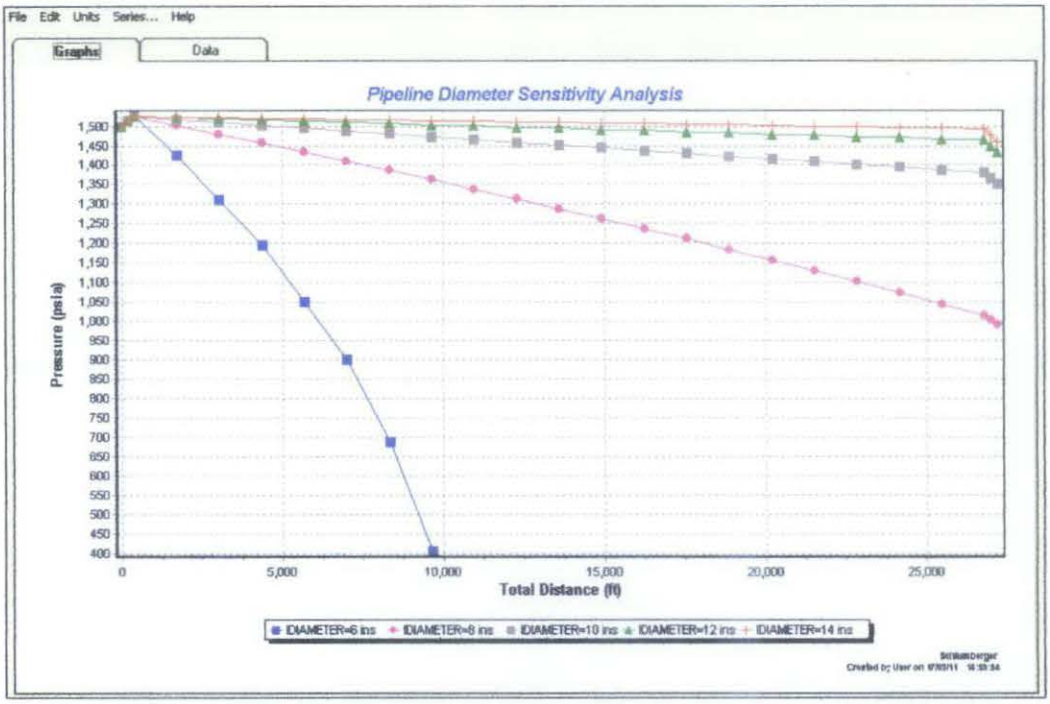


Figure 5: Diameter sensitivity analysis in Pressure vs Total Distance graph.

Diameter	**6"**	**8"**	**10"**	**12"**	**14"**
Inlet Pressure	1500	1500	1500	1500	1500
Outlet Pressure	414.4 **(below 1000)**	995.1 **(below 1000)**	1352.0	1434.2	1461.3

Table 5: Inlet and outlet pressure for five different pipeline diameter.

4.1.1.1. Discussion

- Among the five pipeline sizes, obviously the 6" diameter pipeline is not suitable to be used in this case, since it experiences rapid pressure drop even before it reaches the outlet end of the pipeline, which is 5 miles (26400 ft) from the inlet end.
- 8" diameter pipeline is not suitable too since the outlet pressure is below the minimum arrival pressure at processing platform, 1000 psia.
- Only the 10", 12" and 14" diameter pipeline is suitable in this case because they can achieve the outlet pressure above the minimum arrival pressure at processing platform.
- By knowing that the larger diameter of a pipeline, the higher the cost is, therefore 10" diameter pipeline is suitable enough to be used in this case. The outlet pressure is higher than the minimum arrival pressure at processing platform and the cost is the least among the three pipeline diameter.

4.1.2. Insulation Thickness Sensitivity Analysis

The smallest thickness of thermal insulation that can be used to insulate the pipeline and maintain an arrival temperature of not less than 75 °F is to be determined. This minimum arrival temperature is required to prevent the formation of hydrates. The insulation has a thermal conductivity of 0.15 Btu/hr/ft/°F and a thickness of 0.6", 0.7", 0.8" or 0.9".

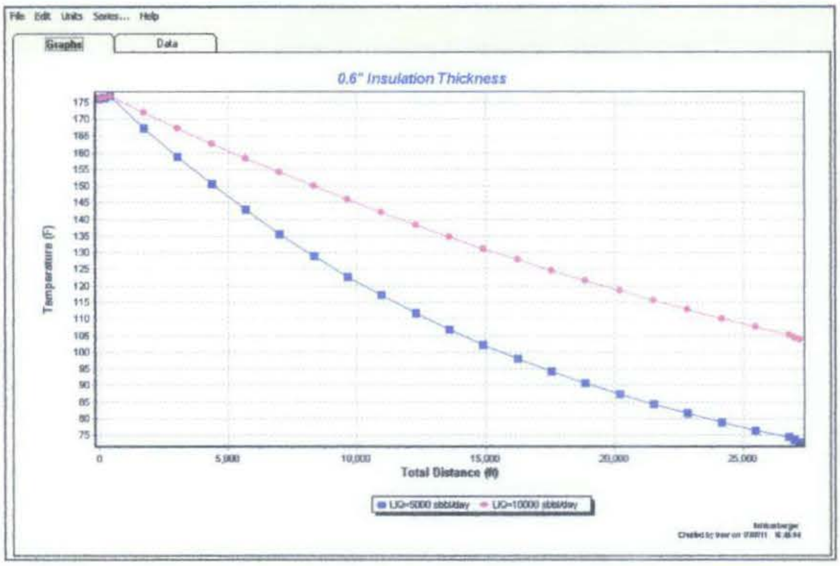


Figure 6: Temperature vs total distance graph for 0.6" insulation thickness

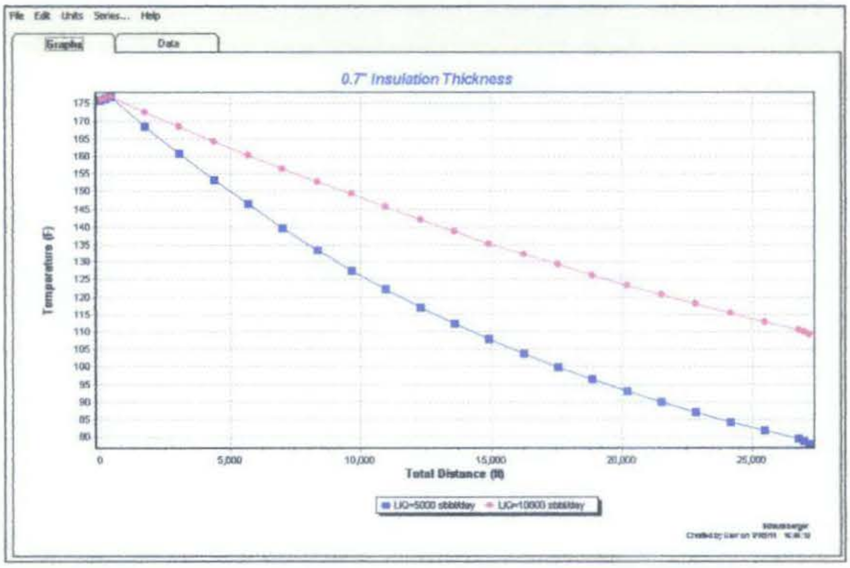


Figure 7: Temperature vs total distance graph for 0.7" insulation thickness

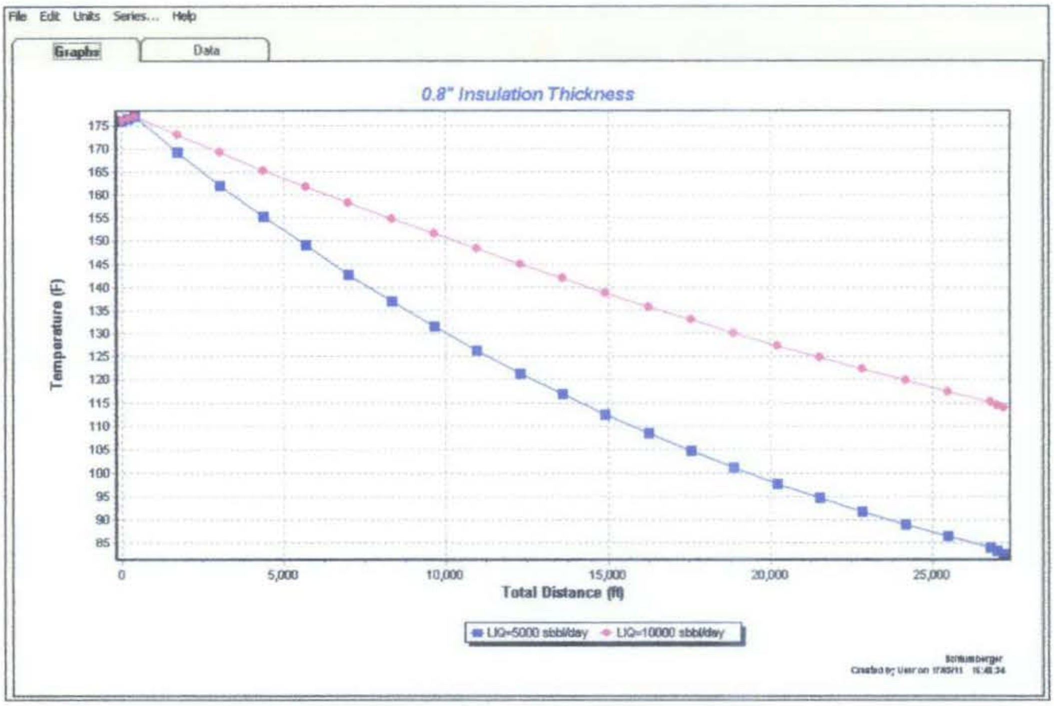


Figure 8: Temperature vs total distance graph for 0.8"insulation thickness

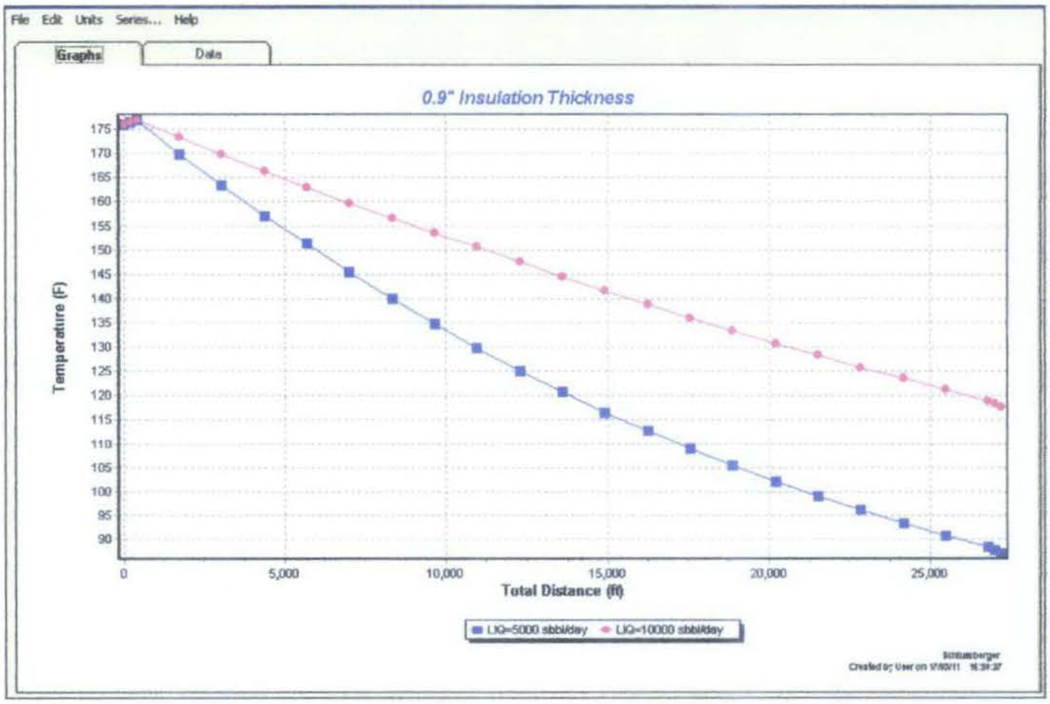


Figure 9: Temperature vs total distance graph for 0.9"insulation thickness

Insulation Thickness	**Arrival (Outlet) Temperature**	
	Design liquid flowrate (10 000 STB/d)	**Maximum turndown (5 000 STB/d)**
0.6"	103.8	72.8 **(below 80)**
0.7"	109.2	78.0 **(below 80)**
0.8"	113.8	82.6
0.9"	117.8	86.9

Table 6: Arrival temperature for four different insulation thicknesses.

4.1.2.1. Discussion

- Among the four pipeline insulation thicknesses, 0.6" and 0.7" insulation thickness is not suitable to be used in this case, since the arrival temperature is below the minimum arrival temperature at processing platform, which is 80°F.
- Only the 0.8" and 0.9" insulation thickness is suitable to be used since the arrival temperature is above the minimum arrival temperature at processing platform.
- By knowing that the thicker insulation of a pipeline, the higher the cost is, therefore 0.8" pipeline insulation thickness is suitable enough to be used in this case. The arrival temperature is higher than the minimum arrival temperature at processing platform and the cost is the least among the two pipeline insulation.

4.2. CASE STUDY 2: Looped Gas Gathering Network

<table>
<tr><th colspan="6">DATA</th></tr>
<tr><td rowspan="9">Completion and Tubing Data</td><td colspan="3"></td><td>Well 1 & 2</td><td>Well 3</td></tr>
<tr><td colspan="3">Gas PI</td><td>0.0004 mmscf/d/psi^2</td><td>0.0005 mmscf/d/psi^2</td></tr>
<tr><td colspan="3">Wellhead TVD</td><td>0</td><td>0</td></tr>
<tr><td colspan="3">Mid Perforations TVD</td><td>4500 ft</td><td>4900 ft</td></tr>
<tr><td colspan="3">Mid Perforations MD</td><td>4500 ft</td><td>4900 ft</td></tr>
<tr><td colspan="3">Tubing I.D.</td><td>2.4"</td><td>2.4"</td></tr>
<tr><td colspan="3">Wellhead Ambient Temperature</td><td>60 °F</td><td>60 °F</td></tr>
<tr><td colspan="3">Mid Perforations Ambient Temperature</td><td>130 °F</td><td>140 °F</td></tr>
<tr><td colspan="3">Heat Transfer coefficient</td><td>0.2 Btu/hr/ft2/F</td><td>0.2 Btu/hr/ft2/F</td></tr>
<tr><td rowspan="9">Pure Hydrocarbon Components (Wells 1 & 2)</td><td colspan="3">Component</td><td colspan="2">Moles</td></tr>
<tr><td colspan="3">Methane</td><td colspan="2">75</td></tr>
<tr><td colspan="3">Ethane</td><td colspan="2">6</td></tr>
<tr><td colspan="3">Propane</td><td colspan="2">3</td></tr>
<tr><td colspan="3">Isobutane</td><td colspan="2">1</td></tr>
<tr><td colspan="3">Butane</td><td colspan="2">1</td></tr>
<tr><td colspan="3">Isopentane</td><td colspan="2">1</td></tr>
<tr><td colspan="3">Pentane</td><td colspan="2">0.5</td></tr>
<tr><td colspan="3">Hexane</td><td colspan="2">0.5</td></tr>
<tr><td rowspan="2">Petroleum Fraction (Wells 1 & 2)</td><td>Name</td><td>Boiling Point (°F)</td><td>Molecular Weight</td><td>Specific Gravity</td><td>Moles</td></tr>
<tr><td>C7+</td><td>214</td><td>115</td><td>0.683</td><td>12</td></tr>
<tr><td rowspan="2">Aqueous Component (Wells 1 & 2)</td><td colspan="3">Component</td><td colspan="2">Volume ratio (%bbl/bbl)</td></tr>
<tr><td colspan="3">Water</td><td colspan="2">10</td></tr>
<tr><td rowspan="9">Pure Hydrocarbon Components (Well 3)</td><td colspan="3">Component</td><td colspan="2">Moles</td></tr>
<tr><td colspan="3">Methane</td><td colspan="2">73</td></tr>
<tr><td colspan="3">Ethane</td><td colspan="2">7</td></tr>
<tr><td colspan="3">Propane</td><td colspan="2">4</td></tr>
<tr><td colspan="3">Isobutane</td><td colspan="2">1.5</td></tr>
<tr><td colspan="3">Butane</td><td colspan="2">1.5</td></tr>
<tr><td colspan="3">Isopentane</td><td colspan="2">1.5</td></tr>
<tr><td colspan="3">Pentane</td><td colspan="2">0.5</td></tr>
<tr><td colspan="3">Hexane</td><td colspan="2">0.5</td></tr>
<tr><td rowspan="2">Petroleum Fraction (Wells 3)</td><td>Name</td><td>Boiling Point (°F)</td><td>Molecular Weight</td><td>Specific Gravity</td><td>Moles</td></tr>
<tr><td>C7+</td><td>214</td><td>115</td><td>0.683</td><td>10.5</td></tr>
<tr><td rowspan="2">Aqueous Component (Well 3)</td><td colspan="3">Component</td><td colspan="2">Volume ratio (%bbl/bbl)</td></tr>
<tr><td colspan="3">Water</td><td colspan="2">5</td></tr>
<tr><td rowspan="2">Data for Looped Gathering Lines (B1,</td><td colspan="3">Rate of undulations</td><td colspan="2">10/1000</td></tr>
<tr><td colspan="3">Horizontal distance</td><td colspan="2">30,000 ft</td></tr>
</table>

B2, B3, and B4)	Elevation difference	0 ft	
	Inner diameter	6"	
	Wall thickness	0.5"	
	Roughness	0.001"	
	Ambient temperature	60 °F	
	Overall heat transfer coefficient	0.2 Btu/hr/ft2/°F	
Data for Deliver Line (B5)	Separator type	Liquid	
	Separator efficiency	100%	
	Compressor differential pressure	300psi, 400 psi or 500 psi	
	Compressor efficiency	70%	
	Aftercooler outlet temperature	120 °F	
	Aftercooler delta P	15 psi	
	Flowline Rate of undulations	10/1000	
	Flowline Horizontal distance	10,000 ft	
	Flowline Elevation difference	0 ft	
	Flowline Inner diameter	8"	
	Flowline Wall thickness	0.5"	
	Flowline Roughness	0.001"	
	Flowline Ambient temperature	60 °F	
	Flowline Overall heat transfer coefficient	0.2 Btu/hr/ft2/°F	
Boundary Conditions	**Node**	**Pressure**	**Temperature**
	Well_1	2,900 psia	130 °F
	Well_2	2,900 psia	130 °F
	Well_3	3,100 psia	140 °F
	Sink_1	800 psia	(calculated)

Table 7: Looped gas gathering network data.

The deliverability of a production network is to be established. The network connects three producing gas wells in a looped gathering system and delivers commingled product to a single delivery point. In this section, the differential pressure of the compressor is to be manipulated, to see how it influences the well flowrate and the inlet pressure of every node that the gas passes towards the sink (customer). The compressor's differential pressure used in this case study is 300 psia, 400 psia or 500 psia.

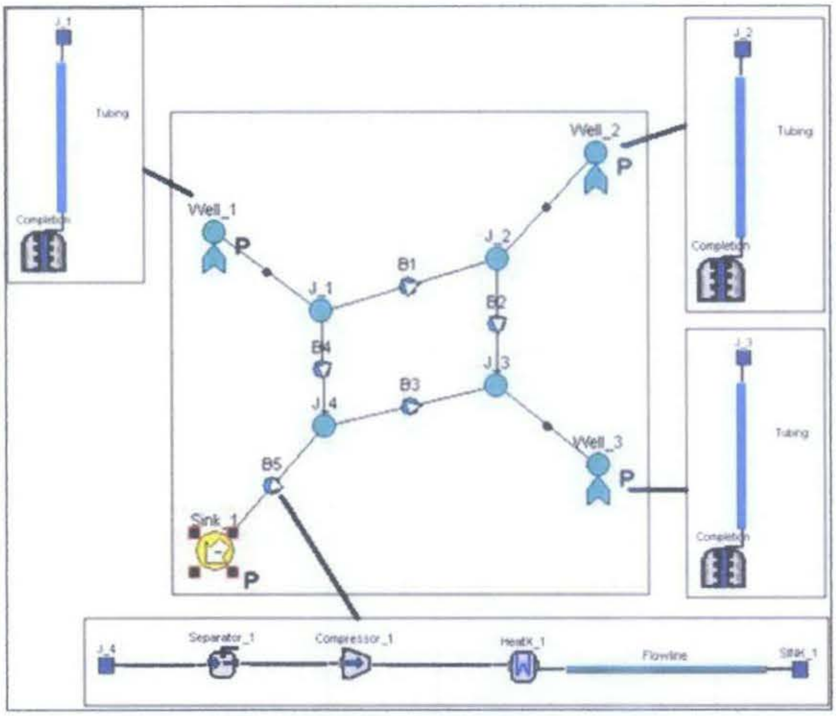


Figure 10: Looped gas gathering network model

4.2.1. Compressor's Pressure Differential, 300 psia (Well 1)

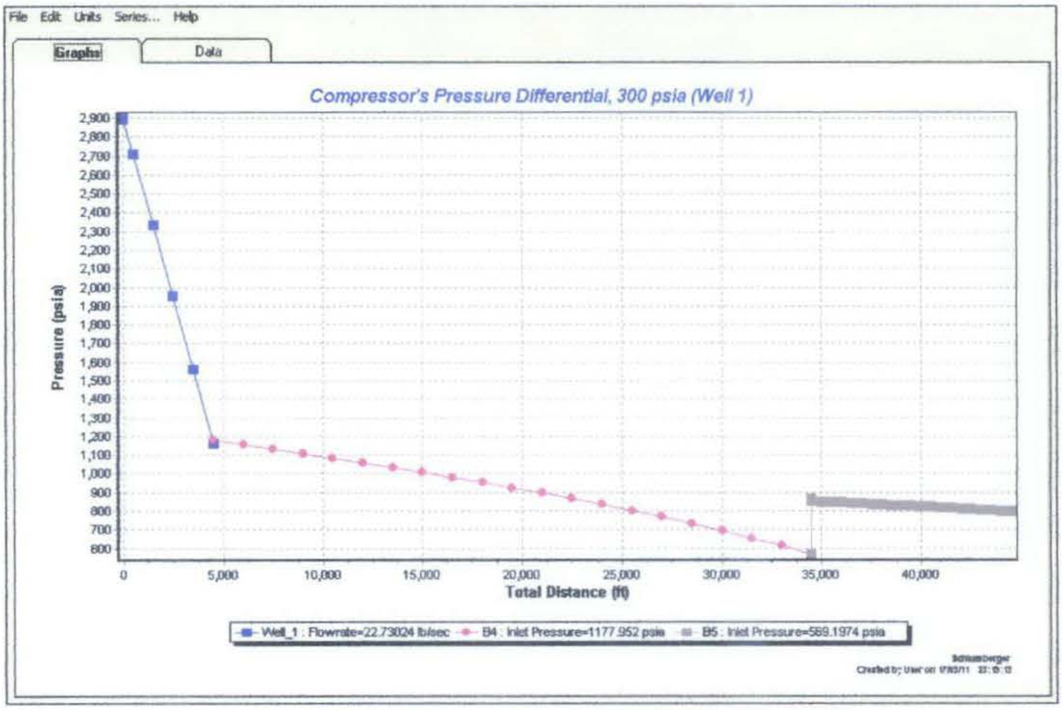


Figure 11: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 300 psia (Well 1)

4.2.2. Compressor's Pressure Differential, 300 psia (Well 2)

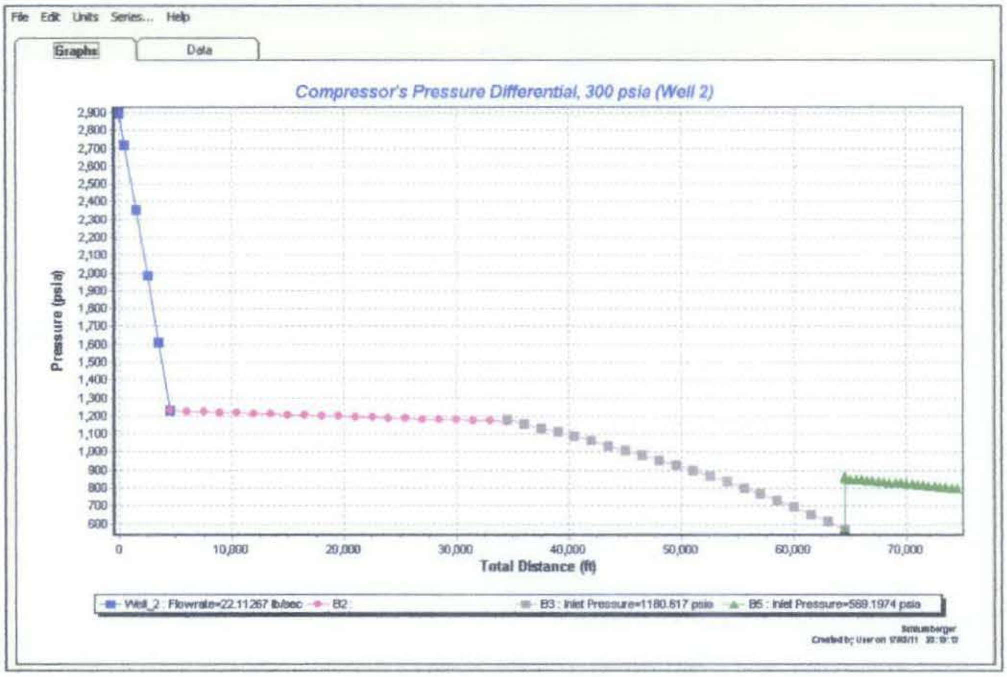


Figure 12: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 300 psia (Well 2)

4.2.3. Compressor's Pressure Differential, 300 psia (Well 3)

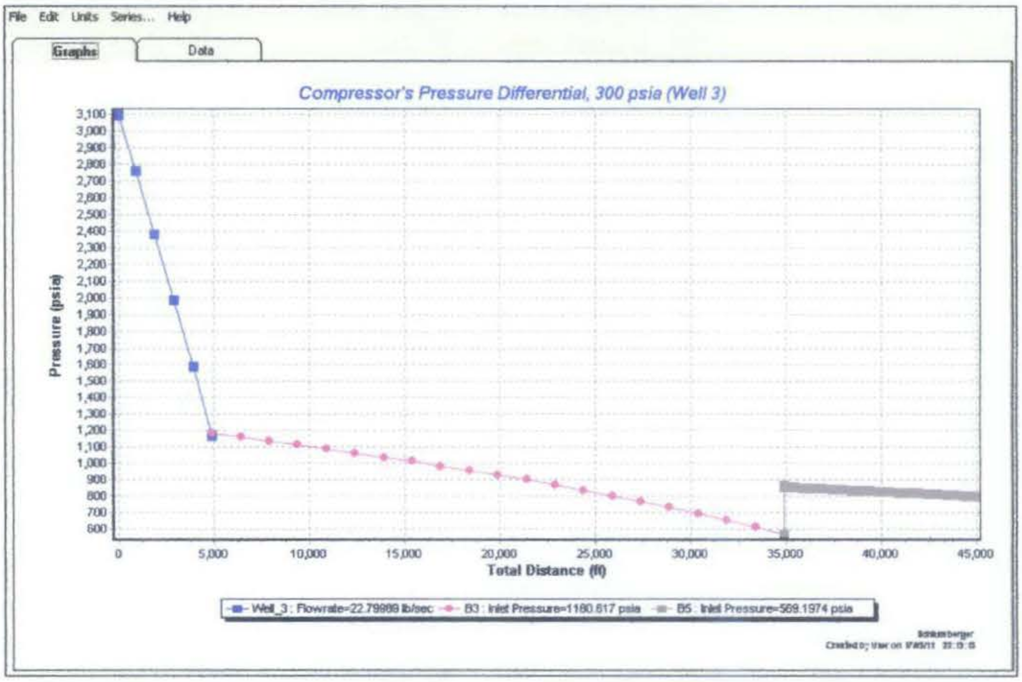


Figure 13: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 300 psia (Well 3)

4.2.4. Compressor's Pressure Differential, 400 psia (Well 1)

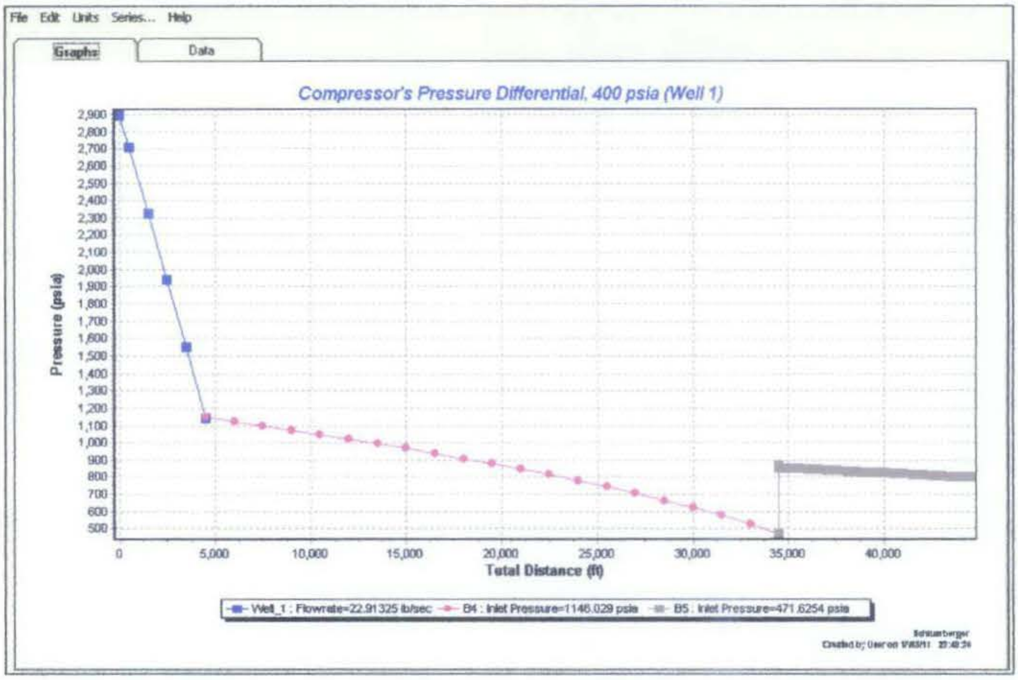


Figure 14: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 400 psia (Well 1)

4.2.5. Compressor's Pressure Differential, 400 psia (Well 2)

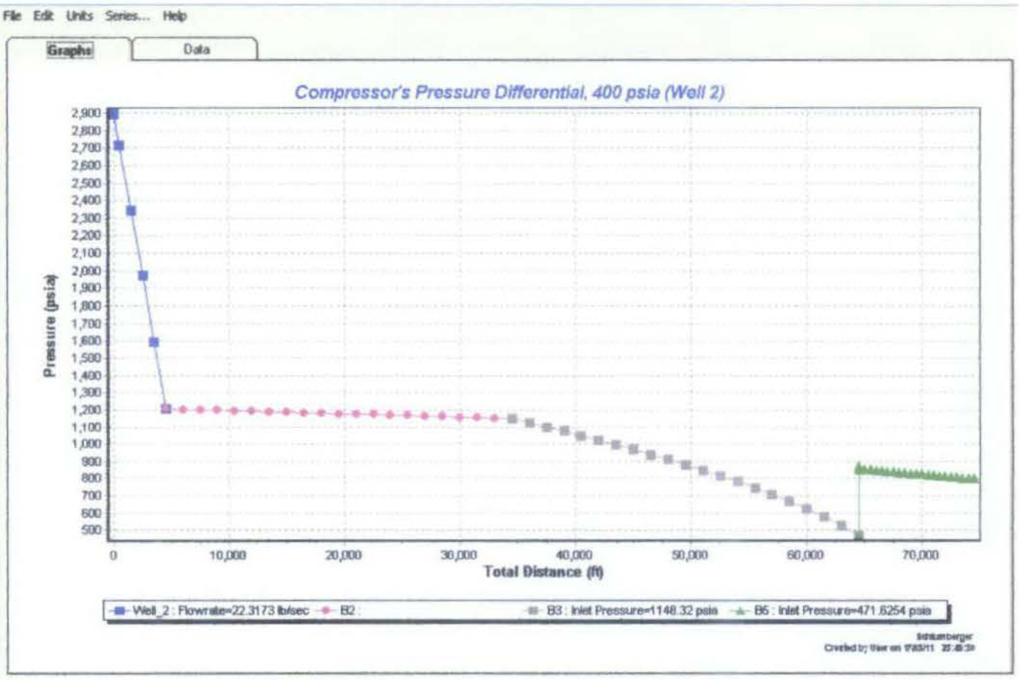


Figure 15: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 400 psia (Well 2)

4.2.6. Compressor's Pressure Differential, 400 psia (Well 3)

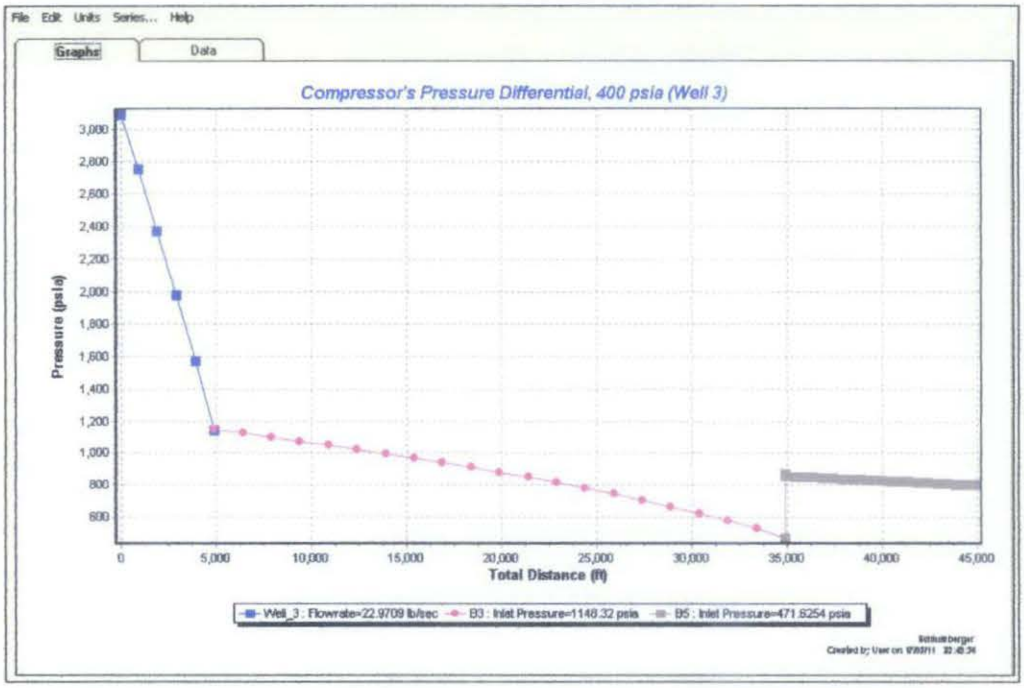


Figure 16: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 400 psia (Well 3)

4.2.7. Compressor's Pressure Differential, 500 psia (Well 1)

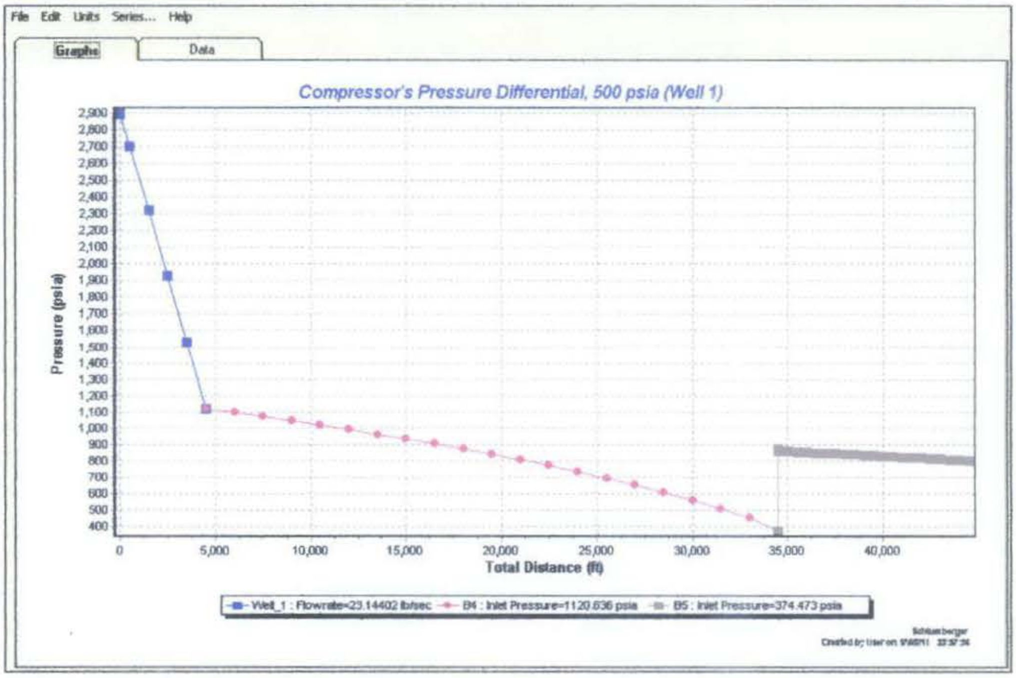


Figure 17: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 500 psia (Well 1)

4.2.8. Compressor's Pressure Differential, 500 psia (Well 2)

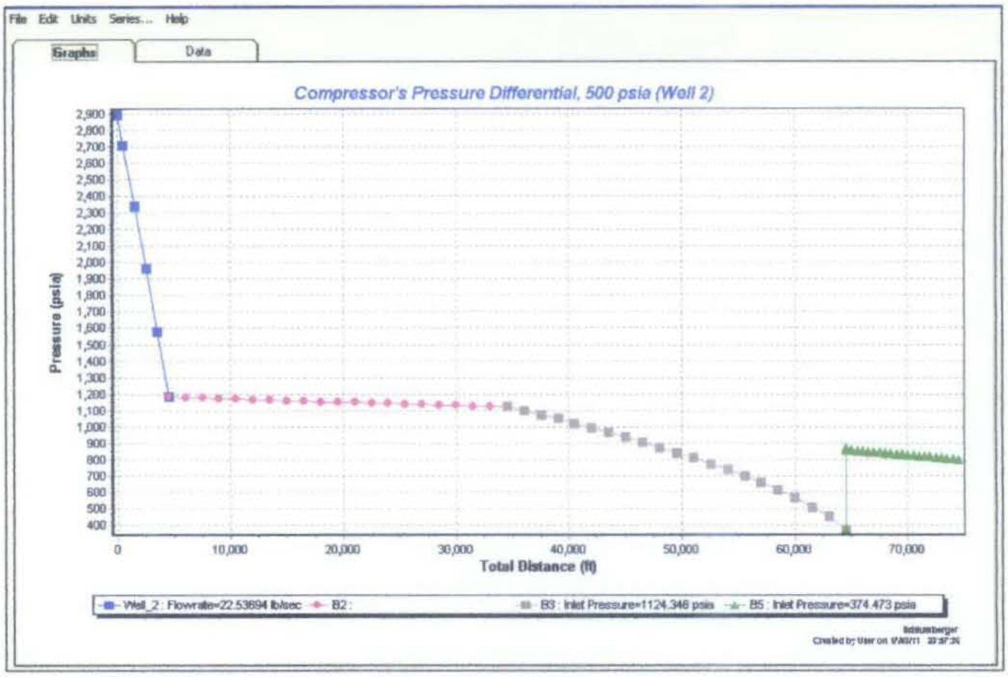


Figure 18: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 500 psia (Well 2)

4.2.9. Compressor's Pressure Differential, 500 psia (Well 3)

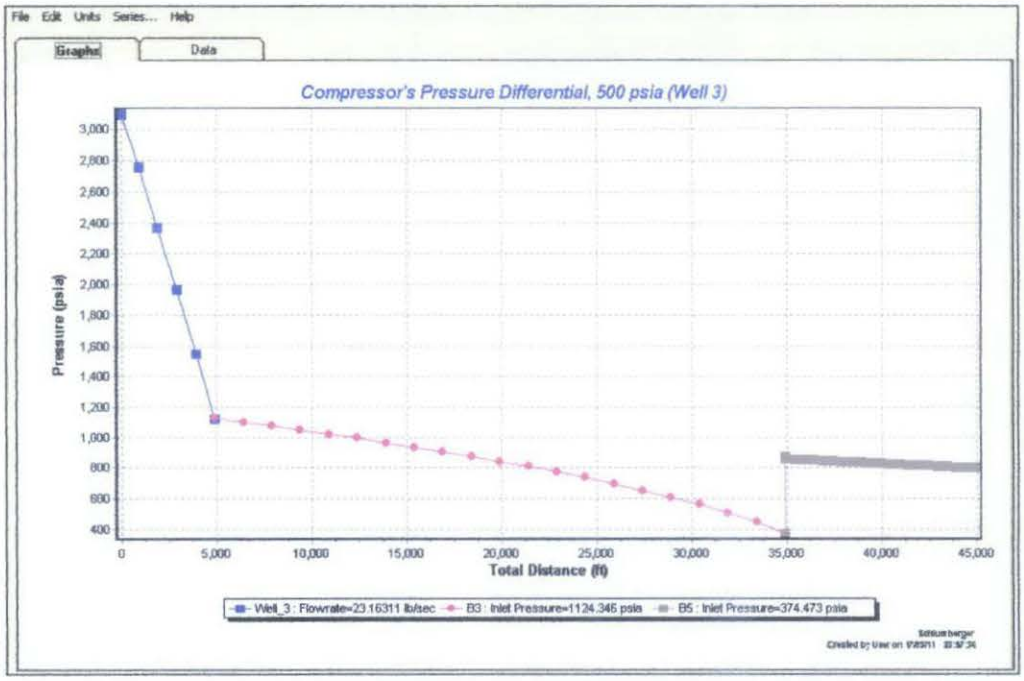


Figure 19: Pressure vs Total Distance graph for $\Delta P_{compressor}$ 500 psia (Well 3)

4.2.10. Compressor's Pressure Differential (Summary)

Compressor's Pressure Differential	Well 1		Well 2		Well 3	
300 psia	**Flowrate (lb/sec)**		**Flowrate (lb/sec)**		**Flowrate (lb/sec)**	
	22.73024		22.11267		22.79989	
	Inlet Pressure (psia)		**Inlet Pressure (psia)**		**Inlet Pressure (psia)**	
	B4 B5	1177.952 569.1974	B2 B3 B5	1227.3777 1180.617 569.1974	B3 B5	1180.617 569.1974
	Outlet Pressure at Sink = 800 psia					
400 psia	**Flowrate (lb/sec)**		**Flowrate (lb/sec)**		**Flowrate (lb/sec)**	
	22.91325		22.3173		22.9709	
	Inlet Pressure (psia)		**Inlet Pressure (psia)**		**Inlet Pressure (psia)**	
	B4 B5	1146.029 471.6254	B2 B3 B5	1205.7075 1148.32 471.6254	B3 B5	1148.32 471.6254
	Outlet Pressure at Sink = 800 psia					
500 psia	**Flowrate (lb/sec)**		**Flowrate (lb/sec)**		**Flowrate (lb/sec)**	
	23.14402		22.53694		23.16311	
	Inlet Pressure (psia)		**Inlet Pressure (psia)**		**Inlet Pressure (psia)**	
	B4 B5	1120.636 374.473	B2 B3 B5	1182.1574 1124.346 374.473	B3 B5	1124.346 374.473
	Outlet Pressure at Sink = 800 psia					

Table 8: Summary of well flowrate and junction inlet pressure.

4.2.10.1. Discussion

- From the result in the table above, it can be summarized that the increment of compressor's pressure differential lead to the decrement of inlet pressure for every junction, to reach the specified arrival pressure, which is in this case, 800 psia.
- On the other hand, every increment of compressor's pressure differential lead to the increment of well flowrate to reach the specified arrival pressure, 800 psia.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In conclusion, considering all the engineering analysis of a gas pipeline, after all, it is all about business. Pipeline designers are trying to minimize the cost by manipulating any variables, which at the same time to optimize the performance of a gas pipeline. Optimization of gas pipeline transmission design in this case is to manipulate the variables such as the pipeline diameter, thickness of insulation material, and the compressor's pressure differential. Of course there are a lot of variables need to be taken into consideration, but in terms of simplicity, these variables are made constant.

Based on the condensate pipeline in case study 1, only the 10", 12" and 14" diameter pipeline satisfy the need of targeted terminal pressure, which is 1000 psia. By knowing that the larger diameter of a pipeline, the higher the cost is, therefore 10" diameter pipeline is the most suitable pipeline diameter to be used. On the other hand, the insulation thickness is only manipulating the cost of the pipeline, and not interfering the terminal temperature in terms of engineering technology. It depends entirely on the locations of the pipeline, because cold weather places need more insulation compared to tropical weather. By referring to the result, only the 0.8" and 0.9" insulation thickness satisfy the need of targeted terminal temperature, which is 80ºF. By knowing that the thicker insulation of a pipeline, the higher the cost is, therefore 0.8" pipeline insulation thickness is the most suitable insulation thickness to be used. Based on the looped gas gathering network in case study 2, the higher the compressor's pressure differential, the higher the well flowrate and the lower the inlet pressure for every junction, to reach the specified terminal pressure, which is 800 psia.

Pipeline material grade in fact must be taken into consideration, provided that we have similar pipe internal diameter, but comes from different grade of material. This is because different grade has different mechanical properties and chemical composition, regardless of its size. Pipeline designers should select the best material at least cost, because the main point of this optimization is to improve performance and reduce the overall project cost.

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