Aneth Henry VEGULA DESIGN OF AN OFFSHORE PIPELINE FOR NATURAL GAS TRANSPORTATION: A CASE STUDY OF SONGOSONGO FIELD, TANZANIA MASTER THESIS 2023

NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF PETROLEUM AND NATURAL GAS ENGINEERING

DESIGN OF AN OFFSHORE PIPELINE FOR NATURAL GAS TRANSPORTATION: A CASE STUDY OF SONGOSONGO FIELD, TANZANIA

M.Sc. THESIS

Aneth Henry VEGULA

Nicosia

June 2023

NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF PETROLEUM AND NATURAL GAS ENGINEERING

DESIGN OF AN OFFSHORE PIPELINE FOR NATURAL GAS TRANSPORTATION: A CASE STUDY OF SONGOSONGO FIELD, TANZANIA

M.Sc. THESIS

Aneth Henry VEGULA

Supervisor

Prof. Dr. Cavit ATALAR

Nicosia

June, 2023

Approval

We certify that we have read the thesis submitted by Aneth Henry VEGULA, titled "**Design of an Offshore Pipeline for Natural Gas Transportation: A Case Study of Songosongo Field, Tanzania**" and that in our combined opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Applied Sciences.

Examining Committee	Name-Surname	Signature
Head of the Committee:	Prof. Dr. Salih SANER	....
Committee Member:	Prof. Dr. Dilek ARSOY	....
Supervisor:	Prof. Dr. Cavit ATALAR	....

Approved by the Head of the Department

02/07/2023

Prof. Dr. Cavit ATALAR

Head of Department

Approved by the Institute of Graduate Studies

02/07/2023

Prof. Dr. Kemal Hüsnü Can Başer

Head of the Institute

NEAR EAST UNIVERSITY INSTITUTE OF GRADUATE STUDIES 1988

Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of the Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Aneth Henry VEGULA

02/07/2023

Acknowledgments

Firstly, my sincere gratitude and respect to my thesis supervisor Prof. Dr. Cavit ATALAR for his guidance, support, and encouragement throughout the entire research process. His expertise and patience have been instrumental in shaping my work and helping me achieve my goals. I would also like to thank and appreciate Prof. Dr. Salih Saner, Assoc. Prof. Dr. Serhat Canbolat and all my instructors taught me both in class and online throughout my master's degree. I do appreciate all that.

Secondly, I would like to express my deepest appreciation to Miss Palang Moronke Guful for the guidance and assistance during my thesis from the start together with the simulation. I would also give my sincere appreciation to Prof. Dr. Dilek Arsoy for the time and suggestions in my defense as a jury member.

Finally, I would like to offer my deepest appreciation to my family, father, mother, brothers, and all TPDC (GASCO) workers especially the supervisor who has been a constant source of support, and motivation throughout my academic journey. Their unwavering encouragement and belief in me have been a driving force in my success.

Aneth Henry VEGULA

Abstract

Design of an Offshore Pipeline for Natural Gas Transportation: A Case Study of the Songosongo Field Tanzania

VEGULA, Aneth Henry

MSc, Department of Petroleum and Natural Gas Engineering

June, 2023, 66 pages

The offshore pipeline design located on the coast of Tanzania begins with a comprehensive analysis of the requirements including the designed pressure, flow rate, temperature, and pipeline diameter conditions. Different designs determine the flow assurance as the gas flows through the pipeline.

This design aims to determine and compare different pipeline properties of design scenarios such as pressure, temperature, gas flow rate, mass flow rate, pipe size of the current pipeline, and the simulation done in this research.

The PipeSim simulation model was used in research to determine the results needed. It facilitated the evaluation of various factors affecting the performance of the pipeline such as flow stability, compressibility effects, and pressure drop through the pipeline.

Finally, the simulated results such as pressure, temperature, flow rate, pipe size, and inside diameter of the pipe were compared with the proposed design and operating properties of the current pipeline. Showing the results of pressure drop and required temperature and also the phase envelope to reduce hydrate formation.

Keywords: Flowline, natural gas, pressure drop, hydrate, PipeSim.

Özet

Doğal Gaz Taşımacılığı İçin Sahil ilerisi Boru Hattı Tasarımı; Songosongo Sahası vaka çalışması, Tanzanya

VEGULA, Aneth Henry

MSc, Petrol ve Doğal Gaz Mühendisliği Bölümü

Hazirani, 2023, 66 Sayfa

Tanzanya kıyılarında yer alan sahil ilerisi boru hattı tasarımı, tasarlanan basınç, akış hızı, sıcaklık ve boru hattı çapı koşulları dahil olmak üzere gereksinimlerin kapsamlı bir analizi ile başlar. Farklı tasarımlar, gaz boru hattından akarken akış güvencesini belirler.

Bu tasarım, mevcut boru hattının basınç, sıcaklık, gaz debisi, kütle debisi, boru boyutu gibi tasarım senaryolarının farklı boru hattı özelliklerini ve bu araştırmada yapılan simülasyonu belirlemeyi ve karşılaştırmayı amaçlamaktadır.

Araştırmada ihtiyaç duyulan sonuçları belirlemek için PipeSim simülasyon modeli kullanılmıştır. Akış kararlılığı, sıkıştırılabilirlik etkileri ve boru hattı boyunca basınç düşüşü gibi boru hattının performansını etkileyen çeşitli faktörlerin değerlendirilmesini kolaylaştırdı.

Son olarak, basınç, sıcaklık, akış hızı, boru boyutu ve borunun iç çapı gibi simüle edilmiş sonuçlar, mevcut boru hattının önerilen tasarımı ve işletme özellikleri ile karşılaştırılmıştır. Basınç düşüşü ve gerekli sıcaklığın sonuçlarını ve ayrıca hidrat oluşumunu azaltmak için faz zarfını gösterir.

Anahtar Kelimeler: Akış hattı, doğalgaz, basınç düşüşü, hidrat, PipeSim.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

API:	American petroleum institute
CD:	Compact disc
CPTDC:	China petroleum technology and development corporation
***d*:**	Diameter of the pipe
***E*:**	Pipeline efficiency
Eq:	Equation
EWURA:	Energy and water utilities regulatory authority
***f*:**	Moody friction factor
GASCO:	Gas company
HDPE:	High density polyethylene plastic
ID:	Inside diameter
***L*:**	Length of the pipe
LRFD:	Load and resistance factor design format
OD:	Outside diameter
P_1**:**	Pressure at the source
P_2**:**	Pressure at the sink
PE:	Polyethylene
PP:	Polypropylene
PPF:	Polypropylene foam
PUF:	Polyurethane foam
***Q*:**	Gas flow rate

***Re*:**	Reynolds number
***S*:**	Specific gas gravity
***T*:**	Absolute temperature
TPDC:	Tanzania petroleum development corporation
***v*:**	Gas velocity
***z*:**	Gas compressibility factor
***ρ*:**	Gas density
***μ*:**	Gas viscosity

CHAPTER I

Introduction

Natural gas is an efficient and a cheap source of energy as it is a versatile fossil fuel that has a wide range of uses in residential, commercial, industrial, and transportation sectors. Natural gas is most commonly used for electricity generation, heating, cooking, transportation, and fertilizer production (Muhongo, 2013)

The natural gas pipeline can either be interstate or intrastate, depending on whether they cross state lines. They can also be transmission pipelines which transport large quantities of gas over long distances or distribution pipelines which deliver to end users. The design of pipelines is safe and several measures are included such as corrosion protection, pressure regulation, and emergency shut-off valves (Marfo et al., 2018). Natural gas pipelines are equipped with monitoring and control systems that continuously monitor the flow of gas and other parameters.

An offshore pipeline is used to transport oil and natural gas from offshore platforms to offshore facilities or other locations, as it is designed to withstand the harsh marine environment. Offshore natural gas transportation is an important part of the global energy industry as it allows the efficient and cost-effective transportation of natural gas from offshore production platforms to markets around (Kimambo, 1996).

The effects of the offshore pipeline depend on the location of the pipeline, the nature of the surrounding environment, and the measures taken to mitigate the impacts associated with the construction and operations. It can also lead to a change in the food chain hindering the economic development of regions on the coast that depend on fishing (Akhmetkaliyeva, 2020). The formation of hydrates can be particularly problematic in deep water or subsea gas pipelines where the water temperature is lower and pressure is higher. If there are impurities in the gas such as sulfur or carbon dioxide they can increase the hydrate formation. The hydrates can accumulate and block the flow of gas in the pipeline which can lead to operational issues, safety concerns even damage the pipeline (Marfo et al., 2018)

The Songosongo gas pipeline is a natural gas pipeline in Tanzania that runs from the Songosongo gas field to the state-owned Tanzania Petroleum Development Cooperation (TPDC) processing plant in Madimba. (Figure 1.1) (TPDC, 2012) shows the pipeline layout. The pipeline is approximately 207 km long and has a capacity of 140mmscfd. It is located on the coast of the southern part of Tanzania producing natural gas since 2004 and was discovered in 1974 (TPDC-GASCO, 2012). The pipeline has helped to provide a reliable and cost-effective source of energy for power generation and industrial use, reducing the country's dependence on imported fossil fuels and helping to support the expansion of key industries such as manufacturing and agriculture (Kimambo, 1996).

Figure 1.1 *General Layout of the Offshore Pipeline (TPDC, 2012)*

As of June 2020 the natural gas infrastructures installed in the country includes processing plants with a total processing installed capacity of 470 MMscf/d, transmission pipelines with installed capacity of 904 MMscf/d with 792 km long and distribution network with 320 MMscf/d as and combined 102.54 km length. By June 2020, natural gas contributed about 62.4% to the power generation. In addition, natural gas is used in other sectors such as industrial heating, commercial, institutions, as fuel for CNG-Vehicles and households (Muhongo, 2013)

Problem of Study

The TPDC Songosongo pipeline was constructed by a consortium of companies, the lead constructor for the project was China Petroleum Technology and Development Cooperation (CPTDC), a subsidiary of China National Petroleum Cooperation (CNPC). This construction was a major infrastructure project for Tanzania and it helped to establish the country as a regional leader in natural gas production and export (Lukonge & Cao, 2019). The current offshore pipeline system is designed by DNV-OS-F101 and its recommended design codes.

This design format is upon a limited state and partial safety factor methodology known as the load and resistance factor design format (LRFD) (TPDC-GASCO, 2012). DNV-OS-F101 is a technical standard that provides guidelines for the design, fabrication, installation, and operation of offshore pipelines. The standard covers pipeline materials, pipeline design principles, installation methods, and integrity management.

Load and Resistance Factor Design Format (LRFD) is a design method that is widely used in structural projects including offshore pipelines. LRFD method provides a standard format for designing structures that can withstand loads and stresses. It considers loads such as the weight of the pipeline, the weight of any fluids flowing through the pipeline, external environmental loads, and internal pressure loads.

PipeSim is a pipeline design software tool that is commonly used in the offshore oil and gas industry. It is designed to support the design of subsea pipelines including risers and flow lines. PipeSim provides features that allow engineers to design and analyze pipelines including route selection and optimization, pipeline design, structural analysis, and stability analysis. PipeSim takes into account the physical properties of fluids such as density, viscosity, and compressibility as well as the pipeline's geometry and operating conditions such as flow rate, pressure, and temperature. By simulating the behavior of fluid in the pipeline, PipeSim can provide valuable into the performance of the pipeline including pressure drop, flow rate, and temperature profiles (TPDC-GASCO, 2012).

Aim and Importance of the Study

This research aims to design the Songosongo pipeline using PipeSim, though there is a current pipeline which is ongoing but with the use of PipeSim we can determine the properties of the natural gas flowing through the pipeline, minimize the pressure drop of the fluid through it to optimize pipeline performance, to determine the phase envelope of different gas composition of Songosongo field and also to ensure that the pipeline is designed to meet safety and reliability requirements.

Limitations of the Study

The design of an offshore natural gas pipeline is a complex task that requires consideration of various factors such as flow rate, pressure, material properties, environmental factors, terrain, and safety. These limitations associated with such factors can impact the design, construction, and operation of the pipeline and must be carefully considered to ensure the reliability and safety of the pipeline. These limitations of the design of offshore natural gas transportation are as follows (Triantafyllaki et al., 2023)

- Safety limitations
- Regulatory limitations
- Technical limitations, these factors include water depth, seabed conditions, flow rate, temperature, pressure, and pipeline diameter.
- Environmental limitations, offshore pipelines, can be impacted by environmental factors such as weather conditions, natural disasters, and marine life.
- Cost limitations, the offshore transportation system projects can be expensive due to the complexity of the construction, design, and operation. This can impact the design decisions and material and equipment selection used in the construction of the pipeline.

Overview of Study

To briefly discuss how this project was carried out, the following guidelines were followed.

Chapter 1 is an introduction that provides an overview of the significance of natural gas as a clean and abundant energy source and also the need for an optimized pipeline design to ensure its efficient transport and also the limitation of the study.

Chapter 2 is the Literature review that examines the factors of the pipeline design, flow optimization technique, and the research that are related to this topic and establishes the basis for the research.

Chapter 3 describes the methodology of this paper applied. All the procedures and simulation software are discussed and shown in detail for this project. And all the pipeline study data used.

Chapter 4 are the results and discussions that were obtained on this research is shown. All the simulation results are analytical techniques used and show comparisons of different design scenarios.

Chapter 5 are conclusions and recommendations of this study. This chapter summarizes the conclusive remarks and suggests areas for future remarks and improvements too and some recommendations on the research.

CHAPTER II

Literature Review

This chapter of the research illustrates the various aspects of offshore pipeline design. The design is a critical infrastructure project that requires careful planning and design to ensure safety, efficiency, and reliability. The aspects of this design include the description below.

Background of Pipeline Designs for Natural Gas

Natural gas transportation pipeline is made from carbon steel designed to withstand high pressure varying from 35 bar to 150 bar to transport natural gas over long distances. Russia has the largest natural gas pipeline network with a total length of 171,000 km with more than 280 compressor stations. Currently drilling for gas is a routine in all offshore environments with major deep water (>200m) production areas (Cordes et al, 2016). China has more operational gas pipelines in the world with 226 functional pipelines and more 159 being under construction .In the United States, the transmission of gas systems is large by volume approximately 4.83 million miles for production to end users across the country. Canada has over 265,000 km of natural gas pipeline network from the west of Canada Fields to the eastern part of Canada and the USA. Although extensive research in two-phase flow has been conducted for the last 25 years, most of the research has concentrated on either horizontal or vertical flow (Beggs & Brill, 1973).

With recent discoveries of natural gas in Africa, Nigeria is the largest producer of natural gas in the west and Algeria also has the largest Natural Gas Pipeline Network in Africa with over 6000 km of pipelines exporting natural gas in the form of LNG to European countries such as Italy and Spain. In the Eastern part of Africa, the discoveries of Natural Gas are growing especially in Tanzania as the Pipeline system is limited. As there are only two main natural gas pipelines with a total of 542 km running from Songosongo and Madimba connecting at Somanga then the pipe runs to Dar es Salaam. Meanwhile, there is undergoing construction of a pipeline that is connecting Tanzania to Uganda (EWURA, 2020).

From the amount of gas being transported in the pipeline system and being stored, different potential hazards are expected in the projects such as leakages causing fire, pollution, and economic prejudice caused by gas leaking or spilling. Therefore, this is the basis for designing and executing measures to prevent hazards such as regular maintenance and inspections, emergency response plan, cathodic protection, pressure control, and leak detection systems (Chukwuma et al., 2022).

The design of a pipeline has been researched by different people talked about the optimal design of an offshore natural gas pipeline system in the selection of pipe diameter to minimize the operational costs and minimum cost of network structures. (Kimambo, 1996) did research on the modeling of a line break in high-pressure gas pipes by the use of Quant software to analyze the flowing line break in the natural gas pipeline.

Flow Assurance

Flow assurance ensures that natural gas flows smoothly and safely through pipelines from the reservoir or the source to the end user. This involves a range of engineering activities and techniques to manage the risks associated with the transportation of gas including maintaining the pressure, temperature, and composition of the gas within acceptable limits. Flow assurance activities begin with the design and construction of the pipeline infrastructure. This includes the selection of appropriate materials, insulation, and coating to ensure that the pipeline can withstand the corrosive effects of gas over time as well as the installation of valves, sensors, and other equipment that enable the safe and efficient operation of the pipeline. Advanced modeling techniques are also used to stimulate the behavior of the pipeline and identify potential issues before they occur (Zhang et al., 2017).

In addition to monitoring the pipeline, offshore gas pipeline assurance also involves the maintenance of equipment used in the gas production and transportation process. This includes the inspection and maintenance of valves, compressors, and other equipment used to regulate gas flow and maintain the pressure of gas within acceptable limits (Bai & Bai, 2005).

Hydrate Formation in the Pipeline

In the gas and oil industry, hydrate formation is a significant challenge for offshore gas production, as it can cause blockages in production equipment and pipelines leading to safety risks, operational downtime, and reduced production efficiency. Hydrates are solid crystalline compounds that form when water and natural gas combine under certain conditions that form when water and natural gas combine under certain conditions of pressure and temperature (Chukwuma et al., 2022). They can accumulate within production equipment and pipelines, obstructing the flow of gas and causing damage to the equipment.

The hydrate formation is influenced by several factors including water content, gas competition, temperature, and pressure. The presence of water in the gas stream is a critical factor in hydrate formation as the water can combine with the natural gas to form hydrates under the right conditions. The composition of the gas stream including the concentration of hydrocarbons and other components also plays a role in hydrate formation (Guo et al., 2016).

Hydrate mitigation and remediation

Hydrates are solid crystals that form when natural gas or other hydrocarbons combine with water at high pressure and low temperatures, obstructing the pipeline flow and potentially damaging the infrastructure. Mitigation and remediation strategies for hydrate formation in offshore pipelines include the following (Bai & Bai, 2014).

1. Heat tracing; this is a method of heating the pipeline to prevent the formation of hydrates. Heat tracing involves wrapping the pipeline with electric or steam heating cables that provide a constant source of heat to keep the pipeline above the hydrate formation temperature.
2. Insulation; This helps to maintain the pipeline temperature by insulating materials that can be added around the pipeline to retain heat.
3. Chemical inhibition; this is added to the natural gas or other hydrocarbons to prevent hydrate formation. These chemicals change the conditions under which hydrates can form such as altering the pressure, temperature, or concentration of water.
4. Methanol or glycol injection; these are injected into the pipe to dissolve hydrates that have already formed, preventing further blockages. This process also helps to lower the freezing point of water, reducing the risk of hydrate formation.
5. Pigging; Pigs are devices that are inserted into the pipeline and pushed along by the flow of gas. These devices can scrape the inside of the pipe and remove all the hydrates formed, leaving the pipe clean.

Pipeline Design Consideration

Factors influencing pipeline design

When constructing a pipeline, especially a long-distance pipeline, many factors are considered to ensure the pipeline is safe, efficient, and cost-effective. These factors are such as pipeline material, diameter, length, and operating pressure since they determine the thickness and strength of the pipeline material required to withstand the pressure (Ozi et al., 2020). Fluid properties such as temperature, pressure, density, and viscosity due to the operating conditions and safety of the pipeline operating pressure, environmental factors, and climate can also impact the pipeline design.

Offshore Pipeline

The design life of the Songosongo to Somanga pipeline system is 30 years. Pipe wall thickness and steel grade are determined to meet the pipeline in-place design, buckling criteria, and installation criteria by following DNV-OS-F101. A wall thickness of 22.23 mm, with steel grade X65, is selected, which meets the requirements of DNV-OS-F101, referring to Wall Thickness Design Report for Offshore Pipeline (TPDC-GASCO, 2012).

Design Parameters

The design parameters of the proposed offshore pipeline system are summarized in Table 2.1 (TPDC, 2012)

Table 2.1. The Designed Parameters for the Proposed Pipeline (TPDC, 2012)

Description		Units	Parameters
Outside diameter		Mm (Inch)	610 (24)
Pressure Reference height (C.D.)		M	7
Installation temperature		˚C	21
Internal Corrosion Allowance		Mm	0
Operation Condition	Content type	-	Natural Gas
	Maximum Operating Temperature		50
	Design Temperature	˚C	55
	Design Pressure @ Reference Height	MPa	9.7
	Content Density	Kg/m^3	75
Hydro test Condition	Hydro test Pressure @ Reference height	MPa	11.20
	Contest density	Kg/m^3	1022
	Temperature	˚C	28

The pressure reference height of pressure is conservatively taken as 7 m (C.D) to account for the elevation of the onshore part pipeline. The content is dry gas and no corrosion allowance is required as per DNV-OS-F101 which is also consistent with the onshore pipeline. Hydrotest pressure is taken as 1.55 times the design pressure as per DNV-OS-F101. Hydrotest content density is assumed to be equal to the seawater density.

Equations Required in Pipeline Design

The equations derived to calculate gas flow in pipes are based on fluid mechanics and thermodynamics principles. The most commonly used equations for calculating gas flow in pipes are the Weymouth Equation and the Panhandle Equation.

Weymouth Equation (Eq 2.1) is based on the principle of energy conservation which states that the energy of the fluid must remain constant throughout the pipeline. This equation is typically used for natural steady flows and the pipeline is assumed to be horizontal (Bejanaro, 2021).

The Weymouth Equation is given by:

$$Q = 1.1\,\mathrm{d}^{2.67}\left(\frac{p_1^2 - p_2^2}{LSZT_1}\right)^{1/2} \qquad 2.1$$

Where:

Q = Natural gas flow rate in (MMscf/d)

$P_1{}^2 - P_2{}^2$ = Change in pressure drop (ΔP) in the pipeline (in Pascals or psi)

L = Length of the pipeline between 1 and 2 (in kilometers)

d = Inside diameter of the pipe (in millimeters or inch)

T_1 = Base temperature, temperature at standard conditions (in ˚C or ˚F)

S = Specific gravity of gas (air=1)

Z = Compressibility factor of the natural gas at the average temperature and pressure of the gas in the pipeline.

This equation also assumes that the gas is ideal with a constant specific heat ratio.

Panhandle equation (Eq 2.2) is another commonly used equation for calculating gas flow in pipelines and is more accurate for high flow rates and large pipe diameters where turbulent flow is more likely to occur. This is based on the roughness of the pipe surface and is dimensionless.

$$Q = 0.028E\left(\frac{p_1^2 - P_2^2}{s^{0.961}ZTL_m}\right)^{0.51d^{2\cdot 51}} \qquad 2.2$$

Where:

Q = Natural gas flow rate in (MMscf/d)

${P_1}^2 - {P_2}^2$ = Change in pressure drop (ΔP) in the pipeline (in Pascal or psi)

E = Pipeline efficiency ranging from 0.85 to 1 (dimensionless)

S = Specific gravity of gas (air=1)

Z = Compressibility factor of the natural gas at the average temperature and pressure of the gas in the pipeline.

T = Temperature at standard conditions (in ˚C or ˚F)

d = Inside diameter of the pipe (in millimeters or inch)

L_m= Length of the pipeline between 1 and 2 (in kilometers)

Reynolds Number and Moody Friction Factor

Reynolds Number (Eq 2.3) is a dimensionless parameter that is commonly used to describe the flow regime in pipelines. It is used to determine the nature of the flow, whether it is laminar or turbulent and to predict the pressure drop and other flow properties.

$$R_e = \frac{\rho v d}{\mu} \qquad 2.3$$

Where:

ρ= Density of gas (in kg/m^3)

Re = Reynolds Number (dimensionless)

v = Velocity of gas (in m/s)

μ = Fluid dynamic viscosity (in kg/m.s)

d = Pipe diameter (in meters)

Re for gases can be expressed as Re=20,100

Moody friction factor describes the number of frictional losses in a pipe. It is a function of Reynolds number, roughness of the pipe, and pipe diameter (Lockhart & Martinelli, 1949). The moody friction factor is typically obtained from a moody diagram or empirical correlations based on experimental data.

The moody friction factor decreases with the increase of Reynolds number for turbulent flow Re>4000, while for laminar flow the friction factor is independent of the Reynolds number and is proportional to the pipe roughness Re<2000 (Watts, 2015). The moody frictional factor is expressed as f=64/Re. The moody fractional factor depends on the relative roughness and Reynolds number where the relative roughness is the ratio of absolute roughness E and pipe internal diameter D (Kimambo, 1996).

Pressure Drop for Gas Flow.

The general equation for gas flow calculation is as follows

$$p_1^2 - p_2^2 = 25 \cdot 5 + \left(\frac{SQZTfL}{d^5}\right) \tag{2.4}$$

Where:

$P_1{}^2 - P_2{}^2$ = Change in pressure drop (ΔP) in the pipeline (in Pascals or psi)

f = Moody friction factor, (dimensionless)

S = Specific gravity of gas (air=1)

Q = Natural gas flowrate in (MMscf/d)

Z = Compressibility factor of the natural gas at the average temperature and pressure of the gas in the pipeline.

T = Flowing temperature, (in ˚C or ˚F)

L = Total length of the pipe (in kilometers)

d = Pipe diameter (in meters)

This is assumed for a steady state flow and f is a constant function of length (Watts, 2015).

One of the primary factors that affect the pressure drop is pipeline diameter. As the diameter of the pipeline decreases, the pressure drop will increase. This is because the gas has to flow through a smaller area, which increases its velocity and causes more frictional losses.

The length of the pipeline is also a significant factor, as the pipeline length increases the pressure drop will also increase because the gas has to overcome more resistance to flow through the pipe. (Watts, 2015).

The roughness of the pipeline's internal surface is another critical factor. The rougher the surface, the more frictional losses there will be, which will increase the pressure drop.

The gas velocities also determine the pressure drop, higher gas velocities will result in higher pressure drops because the gas has to overcome more resistance to flow through the pipeline.

The properties of the gas being transported can also affect pressure drop. The density and viscosity of the gas impact the resistance to flow and increase pressure drop. It is essential to consider all of these factors when designing and operating an offshore gas pipeline to ensure that pressure drop is minimized, and the pipeline operates efficiently and safely. (Watts, 2015).

Pipeline Insulation

Insulation of gas pipelines is an important consideration to minimize heat loss and maintain the temperature of the gas within the pipeline, especially in cold environments where the seawater temperature is low figure insulation helps to prevent the formation of wax and hydrates which can clog the pipeline and cause flow disruptions.

The requirements of insulation materials depend on several factors such as temperature, pressure, heat capacity, location of the pipeline, and the desired level of insulation. Therefore, this design can provide additional insulation compared to single-layer insulation methods and is often used for higher temperature or cryogenic applications. Some common insulation materials used for pipe in pipe design include polyurethane foam (PUF), mineral wool, cellular glass, phenolic foam, polypropylene (PP), and polypropylene foam (PPF).

In addition to reducing heat loss, pipeline insulation can also provide other benefits, such as noise reduction and fire protection (Zulkefli & Pao, 2016). However, proper installation and maintenance of thermal pipeline insulation are critical to ensure it is effective over the lifetime of the pipeline system. Regular inspection and testing are necessary to detect and address any potential issues such as insulation damage, water ingress, or corrosion.

Climatic Condition

The offshore pipeline project area, located in the northeastern Lindi region, belongs to the tropical marine monsoon climate.

The annual average temperature is 26.1˚C, with annual average maximum and minimum temperatures of 30.5˚C and 21.7˚C, respectively. Maximum air temperature average 31˚C and peaks during the summer months (November to April). Minimum values average 19 ˚C and peak during the winter months from June to August. Usually, there is one rainy season in the offshore pipeline project area from December to April, centered on December, January, February, and March. Annual rainfall is 1050 mm (TPDC-GASCO, 2012).

Seawater Properties

Salinity values range from an average low of 32.5% to a high of 37.5%. The value increases towards the sea bottom but the differential is less than 1% (TPDC-GASCO, 2012)

The seawater properties are as shown in Table 2.2 below.

Table 2.2. Sea Water Properties

Description	Value	Unit
Density	1022	Kg/m^3
Kinematic Viscosity	1.51×10^{-6}	M^2/s
Specific Heat Capacity	4200	J/kg°K
Thermal Conductivity	0.5	W/m°K

Geological Condition

Geological data is extracted from Songosongo to Somanga offshore route Geotechnical Investigation Report, Doc No TNGP-ODE-GT-RP-5008.

Seabed Feature

The results of field investigations indicate a generally regular sea bottom profile with a small grade in the western area heading to the Somanga shoreline. However, in the eastern part of the pipeline route, and particularly those adjacent to a deep trough identified in the southern area of the pipeline corridor, sea bottom grades increase marked.

Soil Shear Strength

The shear strength of the soil is an important factor since it can affect the safety and stability of the pipeline, especially in areas with waves, soil erosion, and high current. In determining soil shear strength, various geotechnical investigations and laboratory tests were conducted including shear strength testing, core drilling, and soil sampling. The collected data is then analyzed to determine the shear strength of the soil (TPDC-GASCO, 2012). This is used to determine the thickness of the pipeline to withstand external loads such as wave and current forces as well as the maximum allowable pipeline burial depth to ensure stability and prevent excessive bending. Also is used to design anchoring systems and pipeline supports to ensure the pipeline is secured in place always.

Selection of External Anti-Corrosion Coating

An Offshore pipeline is laid on the seabed, and the corrosion can be quite severe, so the requirements for external anti-corrosion coating are very demanding. The external anti-corrosion coating is required to possess overall performances such as resistance against seawater, bacteria, and sea biological erosion, and impact, good soaking performance, low water permeability, strong adhesion with steel pipes, easy coating, abrasion resistance, good electrical insulation and good resistance to cathode stripping and easy mending (TPDC, 2012).

External anti-corrosion coating applicable to offshore pipelines mainly includes internal fusion bonded epoxy coating and 3-layer PE. There properties are presented as follows:

Fusion Bonded Epoxy Powder

Advantages are such as good bond strength with steel pipe, good corrosion resistance, high mechanical strength, anti-cathodic stripping performance, wide range of application temperature and lower cost for prefabrication (TPDC-GASCO 2012).

Disadvantages are susceptible to damage during lifting, transportation, and construction, it is not easy to patch cut, limited impact resistance, porous materials are formed upon reaction and curing of epoxy powder, the section porosity, adhesion face porosity, and water absorption are rather high, and bubbling is possible upon long-term immersion in water. The current density requiring protection is much higher than the 3-layer PE coating (TPDC-GASCO 2012).

3-Layer PE

Three-layer PE anti-corrosive coating has advantages such as good insulating properties, low water absorption, high mechanical strength, tenacity wear resistance, acid, alkali, and salt resistance, bacterial corrosion resistance, temperature change resistance, and adequate supply of material (TPDC-GASCO 2012).

HDPE has resistance to bacteria and microbial, yet excellent resistance to seawater soaking. The current density for pipes with 3-layer PE anti-corrosive coating is quite small, and the operating costs are relatively low. 3-layer PE has advantages of both fusion-bonded epoxy and polyethylene, such as strong adhesive force, resistance to cathode stripping, and impact resistance. Moreover, the cost is low in the long term. A single layer of epoxy power is not enough for corrosion prevention for offshore pipelines because of its relatively high water absorption rate. Hence, it is strongly suggested that 3-layer PE be used in a single project to achieve a long service life of the pipeline (TPDC-GASCO 2012).

Cathodic Protection

Considering cathodic protection range and offshore pipeline security, insulation devices and cathodic protection test pile will be installed between the offshore pipeline and onshore pipeline. Test pile can be used to test the pipeline cathodic protection effect. Based on the past engineering experience of offshore pipeline design, it is recommended that bracelet aluminum anode be used for cathodic protection in this project. The offshore section protected by cathodic protection system must be electrically isolated with the onshore section using insulation joint.

Compared with the zinc anode, the aluminum alloy has different advantages such as

1. Theoretic quantity of power generation is great, and the price of aluminum anode is quiet cheap compared to the price of the output power.
2. In seawater and mud, the aluminum anode whose closed potential maintained at level of -1.05V or 1.00V, perform well, corrode uniformly and have functions of automatic regulation of electricity when protecting steel pipelines.
3. Large capacity in power generation from aluminum anode, suitable for manufacturing long service life anode.
4. Small density, light weight and easy installation: rich in aluminum resources, among which any aluminum with purity of more than 99.7% can be used as anode material.

Therefore, aluminum-zinc-indium alloy, of semi-open bracelet type is recommended to be used as the sacrificial anode for submarine pipelines.

Pipeline Route Selection

Selecting the optimal pipeline route for the natural gas transportation involves several critical considerations to ensure the safety, efficiency, and cost effectiveness of the project. The following criteria have been taken into consideration, where appropriate in the selection of the pipeline routes:

1. Minimizing the pipeline route from Songosongo to Somanga.
2. Avoid environmentally sensitive and coral reef area, if possible.
3. Appropriate separation shall be maintained where the pipeline is installed adjacent or parallel to an existing pipeline.
4. The route should be technically accepted and approved by TPDC.
5. Avoid underwater installation and debris.
6. Minimize the number of pipeline crossings when applicable.

In some cases, this may not be achievable due to site constraints, while every effort will be made to satisfy the above criteria.

Related Work Summary

There are different researchers on the design of natural gas pipelines such as Marfo et al., (2018) in the Gazelle field in Cote d'Ivoire. The condition of hydrate to be formed was predicted and simulated to be 65˚C and designing thermal insulation to minimize hydrate formation. Lukonge & Cao (2019) in Tanzania, the transportation and distribution system of natural gas replaced LPG, the aim was to design a natural gas distribution network for supplying clean and safe natural gas for transport, residential, industrial and commercial needs. Mohamed et al., (2022) in Malaysia in understanding the behavior of mercury and distribution in the various streams also mitigating the adverse effects of mercury found in production fields which include the evaluation on the requirement for mercury treatment facility and suitable technology and best location for the production fields and onshore LNG facilities.

Chukwuma et al., (2022) in Nigeria, on optimizing natural gas pipeline design to prevent hydrate formation during gas transportation, the average temperature of 94.03˚C along the pipeline was successful through the rise in temperature at the outlet and inlet of the pipeline. Ozi et al., (2020) on prediction of pressure drop in subsea pipeline using PipeSim software, a 64km subsea pipeline with two sections of inside diameters.

Most of these researches are based on the design of natural gas pipelines and the use of PipeSim and the formation of hydrates. Okologume & Appah, (2015) in Nigeria. This research was about analyzing thermal insulation for effective hydrate prevention in the design of subsea pipelines. In this research, a flow line software model was used in analyzing the thermal insulation thickness and prevention of hydrate. The analyzed result was applied to the pipeline and case study system using PipeSim simulator software. Triantafyllaki et al., (2023) research the design of offshore gas pipelines against the active tectonic fault movement. This paper allows the prediction of critical co-seismic fault displacement.

This research shows the flow rate reports for the years 2018/2019 and 2019/2020 according to EWURA (2020) the report was prepared by Energy and Water Utilities Regulatory Authority so as to determine yearly nominations, performance and consumptions by natural gas field in Tanzania. This project was done using the proposed design following DNV-OS-F101 and the recommended design codes.

CHAPTER III

Methodology

This project was done using the pipeline simulation model and the particular type used was PipeSim software. Secondary data was collected from Tanzania Petroleum Development Cooperation (TPDC) which is the gas composition, gas entry pressure, and gas properties. Computer simulation is the methodology used in this study. This chapter firstly talks about the use of PipeSim software that was applied to design and simulate the pipeline. Different pipeline properties and design parameters such as pressure, temperature, gas flow rate, velocity, pipe size, and thickness are used to compare the current pipeline design. Finally, different scenario applications were analyzed to get the best result for the design pipeline. This section shows the application of PipeSim in detail and procedures.

PipeSim Simulation

The PipeSim model is a steady-state multiphase stimulator used for simulating and modeling fluid flow in pipelines and networks. This software simulates both multiphase and single phase (Wilfred & Appah, 2015). PipeSim uses a comprehensive set of modes to simulate the flow of natural gas through the pipeline. These modes include flow equations, fluid properties, and heat transfer equations. The results in the simulation are used to analyze a variety of pipeline performances such as flow rate, pressure drop, and temperature. PipeSim can also model the effects of pumps, valves, compressors, and heat exchangers. To run the PipeSim simulation, input data from TPDC is required for the study.

The data of the composition of Songosongo natural gas from TPDC-GASCO is shown in Table 3.1 and the design parameters of the proposed offshore pipeline system as shown in Table 3.2 as the boundary conditions and Table 3.3 as the study data for pipeline insulation.

Pipeline data used in the model

Table 3.1. *Composition of Songosongo Natural Gas (TPDC-GASCO, 2012)*

Natural Gas Component	% Mole
Methane	97.960
Ethane	0.96135
Propane	0.13414
iso-Butane	0.02223
n-Butane	0.02901
iso-Pentane	0.00403
n-Pentane	0.00320
Hexanes	0.00250
Carbon Dioxide	0.35700
Nitrogen	0.55648

Table 3.2. *Boundary Conditions (TPDC-GASCO, 2012)*

Parameters	Description	Unit
Fluid inlet pressure at the satellite platform	7.3	MPa
Fluid inlet temperature at satellite platform	32.8	˚C
Design fluid flow rate	140	MMscf/d
Min arrival pressure	7.3	MPa
Min arrival temperature	30.0	˚C

Table 3.3. *Study Data for Pipeline Insulation (TPDC-GASCO, 2012)*

Parameters	Description	Unit
The horizontal length of the pipe	27	Km
Inner diameter ID of the pipe	565.54	mm
Wall thickness	22.23	mm
Pipe thermal conductivity	0.0275	Kcal/hmc
Ambient fluid	Water	
Burial depth	1.5	M
Ambient temperature	21	˚C
Linear thermal expansion coefficient	1.17×10^{-5}	1/˚C
Insulation thickness	3.2	mm

Pipesim Simulation Procedure

The PipeSim software includes the main application form and the child form (Ozi et al., 2020) .The main application form is the primary user interface that provides access to the software's functions and features as shown in Figure 3.1. This form holds other forms such as the toolbar, navigation pane, property editor, graphs, and tables.

The Child form in the PipeSim software is a window that contains a specific set of functions and tools (Marfo et al,. 2018). This is accessed from the main workspace to view more specific types of data. Child form includes component properties, simulation of the flow, and network configuration. Child form can be made to display different types of information and results, it depends on the user's preferences.

From the main application and workspace form, the source, sink, and junction are added from the insert form and internal nodes to connect the pipeline. The source is where the gas starts flowing in PipeSim pipeline and the junction is the connection between the sink. The sink is the end of the flow line in pipeline. After adding the source, junction, and sink, the junction acts as a compressor. The compressor increases the pressure because of the pressure drop due to the friction caused by the gas flow and pipe therefore leaving the flow lines to be from source to compressor and compressor to sink.

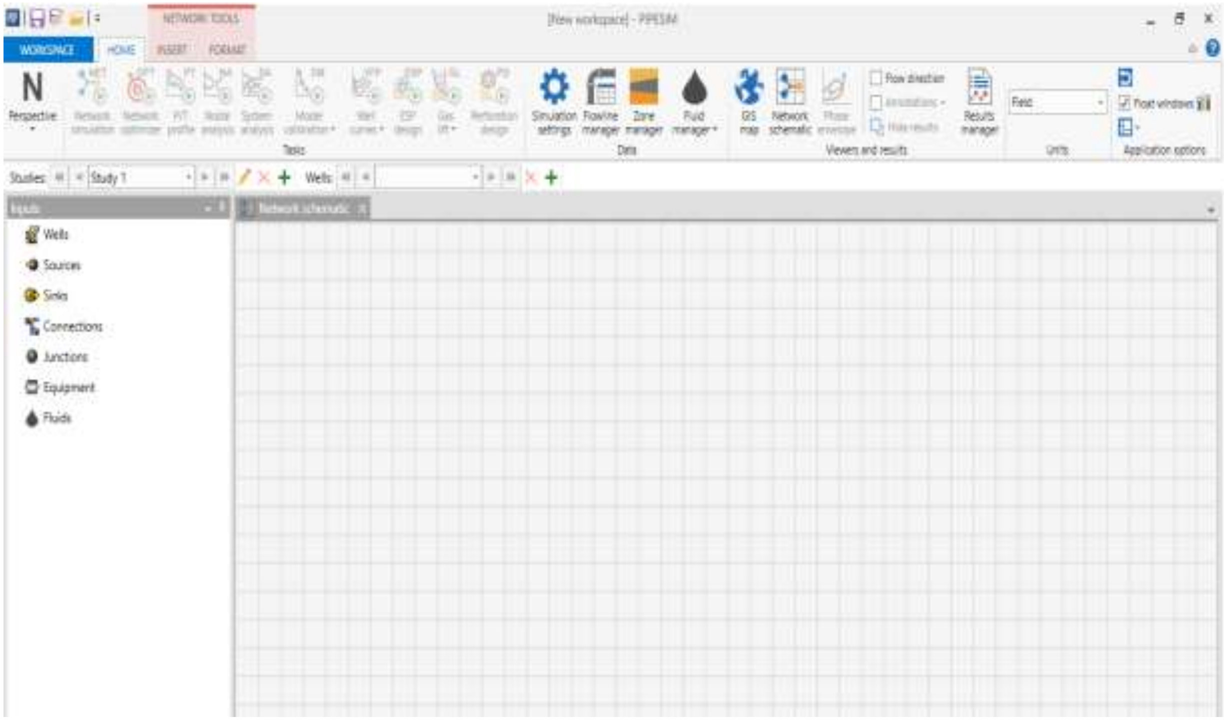


Figure 3.1. Main Application and Child Forms (PIPESIM, 2022)

From the fluid manager on the main application, the home in the menu bar edits fluid and shows calculation methods. Selecting compositional to build fluid components. From the models on the menu form, choosing pedersen for viscosity, multiflash for PVT package, volume shift correlation and thermal coefficient correlation, 3-parameter Peng-Robinson (1976) for Equation of state, Kesler-Lee for Critical property correlation, and Acf correlation. Selecting none to the salinity model and pure components from the fluid components on the table. Choosing the hydrocarbon components by adding new to enter more properties.

By renaming the flow line and editing it to the pipe details and subsea environment. Secondary data is obtained by filling out the pipe data, that is the inside diameter, roughness, and wall thickness as shown in Figure 3.2. The profile data includes the horizontal distance and burial depth. The heat transfer data from the (TPDC-GASCO-2012) is added together with the velocity and calculated. Identifying pipe flow line coating details too as shown in Figure 3.3 below.

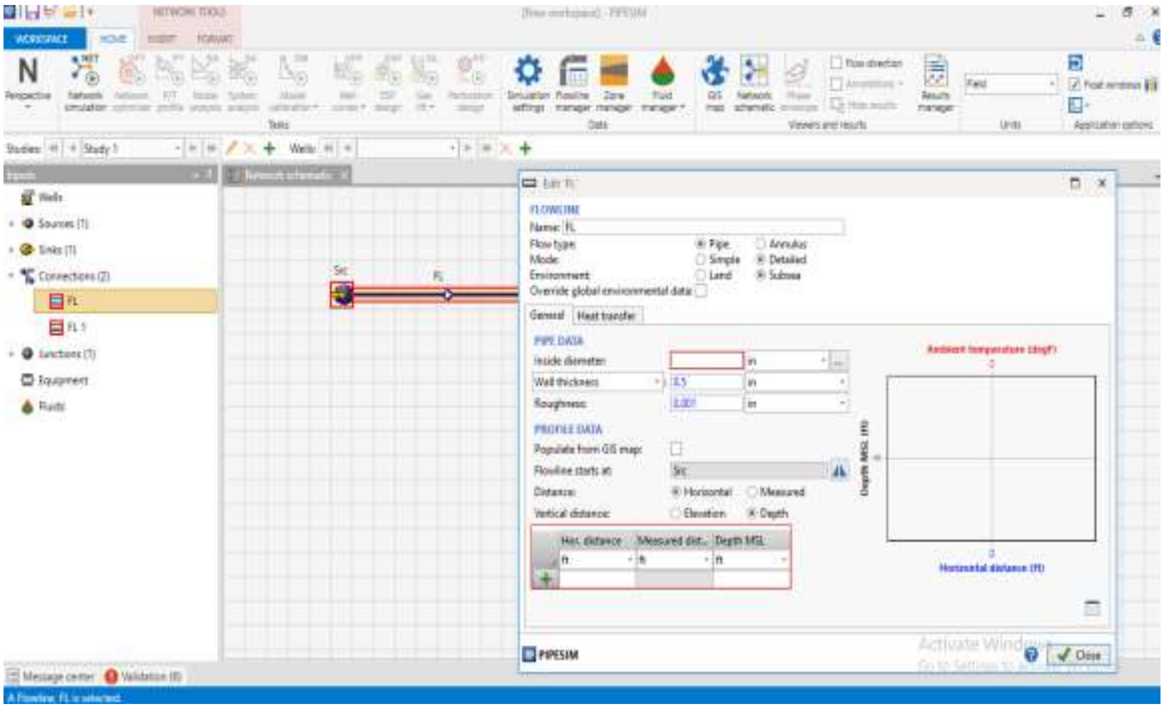


Figure 3.2. Specifying Flowline Details (PipeSim, 2022)

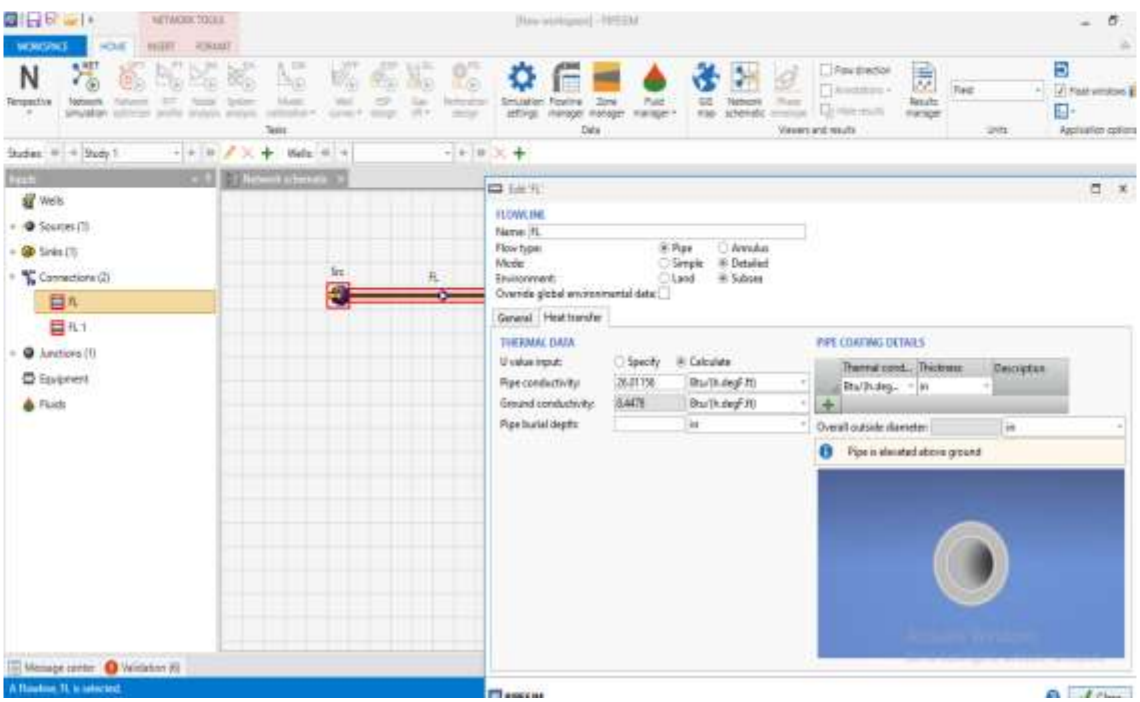


Figure 3.3. Specifying Heat Transfer Details (PipeSim, 2022)

From the source, editing the pressure/flow rate boundary conditions that is the pressure, temperature, and fluid flow rate, this helps to calculate different flow rate nominations as in Figure 3.4.

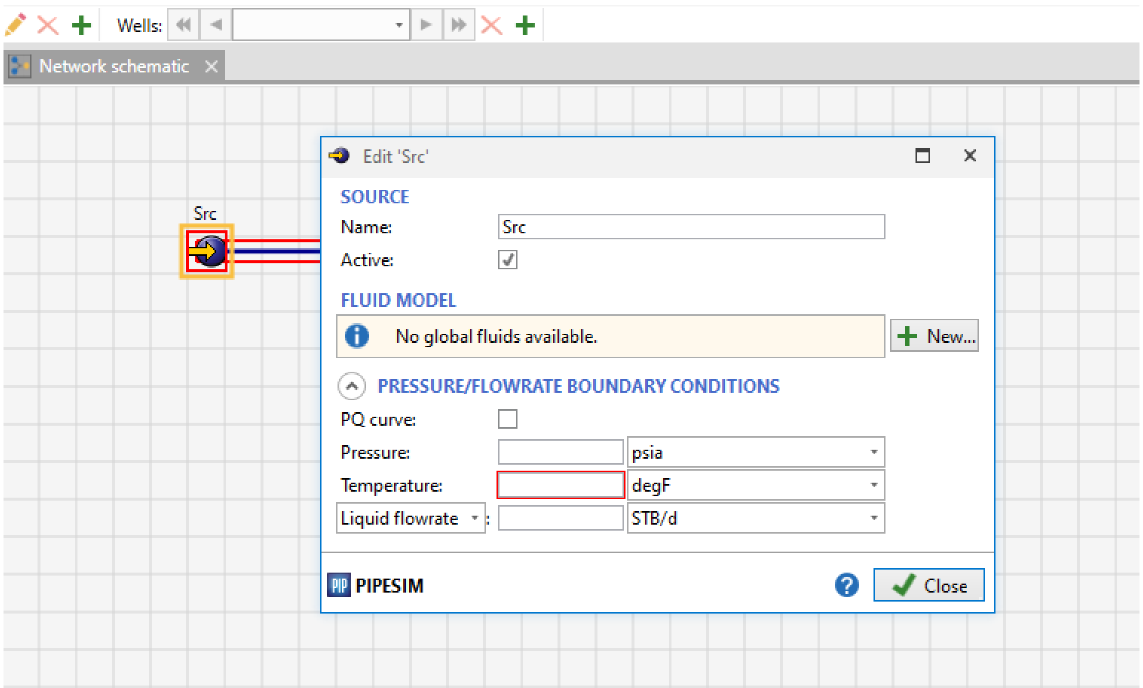


Figure 3.4. Specifying Inlet Conditions (PipeSim, 2022)

On the workspace menu bar, network simulation and initial conditions of the gas are added to run the simulation, and the different profile results will be obtained from pressure against horizontal distance. The results will be shown below and can be viewed in graphs or tables. The pipeline simulation network with the compressor and the flow line from the PipeSim is shown on Figure 3.5.

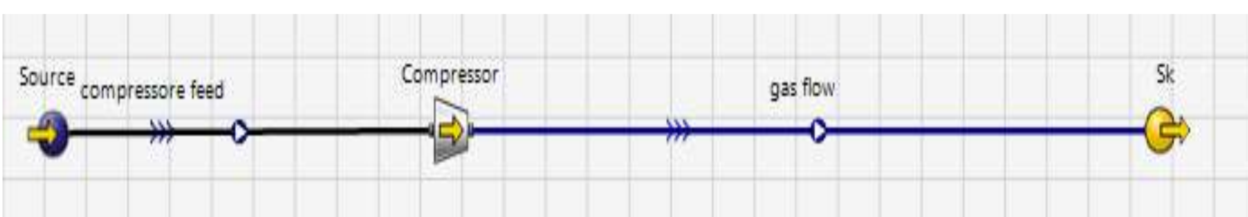


Figure 3.5. Flowline of Natural Gas (PipeSim, 2022)

Pipeline Interaction Data

From the literature review above, Tanzania Petroleum Development Cooperation (TPDC) pipeline project data (2012), the proposed design was following DNV-OS-F101 and the recommended design codes. This design format is based upon limit state and partial safety factor methodology called load and resistance factor design format (LRFD). The design proposed parameters were an outside diameter of 610mm, installation pressure of 21˚C, design temperature of 55˚C, design pressure of 9.7 MPa, and wall thickness of 22.23 mm. DNV-OS-F101 standard provides the guidelines and requirements for the installation, design, and operation of offshore pipelines, while PipeSim is a software developed by Schlumberger used for simulation and analysis of flow and performance in pipelines.

This simulation tool optimizes performance by considering factors such as fluid flow, pressure drop, and heat transfer. It also uses computational fluid dynamics techniques for simulation and analyzing various parameters affecting pipeline performance such as flow rates, pressure profiles, and distribution of temperature. PipeSim also analyses the impact of different parameters of the design such as pipe diameter, roughness of the pipe, and operating conditions. DNV-OS-F101 is limited flexibility since there are no simulations to analyze different parameters of the pipeline and has a limit in design options. In this project simulation process, pressure, temperature, gas flow rate, velocity, and pipe size are created. Also shown in different P/T profiles to determine a favorable gas flow rate to operate.

The EWURA (2020) report showed the flow rate in 2018/2019 was 4445.11MMscf and in 2019/2020 was 9,175.8 MMscf while the nomination was 40mmscfd and the highest demand being the nomination of 40.3 MMscf/d.

Designed and Proposed Parameters

The figures below show the currently proposed design, Figure 3.6 shows the design pressure of 9.7 MPa and operation pressure of 7.2 barg of the current pipeline against the total horizontal distance. For the simulation to be validated, the pre-conditions at the beginning of the simulation should be known, which included the inlet pressure, inlet temperature, gas flow rate, and velocity. In this project, the designed inlet pressure of 97 barg with a reference height of 7 m, the designed inlet temperature of 32.8˚C, the gas flow rate of 34.7 MMscf/d, and the velocity of 3.2 ft/s. These parameters were imputed to define the initial condition of the simulation model.

From Figure 3.6 the operating pressure of 72 barg the flow rate is 317 MMscf/d while the design pressure of 97 barg the flow rate was 852 MMscf/d showing more pressure drop. Figure 3.7 shows an operating temperature of 32.8˚C and drops to 22.5˚C. The pressure drops due to the adiabatic cooling effect, with no heat transfer occurring due to gas rapidly being compressed and the adiabatic temperature being 21˚C. Figure 3.8 shows the operating gas flow rate of 34.175 MMscf/d and drops to 34.164 MMscf/d over the total distance and the operating conditions given.

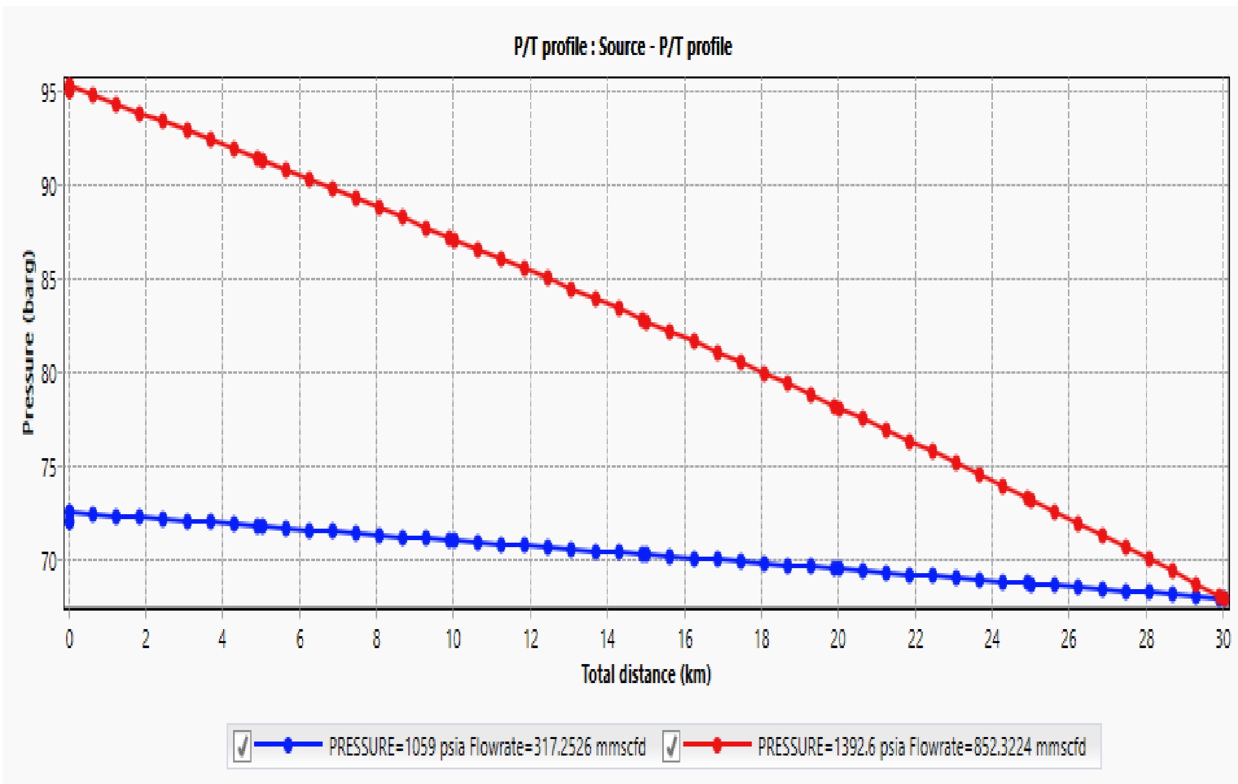


Figure 3.6. Simulated Pressure vs Total Horizontal Distance (PipeSim results, 2022)

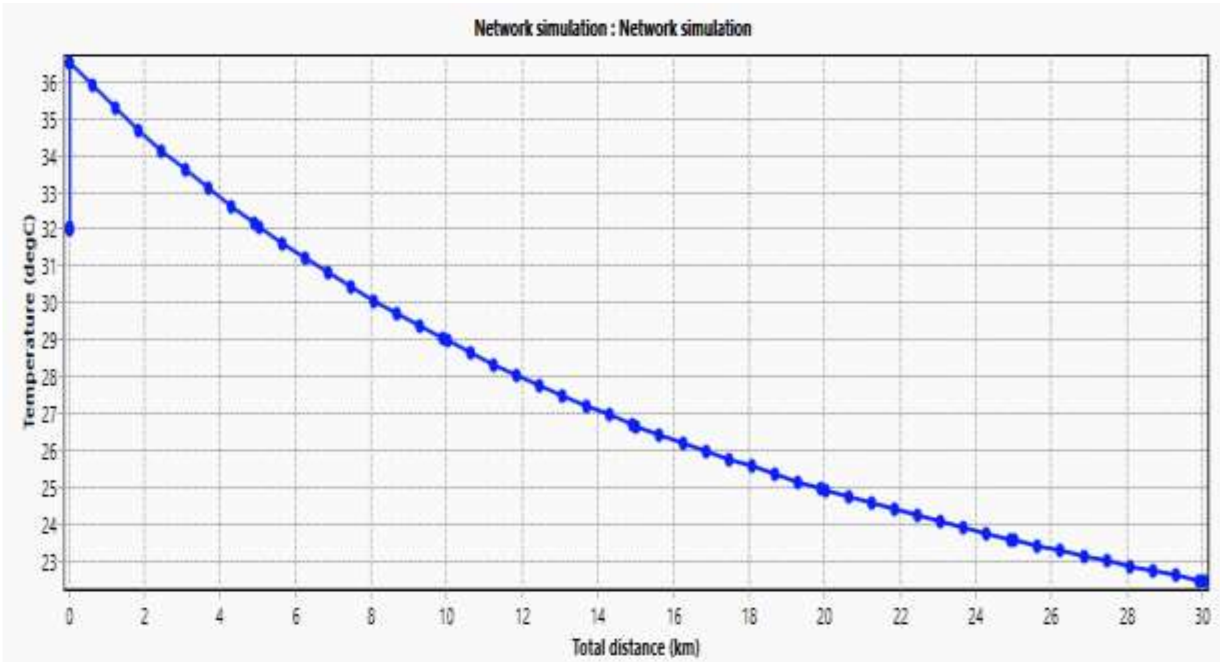


Figure 3.7. Simulated Temperature vs Total Horizontal Distance (PipeSim results, 2022)

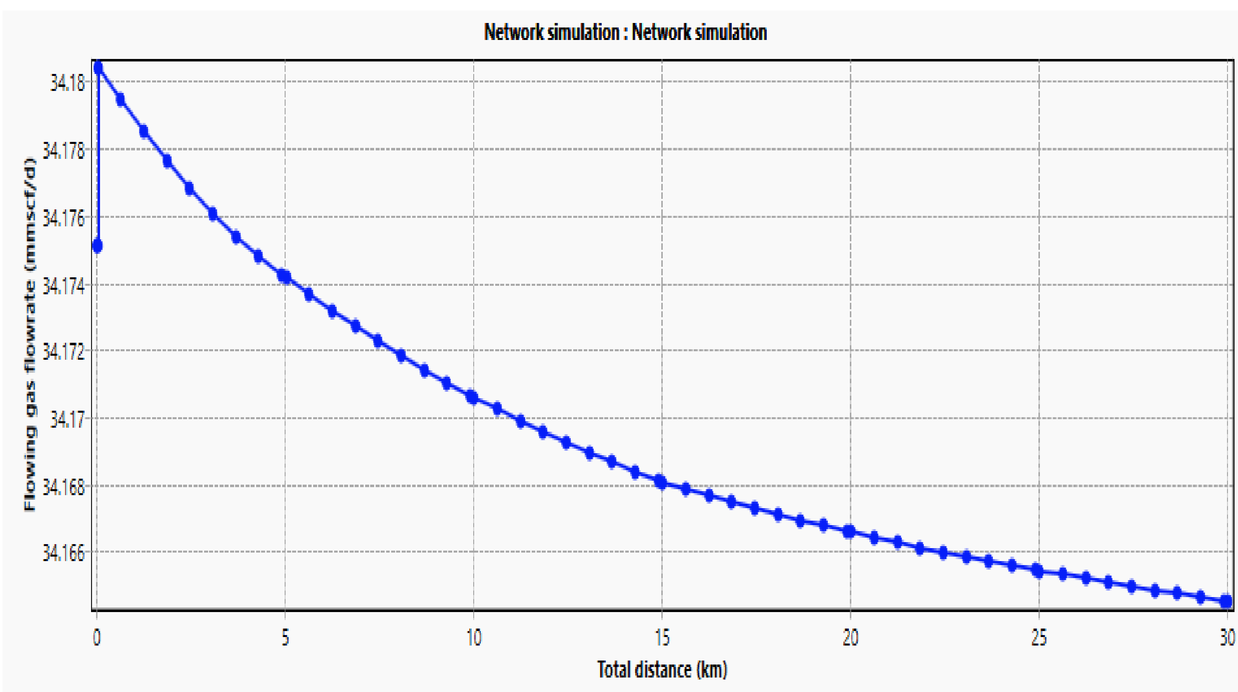


Figure 3.8. Simulated Flow rate vs Total Horizontal Distance (PipeSim results, 2022)

CHAPTER IV

Findings and Discussions

In this chapter, the PipeSim simulation will be examined and discussed in all scenarios. The results include hydrocarbon components and hydrate phase envelope, thermal insulation thickness maintaining the minimum temperature of 65 bar, and the pressure and temperature profile graphs for the flow path. Analyzing these results is essential for making informed decisions as nominations from customers, optimizing operations, reduce risks and ensuring safety.

Simulation Results and Discussions

The below Figure 4.1 shows the depth and horizontal distance of the pipe based on the pipe's outer diameter given as 24 inches, the internal diameter of the pipe was selected based on the American Petroleum Institute (API), and the wall thickness of an approximate 1 inch since this criterion is based because the fluid transported is Gas.

The design describes the minimum temperature the pipeline should drop required by the flow assurance to prevent the formation of hydrates. Also, the thickness of the insulation material (Polyurethane) was estimated at the pipeline to prevent the formation of hydrates as it maintains the temperature of the fluid being transported. PipeSim provides temperature profiles and heat loss values. The output values are used to evaluate the minimum heat losses in the pipeline and identify any areas where insulation may need to be improved. The ambient temperature predicted from the simulation in Figure 4.1 is between 67˚F and 71˚F, whereby the design Ambient Temperature is 70˚F.

Identification of the Hydrate Envelope

The results for hydrate formation using the components of the gas from the table, the hydrates tend to form on the left regions from the hydrate line (Rothfarb et al,. 1970). The critical point for pressure is 47.49 barg and -79˚C where at this point the liquid and gas phases become indistinguishable the operating pressure is not supposed to reach 47.49 barg and the critical point for temperature is -79.47˚C meaning the operating temperature should be above it. The hydrate curve formed separates the gas phase region from the hydrate phase region. In this study, hydrate formation was simulated to occur at temperatures 55˚F/12˚C. The water line shows the condition under which water and hydrocarbon coexist as separate phases

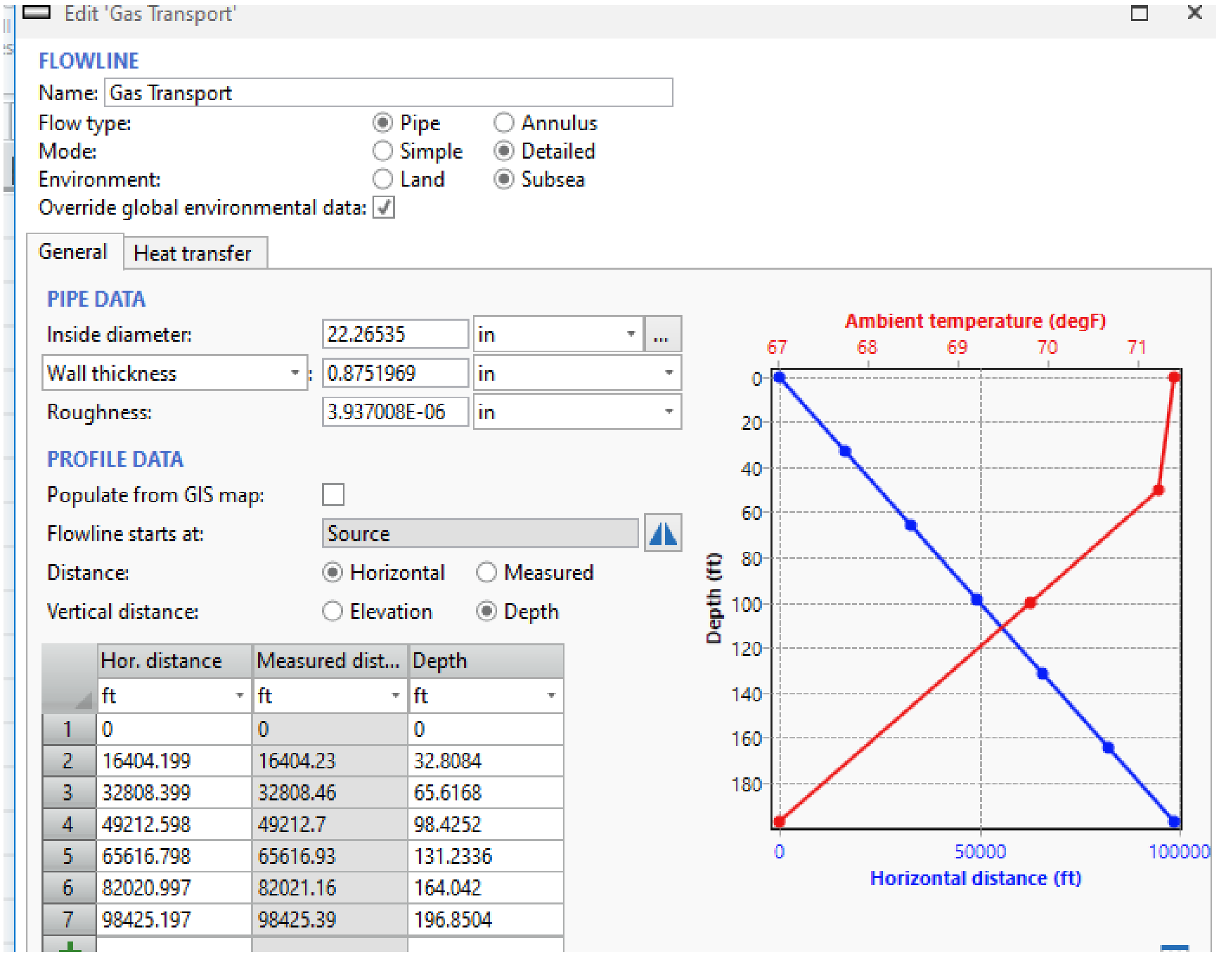


Figure 4.1. Plot of Ambient Temperature vs Depth and Horizontal Distance (PipeSim, 2022)

Therefore, it is advised to operate at a temperature above that to avoid hydrate formation. The corresponding temperature and pressure values shown in Figure 4.2 indicate the conditions at which hydrate formation is possible for this gas component in Songosongo Field.

Figure 4.3 shows the simulation of a pipe diameter of 24.26 inches. The current pipe diameter is 24 inches. Figure 4.3 shows that the difference of 0.26 inches which has no effect on the pressure drop but there is a difference in flow rate.

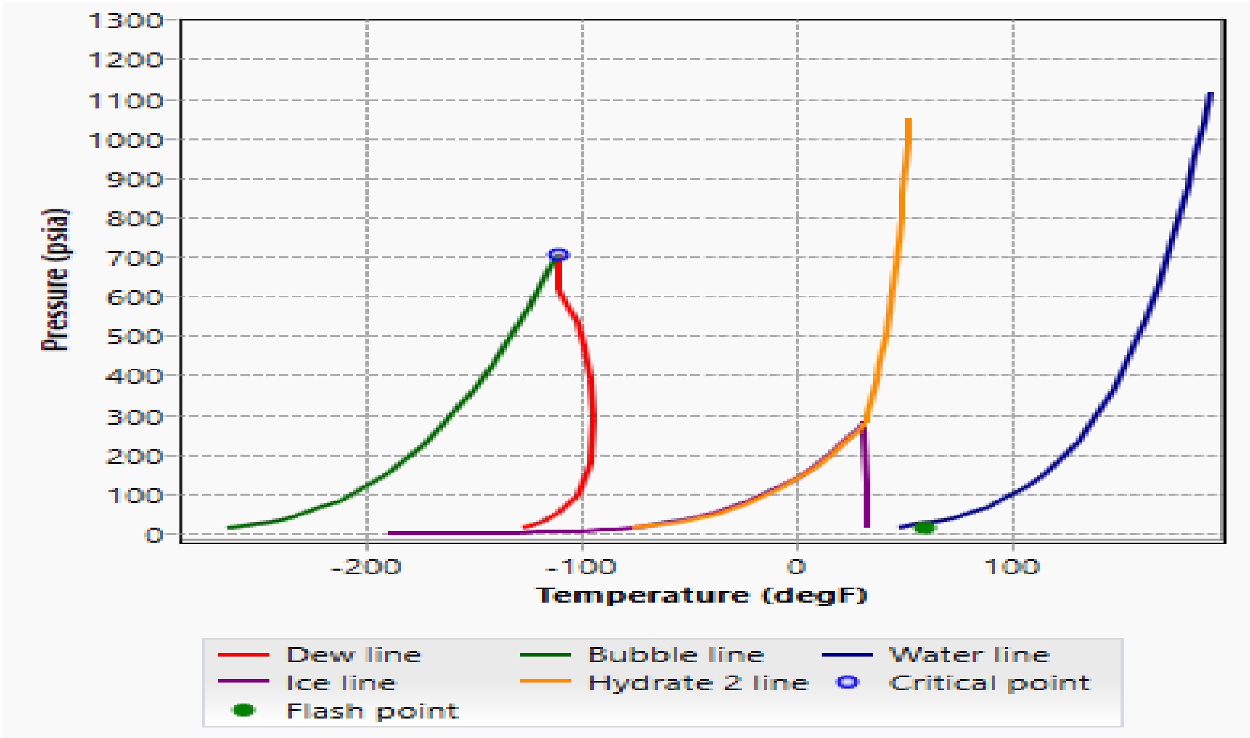


Figure 4.2. Hydrate Formation Line Forming in Phase Envelope (PipeSim results, 2022)

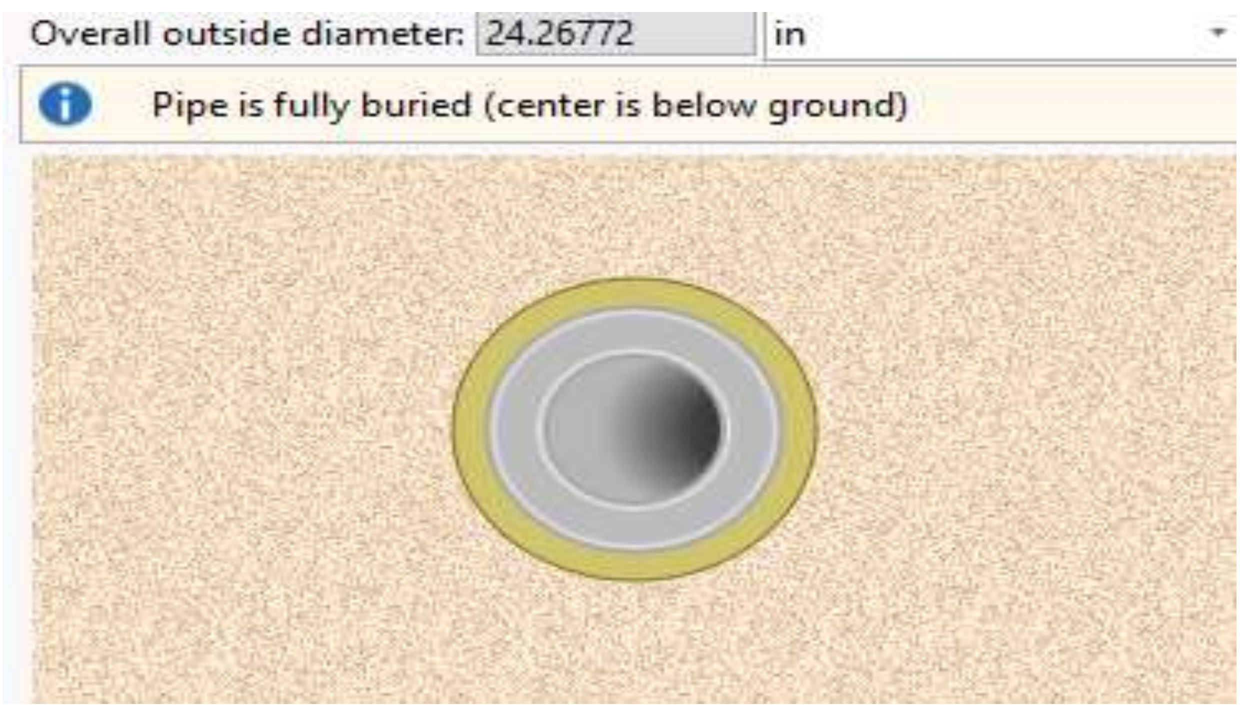


Figure 4.3. Plot Showing Pipe Fully Buried and Outside Diameter (PipeSim results, 2022)

Pipeline Insulation

The minimum arrival temperature is 55˚F to avoid hydrate formation and be on the safe side of the pipeline. The insulation has a thermal conductivity of 0.0184 Btu/hr/ft/˚F and a thickness of 0.1259”. First, the pressure-temperature profile was used to do the simulation for the temperature using the design flow rate.

Figure 4.4 shows a 22” pipeline selected using 0.1259” of thermal insulation thickness with the design flow rate of 140 MMscf/d and maximum turndown condition of 50 MMscf/d. Using the same conditions of design flow rate with temperature and pressure, the arrival temperature is above 50˚F. Therefore, the insulation thickness of the pipeline and the inside diameter is fit for the pipeline design.

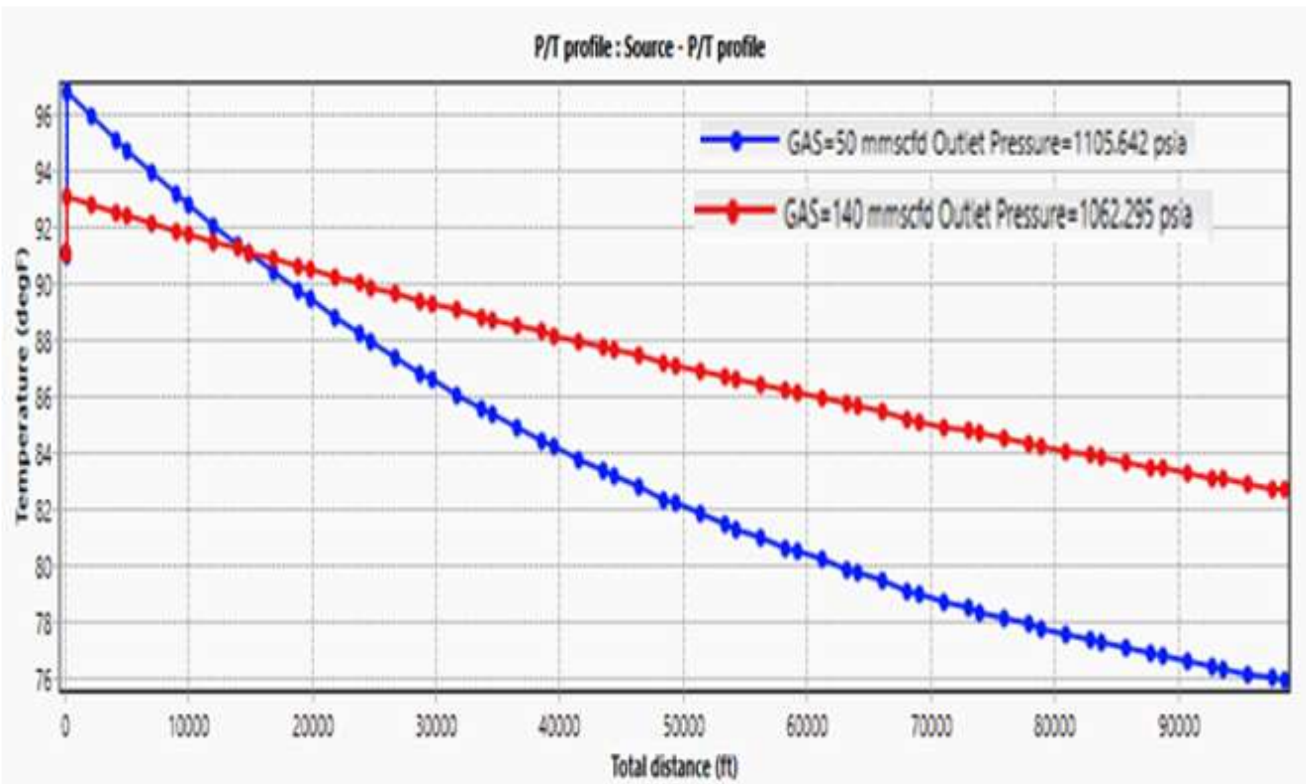


Figure 4.4. Temperature vs Total Distance for Inside Diameter (PipeSim result, 2022)

Different Parameters Scenarios

Using different flow rates in the simulation of pressure outlet and comparing it on the design and the operation of the current pipeline parameters. The flow rate used is 2018/2019 which is 4445.11 MMscf which is 12.17 MMscf/d and 2019/2020 which is 9175.8 MMscf equals 25.13 MMscf/d. By using the inlet pressure of 72 barg, the flow rate of 12.17 MMscf/d gave the outlet pressure of 87 barg and the other flow rate of 25.13 MMscf/d gave the outlet pressure of 80 barg. The simulation of the pressure does not have any pressure drop shown in Figure 4.5. It maintained the pressure all along the flow line and slightly increased the about 2 barg in each of the gas flow rates.

Using the same flow rates above, different scenarios are shown and simulate the temperature at the sink as shown in Figure 4.6.

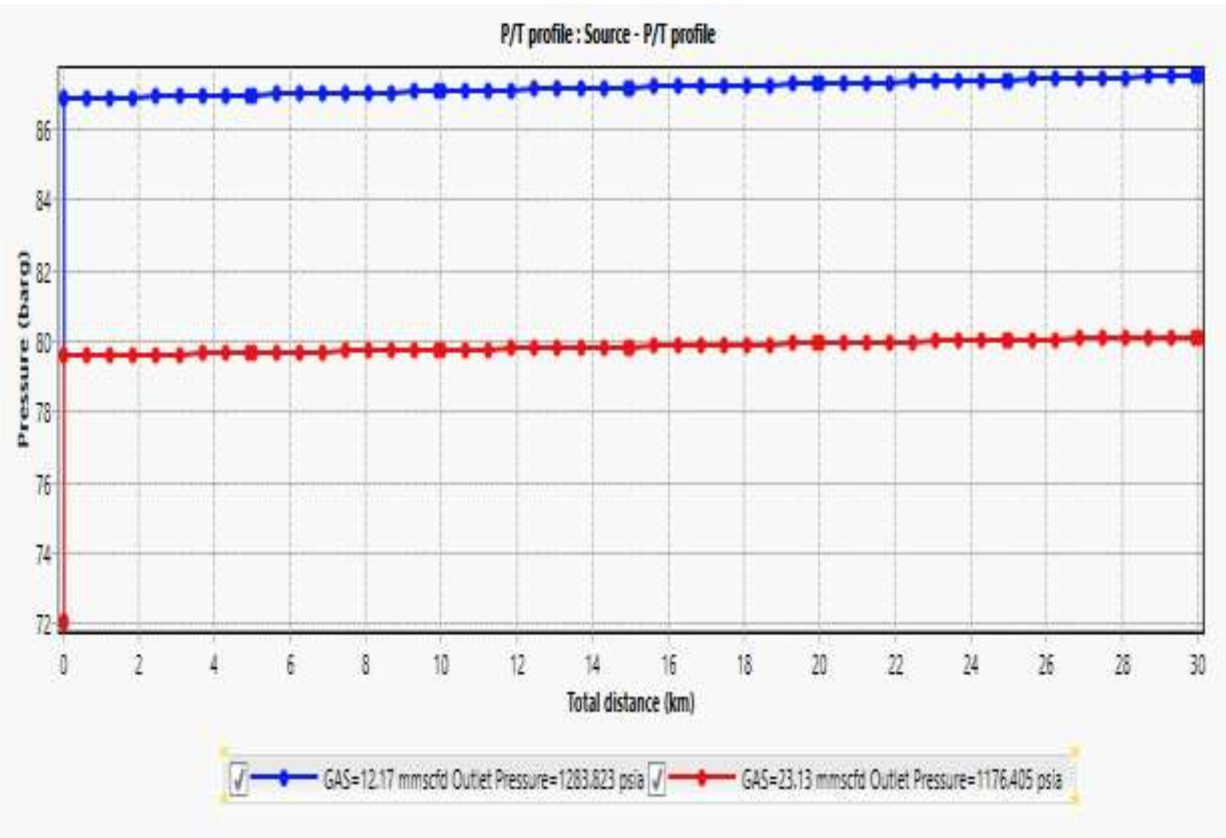


Figure 4.5. Pressure vs Total Horizontal Distance (PipeSim result, 2022)

The temperature at the outlet was simulated using the flow rates of 12.17 MMscf/d and 23.13 MMscf/d, and 34 MMscf/d was used in the simulation of temperature. The temperature of

32˚C has an outlet of 21˚C with also the outlet pressure of 80 barg. The temperature of 38.8˚C has an outlet temperature of 20.5˚C and an outlet pressure of 87.5 barg as shown in Figure 4.6. Using the flow rate of 34 MMscf/d simulated the temperature at the inlet being 32˚C and has an outlet temperature of 22˚C.

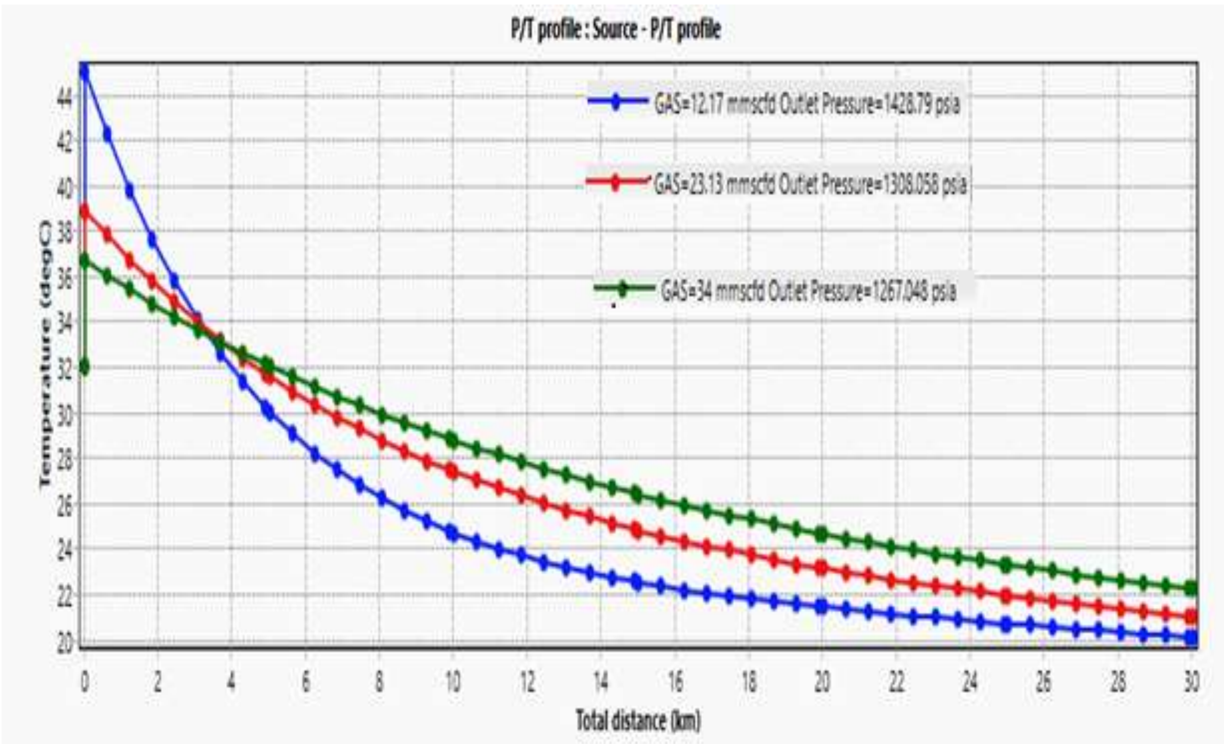


Figure 4.6. Temperature vs Total Horizontal Distance Showing Flowrate (PipeSim result, 2022)

Pressure Drop in Pipeline

The pressure drop in natural gas is normal in pipelines due to the friction that causes pressure losses. Figure 4.7 represents the inlet pressure of 72 barg and the design gas flow rate of 140 MMscf/d, the results of the pressure using the temperatures of 21 ˚C, 30 ˚C, 40 ˚C, 50 ˚C, and 60 ˚C show that the pressure still drops with the use different temperature.

The lower the pressure used the lower the arrival temperature. The same condition of pressure and the flowing gas rate was used in the simulation for the determination of the size of the pipeline system. By computing the production platform inlet pressure, temperature, the design flow rate, overall heat transfer coefficient, roughness, and ambient temperature. Figure 4.8

represents different inside diameters of 22 inches, 24 inches, and 26 inches used. The smallest pipeline size of 22 inches will satisfy the arrival pressure condition of 72.2 barg.

In determining the conditions of pressure in Figure 4.9, different scenarios of gas flow rates were used to study the behavior of pressure using the same conditions of inlet pressure, temperature, and inlet flow rate.

The cases of flow rates used were 110 MMscf/d, 120 MMscf/d, 130 MMscf/d, and 140 MMscf/d. The results show that the flow rate of 140 MMscf/d has an arrival pressure of 72 barg which is the operating desired pressure of the pipeline. The lower the flow rate used, the higher the arrival pressure.

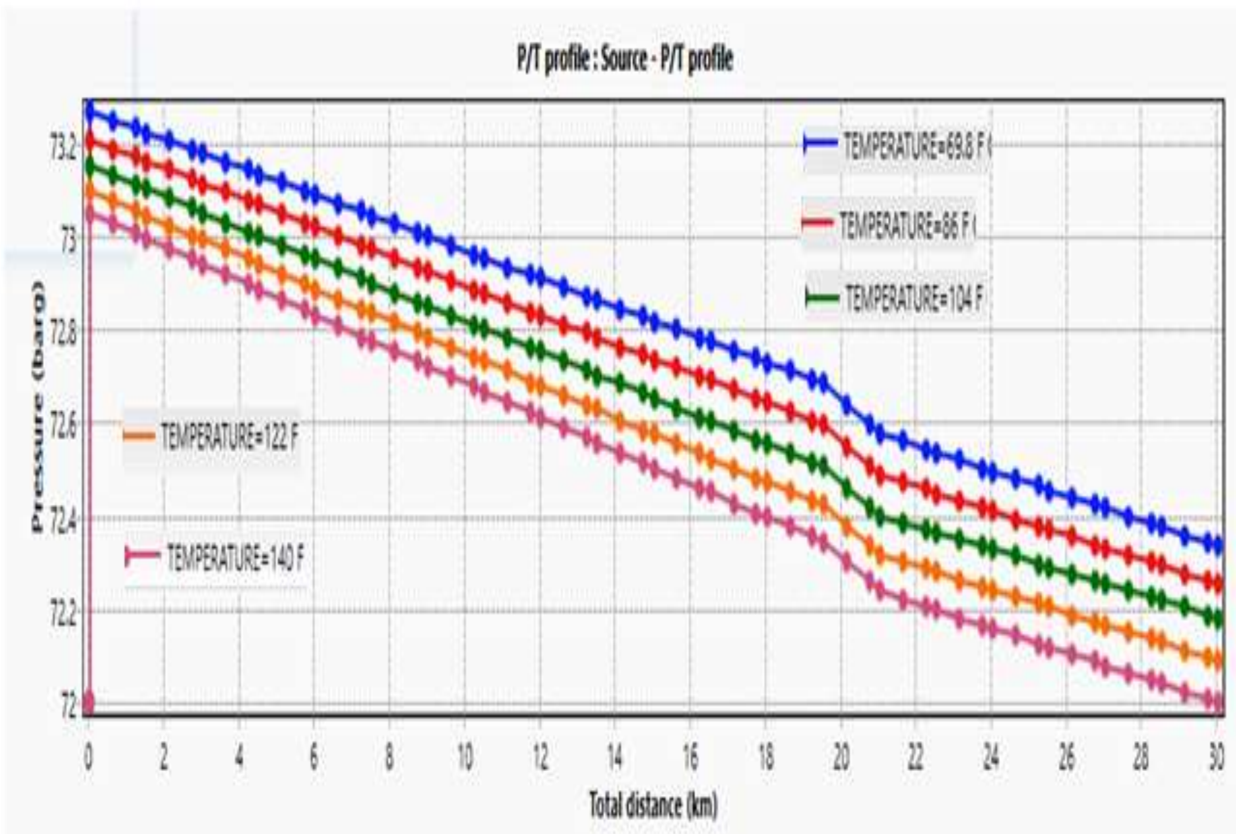


Figure 4.7. Pressure vs Total Distance (PipeSim result, 2022)

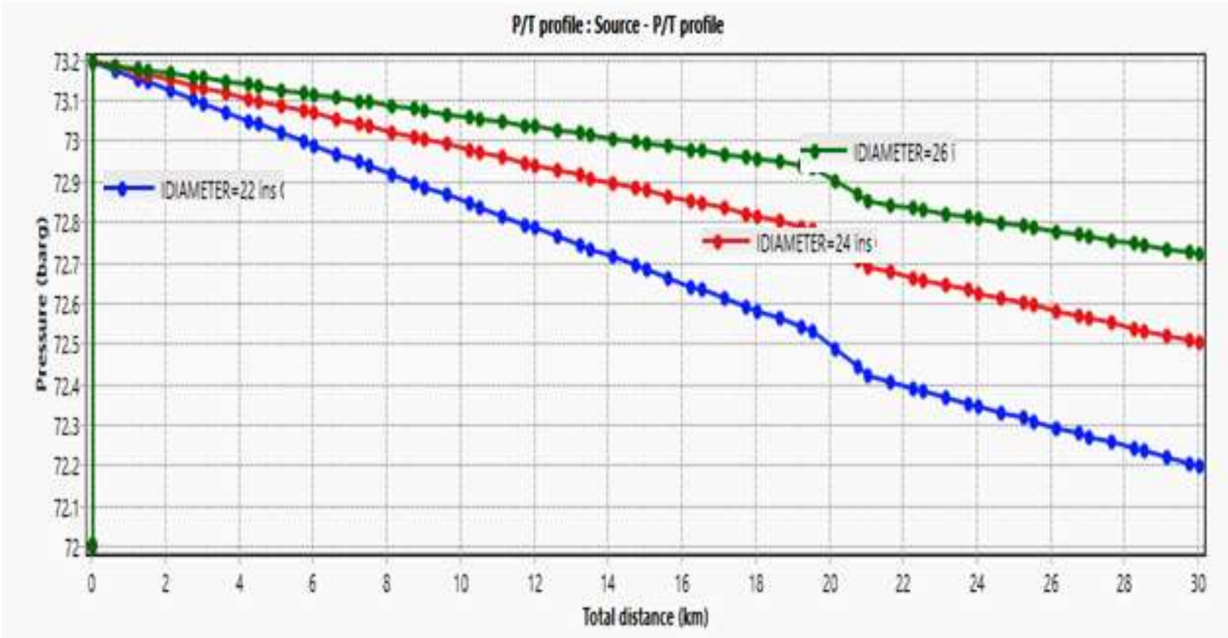


Figure 4.8. Pressure vs Total Distance (PipeSim result, 2022)

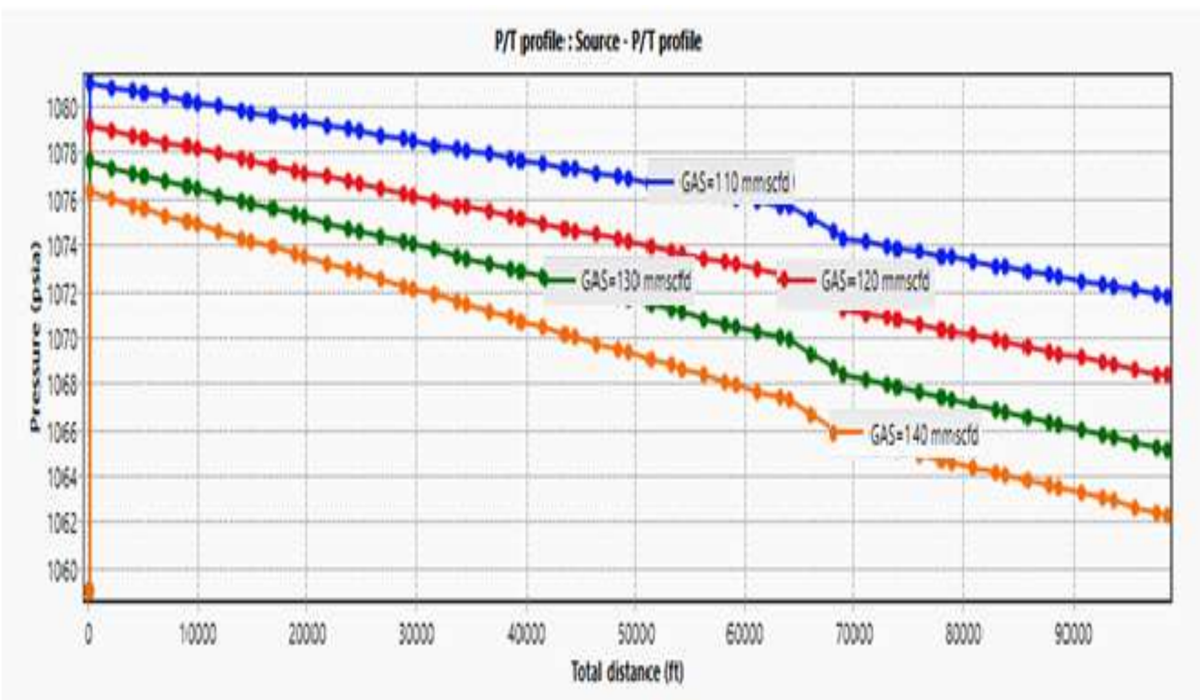


Figure 4.9. Pressure vs Total Distance Showing a Result of Pressure Drop at a Different FlowRate (PipeSim result, 2022)

Simulation of the Pipeline with the Compressor at the Sink

Energy is used in compressing natural gas, and there are energy losses during pipeline transportation due to friction and pressure drops. By compressing gas at the source, the compressed gas is injected at a higher pressure which reduces frictional losses during the transportation and this improves the overall efficiency of the pipeline. Also, the compressor at the source provides more flexibility in managing the gas supply. It allows the operators to control the compression process, and adjust the flow rate and pressure needed depending on the nomination and demand on operational requirements.

The natural gas pipeline is designed to maintain a certain pressure level to ensure the efficient flow of gas. By compressing the gas at the source, the pressure can be maintained throughout the pipeline, preventing pressure drops and ensuring a consistent and reliable supply of gas to the end users. Therefore, Figure 4.10, Figure 4.11, and Figure 4.12 show the design of the pipeline gas with the compressor at the sink and observe the results.

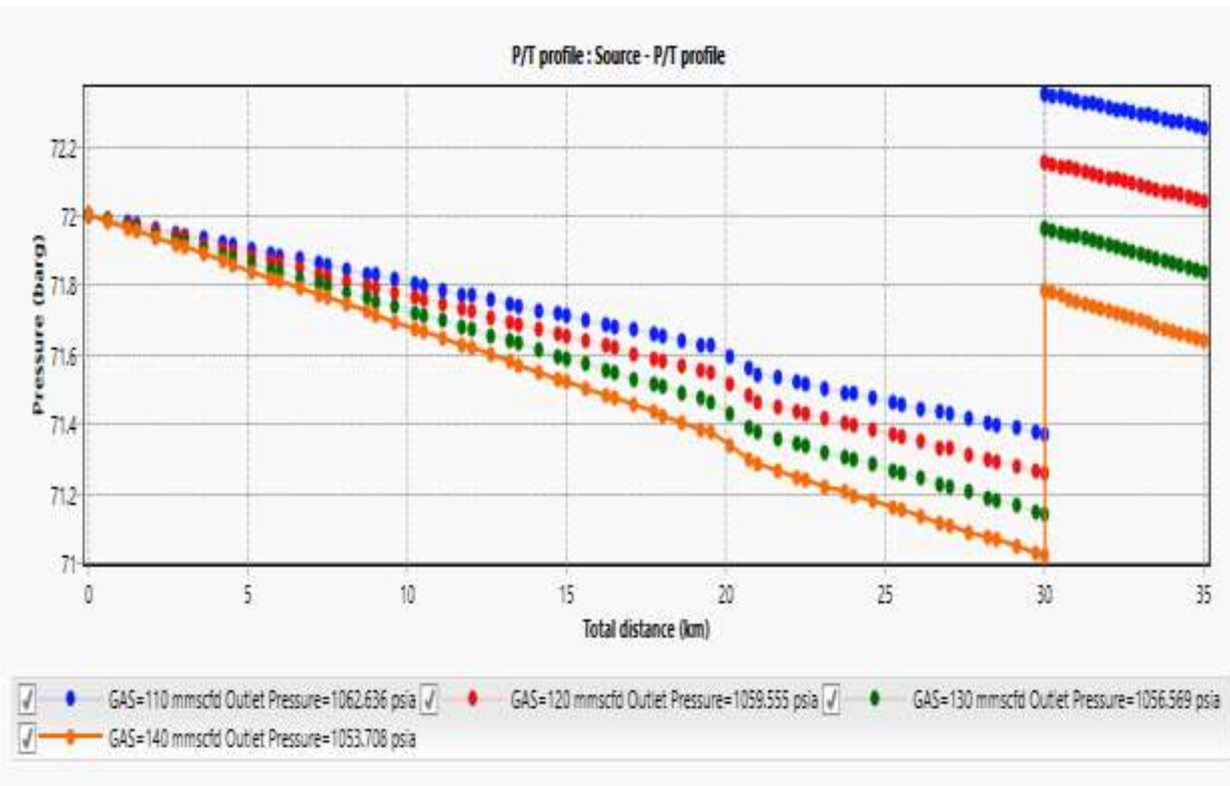


Figure 4.10. Pressure vs Total Distance for Flowrate Showing Compressor Close to the Sink (PipeSim result, 2022)

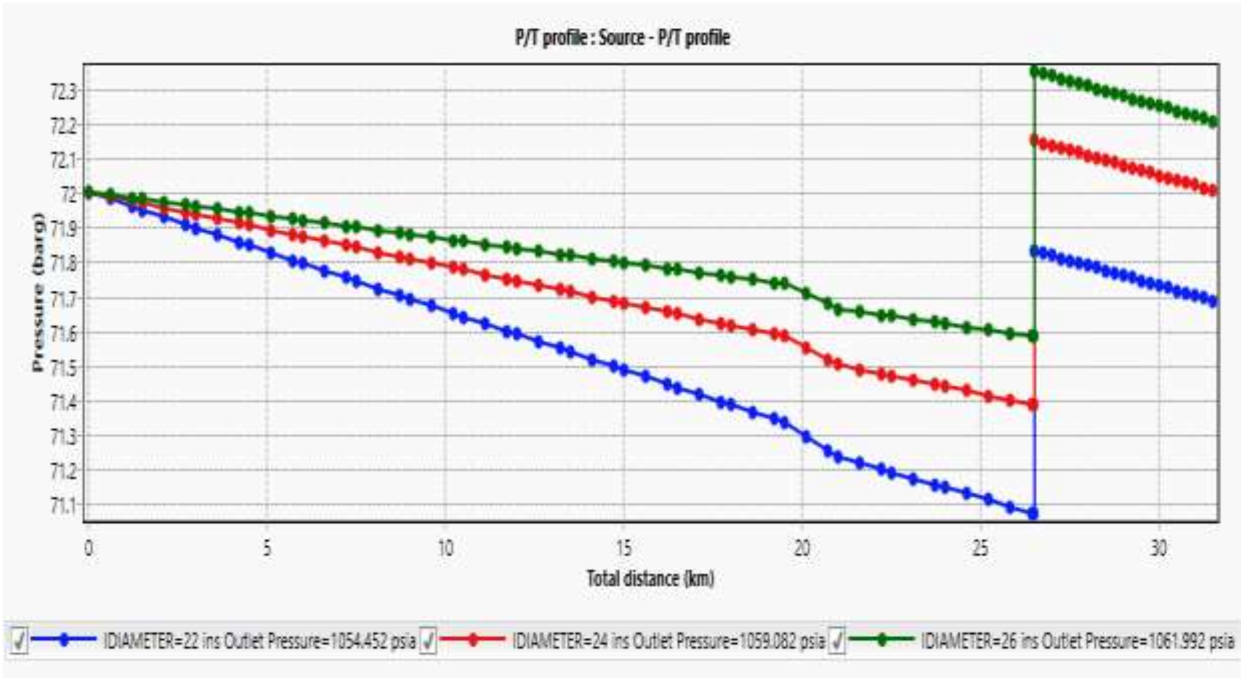


Figure 4.11. Pressure vs Total Distance for Inside Diameter Showing Compressor Close to the Sink (PipeSim result, 2022)

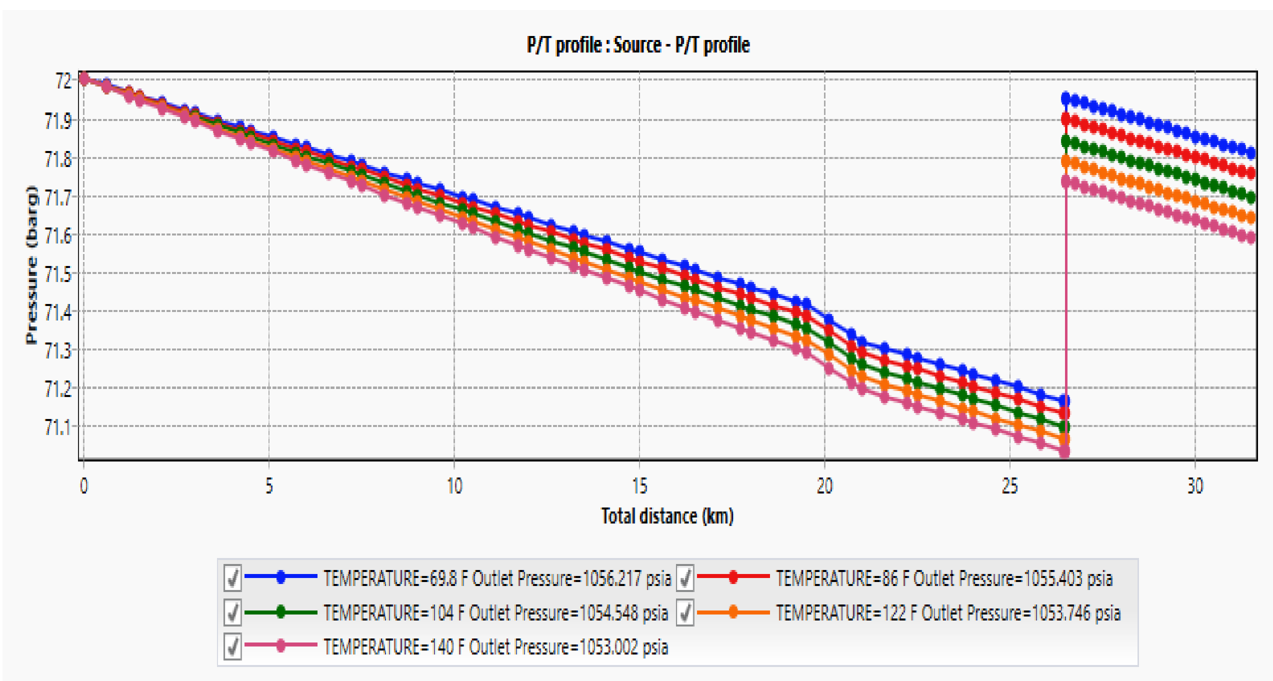


Figure 4.12. Pressure vs Total Distance for Temperature Showing Compressor Close to the Sink (PipeSim result, 2022)

The condition of hydrate to form is 11˚C in temperature, but using both conditions with pressure as shown from the hydrating line in the phase envelope figure above, the pressure condition is 1049 psia or (10˚C and 985 psia), these values are according to the hydrate curve formed from gas components.

From the figures above showing the compressor close to the sink, the arrival pressure is as low as 1053 psia which is close to the hydrate formation pressure condition. This shows that there is a slight possibility of the pressure to reach 1049 barg. And hence, it will destroy the efficiency of the gas flow.

Summary of the Results Showing Different Scenarios

Results from the different scenarios are shown and tabulated in Table 4.1 below. Results such as pressure, temperature, gas flow rate, velocity, and mass flow rate were plotted all together to analyze and give an idea of how the pipeline design is best with the properties and parameters. With the pressure, using the compressor in both scenarios the results show that the pressure drop available gives almost the same results as the pressure.

But using the compressor at the source shows the efficient flow of the gas throughout the pipeline. Below shows different scenarios of the pipeline design. The low scenario happens when the nomination and demand from the consumer is low for the day and this happens if the amount of gas required is lower than usual. The medium scenario happens when the nomination is normal from the consumer, and the high scenario means that the nomination is higher than usual and requires more gas volume and this happens in the gas flow rate.

For pressure Figure 4.13, temperature Figure 4.14 and Figure 4.15 and inside diameter Figure 4.16 show different scenarios that are used to analyze the results and determine the best outcome as shown in Table 4.1 below.

Table 4.1 *Short Description of the Simulated Case Result (PipeSim)*

	Pressure (barg)	Temperature (˚C)	Flow rate (MMscf/d)	Inside diameter (inch)
Design	97	55	140	20
Operation	72	28	34.5	22.3
Low scenario	60	21	12.17	22
Medium scenario	6.5	30	50	24
High scenario	11.2	55	140	26

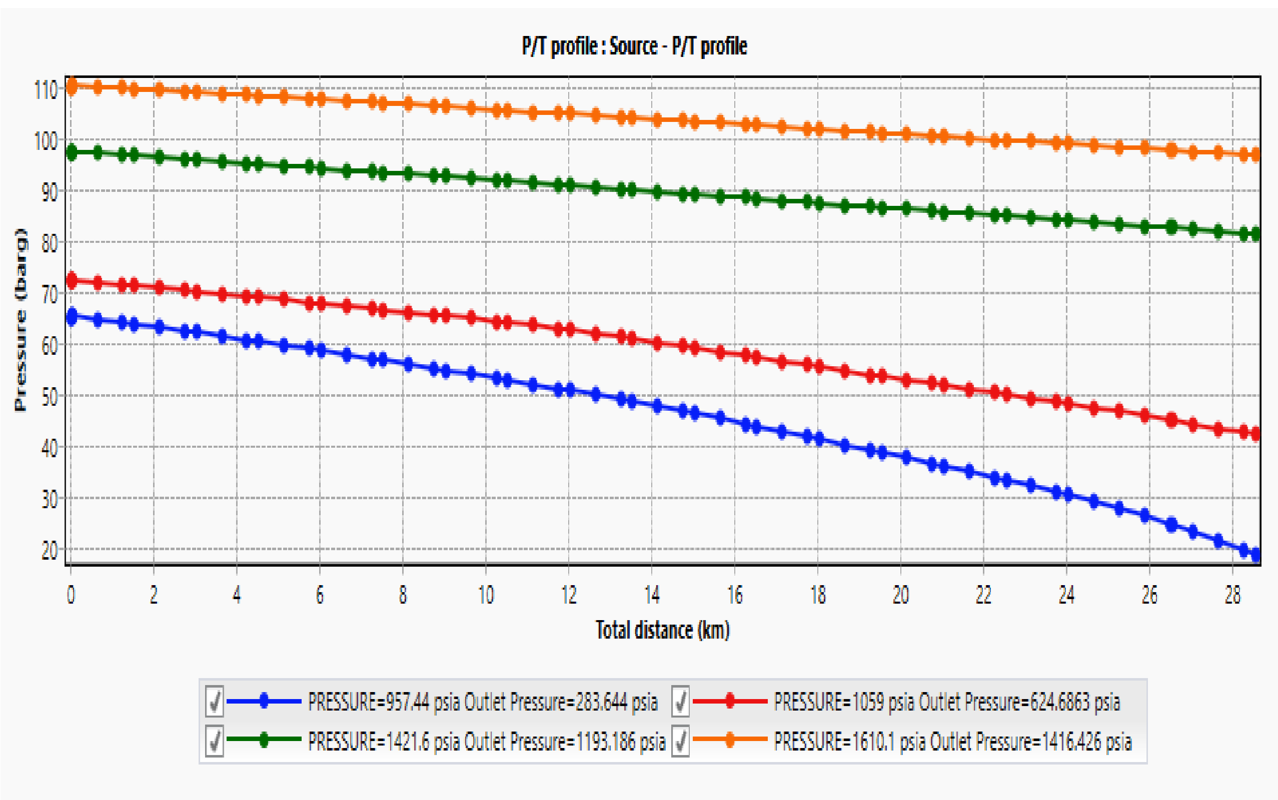


Figure 4.13. Pressure vs Total Horizontal Distance for all Scenarios ((PipeSim, result, 2022)

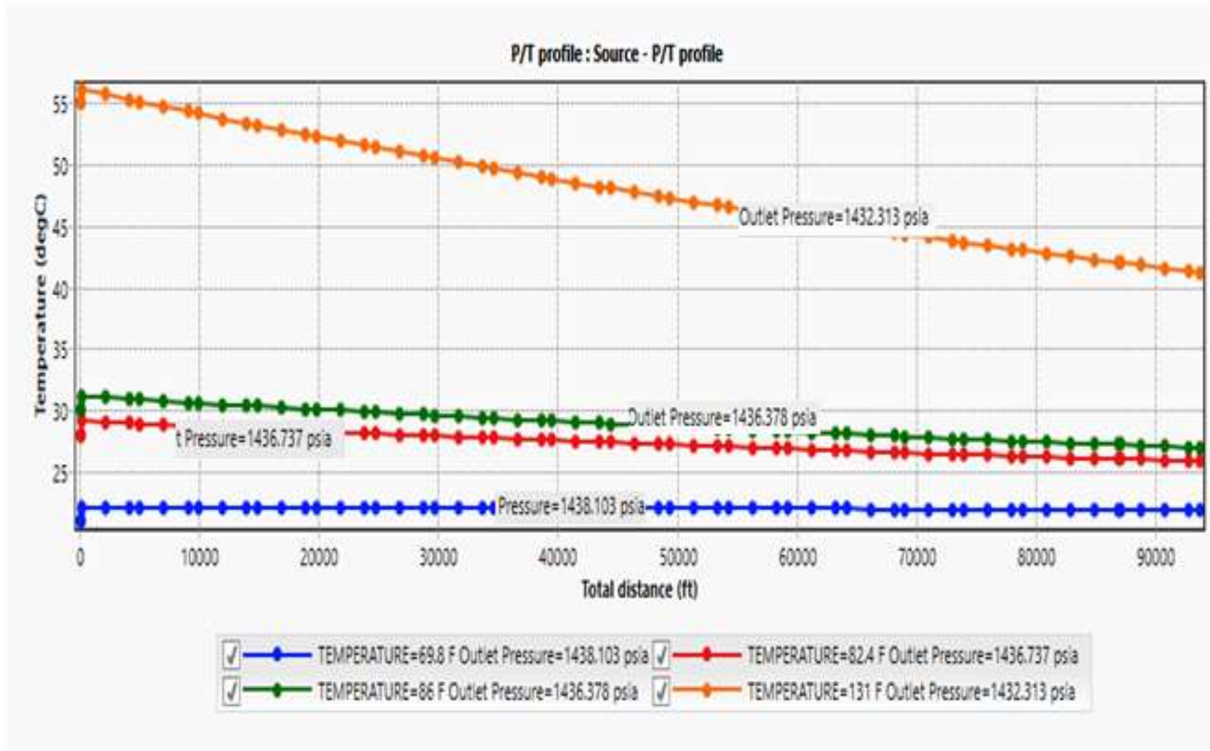


Figure 4.14. Temperature vs Total Horizontal Distance for all Scenarios (PipeSim result, 2022)

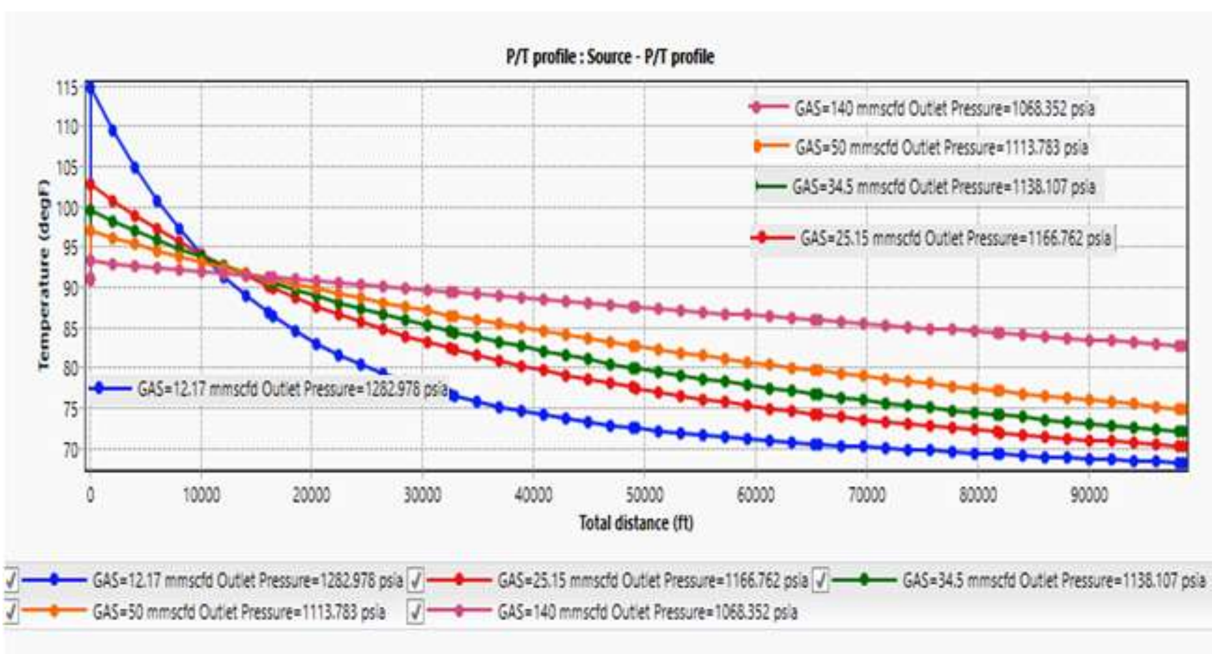


Figure 4.15. Temperature vs Total Distance Showing the Flowrate in all Scenarios (PipeSim result, 2022)

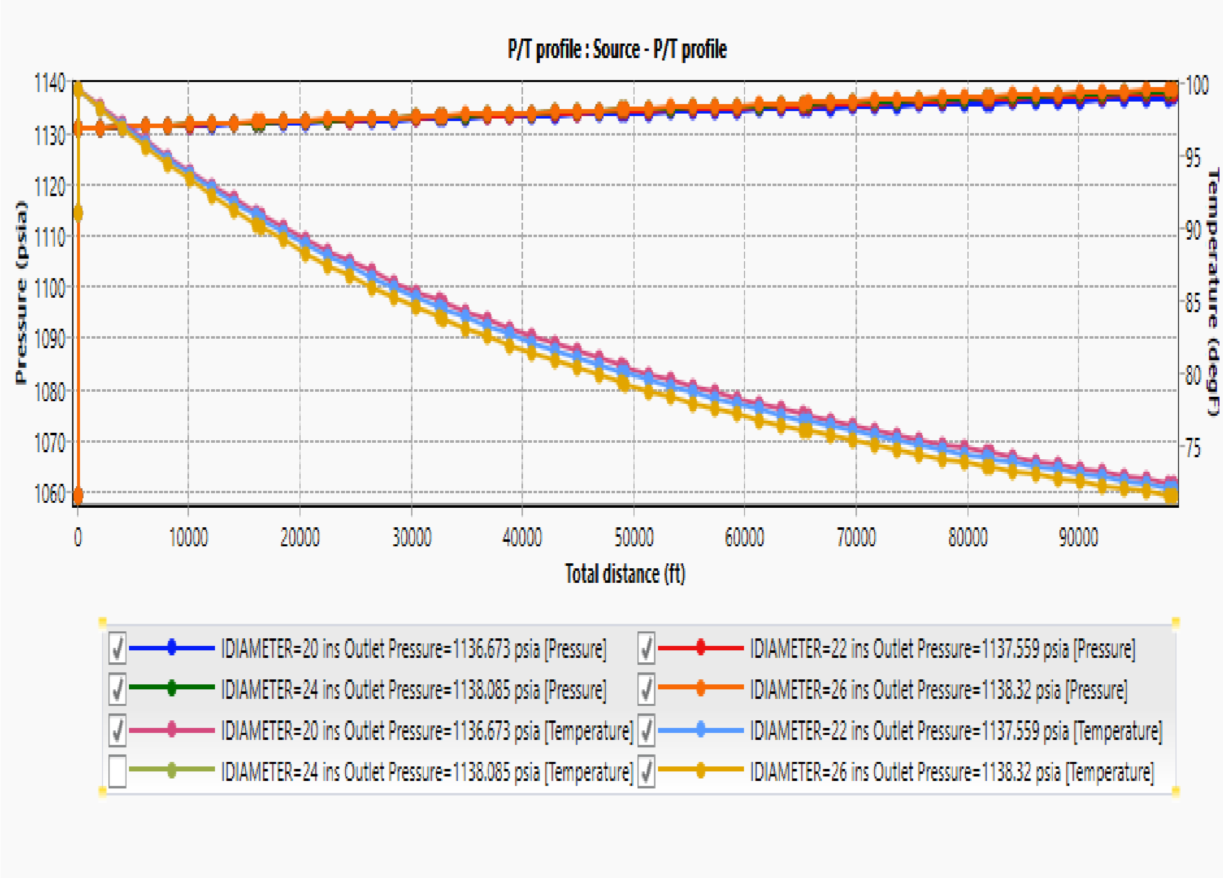


Figure 4.16. Pressure /Temperature vs Total Distance Showing Pressure for all Scenarios of Inside Diameter (PipeSim result, 2022)

CHAPTER V

Discussion

Discussions on Different Simulations

The Simulation results for the pressure profile in a steady state through the pipeline are presented in the simulation together with the original data provided by (TPDC 2012). In calculating the pressure under the design flow rate, it shows the result and formation of pressure drop through the pipeline but using a low flow rate at a low scenario, there is no pressure drop in the simulation. Using the same boundary conditions but different flow rates can show different outlet pressure in the pipe and different pressure drop.

Using the same boundary conditions as the operations and parameters, the overall outside diameter simulated is a little bit higher than the proposed overall diameter which is 610 mm (24 inches) while the simulated overall diameter Figure 4.2 is 616.4 mm (24.26 inches). The slight change doesn't show any difference in the simulation of the design pipeline.

The different inside diameter scenarios Figure 4.8, show that the smaller diameter has a little rise of pressure at the outlet. This means the smaller diameter results in thinner walls that increase heat loss. Therefore, the inside diameter of 24 inches with the outlet pressure of 1138.39 psia results in thicker walls of the pipe that maintain the same gas flow rate.

In simulating the temperature, the higher the inlet temperature, the more temperature drops by using the lower flow rate. To avoid more temperature drops, the flow rate to be used should be higher. Compared to the designed temperature according to TPDC, ranging from 21˚C TO 55˚C, the simulation is within the range but it is better to use the temperature with less pressure drop.

Discussion on Comparing Simulations with the Compressor at the Sink and Source

In comparing the outlet pressure from the different simulations, Figure 4.6 shows that the temperature drops simultaneously till the sink and this is where the compressor is placed right after the source in the pipeline. The outlet pressure varies from 1267 psia to 1428 psia (86 barg and 97 barg) with the gas flow rate of 12.17 MMscf/d and 34 MMscf/d. This pressure is within the proposed design of the pipeline. Using the compressor at the sink, the outlet pressure is varying from 1585 psia/108 barg to 1807 psia/123 barg. This pressure is too big for the design of the pipeline as was proposed and this may cause pipeline failure or even safety hazards and structural damage to the pipeline and the surrounding environment.

Comparing the outlet pressure using the inside diameter and the compressor at the source and the sink, it shows that after the compressor the pressure was increased throughout the pipeline Figure 4.9 and this is because the volume of the gas is reduced. As shown in Table 4.2 the difference in pressure outlet is small, therefore the effects of the compressor with different inside diameters are not much. Table 5.1 shows the summary results of compressor at the sink and source.

Table 5.1. Summary of the Inside Diameter and the Compressor at the Source and Sink.

Inside Diameter (inch)	Compressor (Source) Barg	Compressor (Sink) Barg
22	1061.8	1054.45
24	1066.2	1059
26	1069.4	1061.99

From the conditions of hydrate to form for both temperature and pressure shown in Figure 4.2, in all simulations, the temperature did not reach as low as the hydrate line but for pressure, it sometimes reaches as low as 69 barg if the flow rate is high.

CHAPTER VI

Conclusions and Recommendations

Conclusions

After different successful simulations and results based on different scenarios applied in the project and simulations from designed parameters without compressor, simulations using compressor both at the source and at the sink. The conditions of formation of hydrate in the pipeline. I observed the simulations using the compressor at the source give better results of pressure, temperature, and gas flow rate compared to the current pipeline having the compressor at the sink.

The pipeline size of 22 inches inside diameter and the given thermal conductivity of 0.0184 Btu/hr/ft/˚F and the insulation thickness of 0.1259 inches gave an arrival temperature that is above the condition of hydrate formation, therefore, it fits the design of the pipeline.

The design shows that the temperature tends to fall, it is a subsea pipeline design and the ambient temperature is 21˚C, therefore the temperature falls due to the surrounding temperature and also the effect of adiabatic cooling, as the gas is compressed rapidly there is no time for heat transfer to occur hence resulting to the adiabatic cooling.

The maximum designed flow rate of 140 MMscf/d shows a tendency for pressure drop when it's applied, hence as long as the flow rate is not nominated then the pressure drop occurring in the pipeline will be difficult to occur. Also, the hydrates conditions for temperature and pressure are shown in Table 4.2.

Recommendation

Due to an expansion of interest in the Petroleum Industry in the world and especially in Africa recently, Improvements have been made in many aspects of developing the pipeline design. Different approaches have been made in designing the pipeline (TPDC, 2012) and have been successful. The weakness of the model does not show the properties of the gas inside the offshore pipeline flowing while designing. In the meantime, using PipeSim to design the pipeline limits someone and this acts as a challenge, especially in the pipeline route selection, material selection, and Geographical conditions.

The only recommended further research is combining both the design used by (TPDC, 2012) that is load and resistance factor design format (LRFD) and the design using PipeSim for the design of an offshore pipeline transportation, this will combine the standard covers pipeline materials, pipeline design principles, installation methods, and integrity management. It considers loads such as the weight of the pipeline, the weight of any fluids flowing through the pipeline, external environmental loads, and internal pressure loads and also the PipeSim simulation will determine the hydrate formations and the behavior of the gas through the pipeline and that is good for the design of an offshore pipeline for natural gas.

References

Akhmetkaliyeva, S. (2020). General Environmental Impacts of Subsea Pipelines. Https://Www.eurasian-Research.org/Publication/General-Environmental-Impacts-of-Subsea-Pipelines/. https://www.eurasian-research.org/publication/general-environmental-impacts-of-subsea-pipelines/

Bai, Q., and Bai, Y. (2014). Subsea Pipeline Design, Analysis, and Installation. Gulf Professional Publishing. https://www.sciencedirect.com/book/9780123868886/subsea-pipeline-design-analysis-and-installation

Bai, Y., and Bai, Q., (2005). Subsea pipelines and risers. Elsevier. https://www.sciencedirect.com/book/9780080445663/subsea-pipelines-and-risers

Beggs, D. H., & Brill, J. P. (1973). A Study of Two-Phase Flow in Inclined Pipes. Journal of Petroleum Technology, 25(05), 607–617. https://doi.org/10.2118/4007-p

Bejarano, J. L. (2021). Online Calculator: Flow Rate and Pressure Drop of Gas Through a Pipeline. planetcalc.com, /8242.

Chukwuma, G., Nmegbu, J., & Asueiza, E. (2022). Optimizing Natural Gas Pipeline Design to Prevent Hydrate Formation during Gas Transportation. Thermal Oil Recovery of Nigerian Heavy Crude Deposits View project Research View project Optimizing Natural Gas Pipeline Design to Prevent Hydrate Formation during Gas Transportation. International Journal of Scientific Research and Engineering Development, 5.

Cordes, E. E., Jones, D. O. B., Schlacher, T. A., Amon, D. J., Bernardino, A. F., Brooke, S., Carney, R., DeLeo, D. M., Dunlop, K. M., Escobar-Briones, E. G., Gates, A. R., Génio, L., Gobin, J., Henry, L.-A., Herrera, S., Hoyt, S., Joye, M., Kark, S., Mestre, N. C., Metaxas, A., Pfiefer, S., Sink, K., Sweetman, A. K., & Witte, U. (2016). Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies. Frontiers in Environmental Science, 4(58). https://doi.org/10.3389/fenvs.2016.00058

EWURA. (2020). natural gas sub-sector regulatory performance report for the year ended 30 the united republic of Tanzania ministry of energy and water utilities regulatory authority (ewura). https://www.ewura.go.tz/wp-content/uploads/2021/07/Natural-Gas-Sub-Sector-Performance-Report-for-the-Year-ended-June-2020.pdf

Guo, Y., Sun, B., Zhao, K., & Zhang, H. (2016). A prediction method of natural gas hydrate formation in deepwater gas well and its application. *Petroleum*, *2*(3), 296–300. https://doi.org/10.1016/j.petlm.2016.06.004

Kimambo, C. (1996). Modelling of Linebreak in High-pressure Gas Pipes. Cuthbert ZM Kimambo. https://core.ac.uk/download/pdf/42628216.pdf

Koh, C. A., Sum, A., & Sloan, E. D. (2010). Natural Gas Hydrates in Flow Assurance. Gulf Professional Publishing.

Lockhart, R. W., & Martinelli, R. C. (1949). Proposed Correlation of Data for Isothermal Two-Phase, Two-Component Flow in Pipes. Chemical Engineering Progress, 45(1), 39–48.

Lukonge, A. B., & Cao, X. (2019). Prospect of Natural Gas Distribution Pipelines and Safety in Tanzania-a case Study. IOP Conference Series: Earth and Environmental Science, 342(1), 012019. https://doi.org/10.1088/1755-1315/342/1/012019

Marfo, S. A., Appau, P. O., & Kpami, L. A. A. (2018). Subsea Pipeline Design for Natural Gas Transportation: A Case Study of Cote D'ivoire's Gazelle Field. Subsea Pipeline Design for Natural Gas Transportation: A Case Study of Côte D'ivoire's Gazelle Field, 4(3), 21–34.

Muhongo, S. (2013). United republic of Tanzania the national natural gas policy of Tanzania - 2013 Dar es Salaam. https://www.teiti.go.tz/storage/app/uploads/public/5d0/24b/cb6/5d024bcb67afe044422934.pdf

Ozi, J., Briggs, T. A., & Kuye, A. (2020). Prediction of Pressure Drop in Subsea Pipeline Using Pipesim Software. Industrial Engineering Letters, 10(2), 62. https://iiste.org/Journals/index.php/IEL/article/view/51914

Rothfarb, B., Frank, H., Rosenbaum, D. M., Steiglitz, K., & Kleitman, D. J. (1970). Optimal Design of Offshore Natural-Gas Pipeline Systems. Operations Research, 18(6), 992–1020. https://doi.org/10.1287/opre.18.6.992

TPDC, (2012). Tanzania Mnazibay and Songosongo Natural Gas Processing Plant and Transportation pipeline project

TPDC-GASCO, (2012). Design Basis Report for Offshore Pipeline.

Triantafyllaki, A., Loukidis, D., & Papanastasiou, P. (2023). Design of offshore gas pipelines against active tectonic fault movement. Soil Dynamics and Earthquake Engineering, 166, 107702. https://doi.org/10.1016/j.soildyn.2022.107702

Watts, D. (2015). Pressure drop evaluation along pipelines. PetroWiki. https://petrowiki.spe.org/Pressure_drop_evaluation_along_pipelines

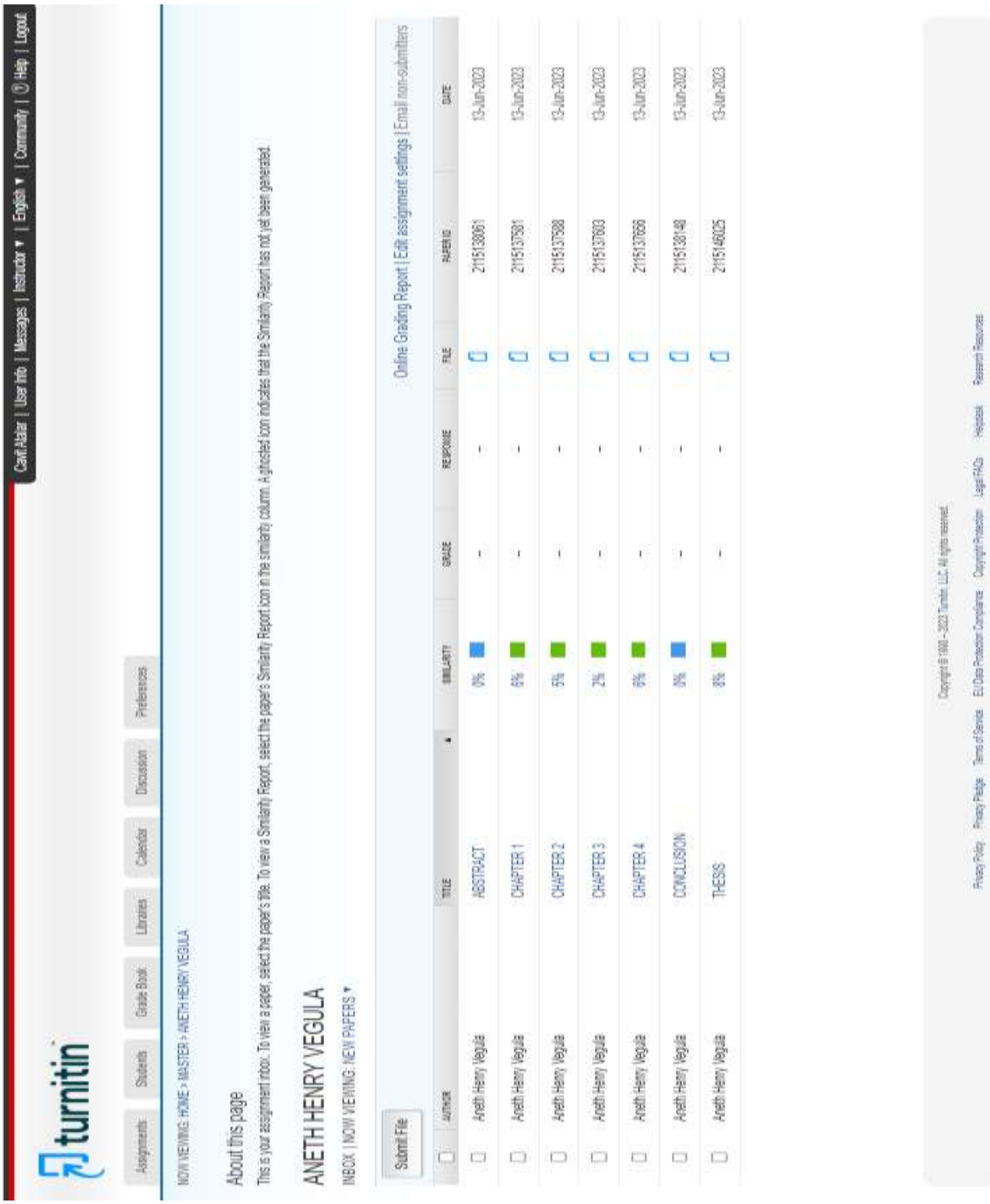
Wilfred, O., & Appah, D. (2015). Analyzing Thermal Insulation for Effective Hydrate Prevention in Conceptual Subsea Pipeline Design. 2492| International Journal of Current Engineering and Technology, 5(4). https://inpressco.com/wp-content/uploads/2015/07/Paper352492-2499.pdf

Zhang, H., Liang, Y., Ma, J., Qian, C., & Yan, X. (2017). An MILP method for optimal offshore oilfield gathering system. An MILP Method for Optimal Offshore Oilfield Gathering System, 141, 25–34. https://doi.org/10.1016/j.oceaneng.2017.06.011

Zulkefli, N., and Pao, W., (2016). Optimum Thermal Insulation Design for Subsea Pipeline Flow Assurance. Optimum Thermal Insulation Design for Subsea Pipeline Flow Assurance. https://doi.org/10.13140/RG.2.2.33853.05603

APPENDICES

Appendix A
Turnitin Similarity Report


Cavit Atalar | User Info | Messages | Instructor ▾ | English ▾ | Community | Help | Logout

turnitin

Assignments | Students | Grade Book | Libraries | Calendar | Discussion | Preferences

NOW VIEWING: HOME > MASTER > ANETH HENRY VEGULA

About this page

This is your assignment inbox. To view a paper, select the paper's title. To view a Similarity Report, select the paper's Similarity Report icon in the similarity column. A ghosted icon indicates that the Similarity Report has not yet been generated.

ANETH HENRY VEGULA

INBOX | NOW VIEWING: NEW PAPERS ▾

Submit File

Online Grading Report | Edit assignment settings | Email non-submitters

AUTHOR	TITLE	SIMILARITY	GRADE	RESPONSE	FILE	PAPER ID	DATE
Aneth Henry Vegula	ABSTRACT	0%	--	--		2115138061	13-Jun-2023
Aneth Henry Vegula	CHAPTER 1	6%	--	--		2115137581	13-Jun-2023
Aneth Henry Vegula	CHAPTER 2	5%	--	--		2115137588	13-Jun-2023
Aneth Henry Vegula	CHAPTER 3	2%	--	--		2115137603	13-Jun-2023
Aneth Henry Vegula	CHAPTER 4	6%	--	--		2115137656	13-Jun-2023
Aneth Henry Vegula	CONCLUSION	0%	--	--		2115138148	13-Jun-2023
Aneth Henry Vegula	THESIS	8%	--	--		2115146025	13-Jun-2023

Copyright © 1998 – 2023 Turnitin, LLC. All rights reserved.

Privacy Policy Privacy Pledge Terms of Service EU Data Protection Compliance Copyright Protection Legal FAQs Helpdesk Research Resources

APPENDIX B

ETHICAL APPROVAL LETTER

YAKIN DOĞU ÜNİVERSİTESİ

ETHICAL APPROVAL DOCUMENT

Date: 02/07/2023

To the Institute of Graduate Studies

The research project titled "**Design of An Offshore Pipeline for Natural Gas Transportation; a Case Study of the Songosongo Field, Tanzania**'' has been evaluated. Since the researcher will not collect primary data from humans, animals, plants or earth, this project does not need through the ethics committee.

Title: Prof. Dr.

Name Surname: Cavit ATALAR

Signature:

Role in the Research Project: Supervisor