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In

GREEN INDUSTRIAL ENGINEERING

Steady State Simulation Of A Typical Gas Storage And Treatment Plant

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LIST OF ACRONYMS AND ABBREVIATIONS

ACRONYM — DESCRIPTION

NG — Natural Gas

NGPN — National Gas Pipeline Network

LNG — Liquefied Natural Gas

UGS — Underground Gas Storage

JT — Joule–Thomson

LTS — Low Temperature Separator

EOS — Equation of State

PR-EOS — Peng–Robinson Equation of State

PCHE — Printed Circuit Heat Exchanger

PFD — Process Flow Diagram

TNR — Transmission Network Requirements *(used contextually with NGPN)*

E-100 — Pre-Heating Unit (Heater Identifier)

TEE-100 — Flow Splitter Unit

MIX-101 — Mixing Unit

Btu — British Thermal Unit

bar — Unit of Pressure (bar absolute)

°C — Degree Celsius

ABSTRACT

The current energy sector relies heavily on Natural Gas because of its strategic nature as an energy-security resource & ability to adapt to seasonal demand swings. Underground Gas Storage is the infrastructure that allows for balancing Supply and Demand, particularly during periods of maximum consumption. However, the Gas withdrawn from these Storage Reservoirs will likely have to go through a treatment stage prior to being delivered because it does not meet the national quality requirements associated with the pipelines used for transporting gas.

The focus of this research is a Steady-State Simulation of a standard Natural Gas Storage and Treatment facility. This research aims to establish sufficient models &! methodologies for analysing the Primary Process Modules used to treat Natural Gas during the Withdrawal Phase; All treated Gas should conform to Pressure, Temperature, & Quality specifications required for safe transport through the Gas Utility Network. Also, primary emphasis will be placed on the investigation & evaluation of the Thermodynamic properties of Natural Gas to prevent nuisance challenges such as Condensation & Hydrate Formation.

The study is developed using Aspen HYSYS, a commercial process simulation software widely adopted in the oil and gas industry. A detailed steady-state model of the plant is built, including separation units, heat exchangers, pressure reduction devices, and low-temperature separation systems. Appropriate thermodynamic models and operating assumptions are selected to realistically represent the physical behaviour of the process.

Simulation results are analysed in terms of temperature and pressure profiles, phase behaviour, and separation efficiency. The obtained results demonstrate that the

proposed process configuration is capable of treating the gas effectively and delivering it under conditions compliant with transmission network requirements. The model also provides useful insights into the operational performance of the plant and highlights the role of process simulation as a valuable tool for design, analysis, and optimization of gas treatment facilities.

This work contributes to a better understanding of gas storage treatment processes and confirms the importance of steady-state simulation for supporting engineering decisions in the natural gas sector.

Chapter 1

Introduction to Natural Gas

Natural gas is a fossil fuel made primarily of methane but also contains smaller amounts of several hydrocarbon gases such as ethane, propane and butane, and other compounds such as nitrogen, carbon dioxide, and trace levels of other impurities. It has a relatively high energy content per unit volume (measured in Btu) compared to other fossil fuels, and when burned produces less carbon dioxide than most other fossil fuels, which means that it can be utilized efficiently by electric utilities to produce electric power.

Natural gas is used by a variety of customers in many different industries, including electricity generators, manufacturers, homeowner/landlord heating systems, and transportation. Because of its versatility, ease of use, and reliability, natural gas is an important component of utility grids around the world, particularly where there is a well-developed pipeline and storage infrastructure. Furthermore, in many places where renewable energy is being added to the utility grid, natural gas is used as the primary way to support the integration of renewable sources of energy into the grid by providing an economical and flexible source of generation as the energy source for electric power.

From an engineer's point of view, the properties of natural gas have an impact on how the natural gas is produced, how it is moved, how it is stored and how it is treated. The many different variables that can affect the physical and thermodynamic properties of natural gas are related to the process of making natural gas available for the user, so it is important that processes involved in producing, transporting, storing, and treating natural gas ensure that the natural gas is of the proper quality for delivery and use.

1.1 History of Natural Gas

Natural gas has had a long history of use as fuel for human use since at least 2500 years ago. Ancient Greeks, Persians, Indians, and Chinese were familiar with gas that leaked from beneath the earth's surface, generally called "burning springs." The burning springs are believed to have been created by natural gases that escaped from the ground and caught fire as they encountered surface air.

Figure 2: Historical photos of gas extraction and transport

Chinese sources claim that around 2500 years ago, they used primitive bamboo tubing to transfer natural gas from shallow wells to evaporating salt brine for production. This considered to be one of the earliest examples of industrial use of natural gas

Over the last 40 years, increasing population and improved technologies for extracting and transporting natural gas have resulted in the increasing demand for and increased use of natural gas as energy. Today, natural gas constitutes more than 25% of the entire global primary energy consumption.

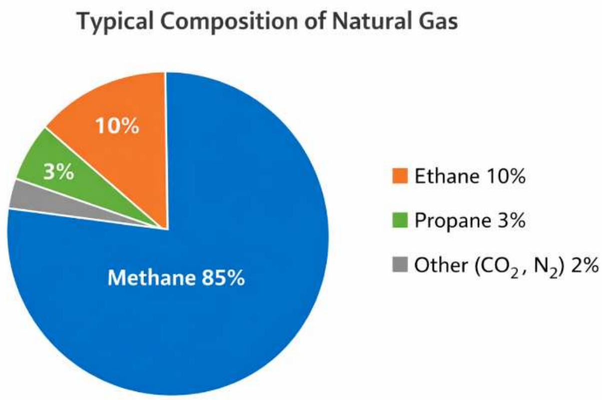

Figure 3:Typical composition of natural gas

1.2 Typical Chemical Composition of Natural Gas

Natural gas is mainly made of methane (CH_4) and generally comprises 70% to 95% of the total volume of natural gas. In addition to methane, heavier hydrocarbons comprise the remaining part of the natural gas, including both ethane (C_2H_6) and propane (C_3H_8), and butanes (C_4H_{10}) and pentanes (C_5+), as well as some other gases that do not contain carbon, such as nitrogen (N_2), carbon dioxide (CO_2), hydrogen sulphide (H_2S), and a very small amount of very rare noble gases like helium (He).

The relative amounts of these components in a gas will vary depending on where the gas comes from dry gas fields consist mainly of methane while wet gas fields contain many condensable hydrocarbons. Thus, having heavier hydrocarbons in a gas will increase the energy content; however, it also provides a higher dewpoint and creates the need for separation and treatment of heavier hydrocarbons prior to transporting through pipelines.

The composition of gases also affects the physical and thermodynamic behaviours of those gases, along with their phase stability, efficiency in burning, and their impact on the environment; thus, correctly conducting a compositional analysis of gas is a critical part of the processing and storing of that gas.

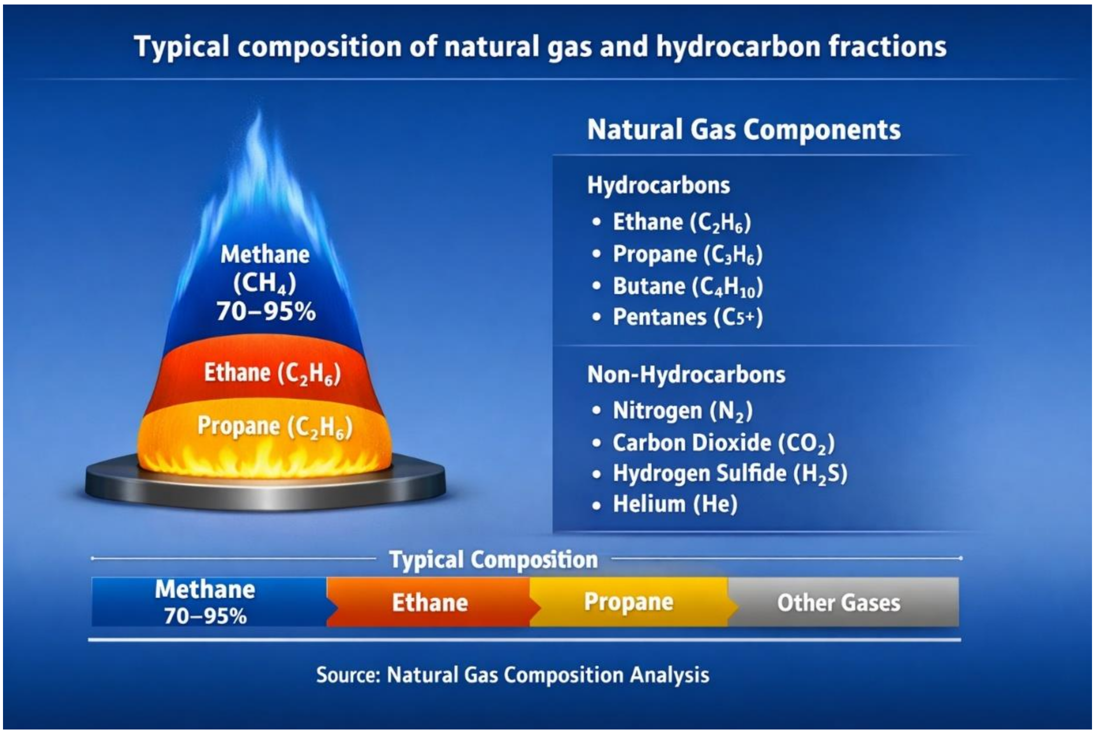

Figure 4: Typical composition of natural gas and hydrocarbon fractions

Compound	Formula	Volume (%)
Methane	CH_4	70-90
Ethane	C_2H_6	0-20
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8
Oxygen	O_2	0-0,2
Nitrogen	N_2	0-5
Hydrogen sulphide	H_2S	0-5
Other gases	A, He, Ne, Xe	Trace

Table 1: *Typical natural gas composition*

1.3 Production and uses of Natural Gas

To discover natural gas, geologists first perform a geological analysis and conduct seismic surveys to locate natural gas-bearing rock formations. In the best-case scenario, the geologists will find gas in conjunction with crude oil; however, this is not always the case.

Once the natural gas has been extracted from the earth, it will contain contaminants such as carbon dioxide, water, heavier hydrocarbons (i.e., tars), hydrogen sulphate, and many more, so it must be taken to a manufacturing facility for processing to eliminate these contaminants and to separate and refine its useful components, including propane and butane.

Natural gas may also be hydrocarbon-gas (the principal component of rattling gas), otherwise known as coalbed methane or by-products of decomposing mass in a landfill; since it is produced through the decomposition process, it is classified as a renewable energy source.

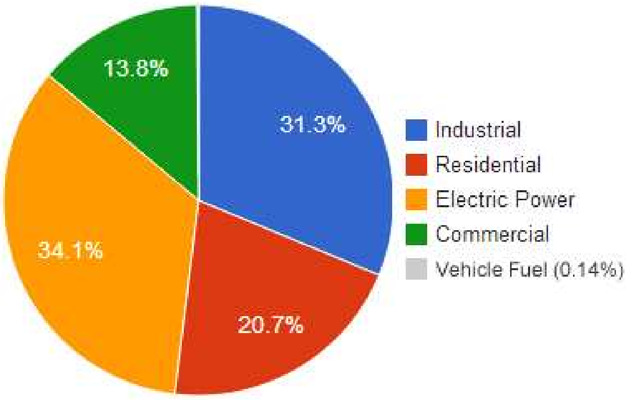

Figure 5 :Natural Gas Use

1.4 Role of Natural Gas in Italy's Energy System

Italy's reliance on imported natural gas extends to Europe as one of the highest natural gas consumption nations. The absence of locally produced products causes Italy to buy virtually all its supply via pipeline or LNG terminals.

Natural gas is used widely throughout Italy for power generation, industrial manufacturing and residential heating applications. Given a strong correlation between the seasonality of demand and the heating needs of the country during the winter months, a significant increase in consumption occurs throughout that time.

Figure 6: Italian natural gas transport network

To guarantee a sustainable and constant energy supply to support peak-demand times in Italy, underground storage facilities for natural gas (in addition to the LNG import terminals) are critical.

Natural gas is a major energy source for many parts of Italy including electricity generation, heating in industry or homes. The bulk of the natural gas used in Italy comes from imports via pipelines from Algeria, Azerbaijan, and Northern Europe and by LNG terminals.

Natural gas storage systems play an important role in balancing the fluctuations between seasons since they allow you to store excess natural gas from low consumer demand and then release it back into the marketplace during times when people's demands for natural gas peak (for example, wintertime). Underground storage also provides energy security, helps maintain a balancing act between supply and demand within a given energy grid, and stabilizes prices by acting as a buffer against unexpected price changes.

Given Italy's strict regulatory requirements on the quality of natural gas (such as moisture content, hydrocarbon dew point, sulphur content, and delivery temperature), the importance of having efficient natural gas treatment processes has increased significantly.

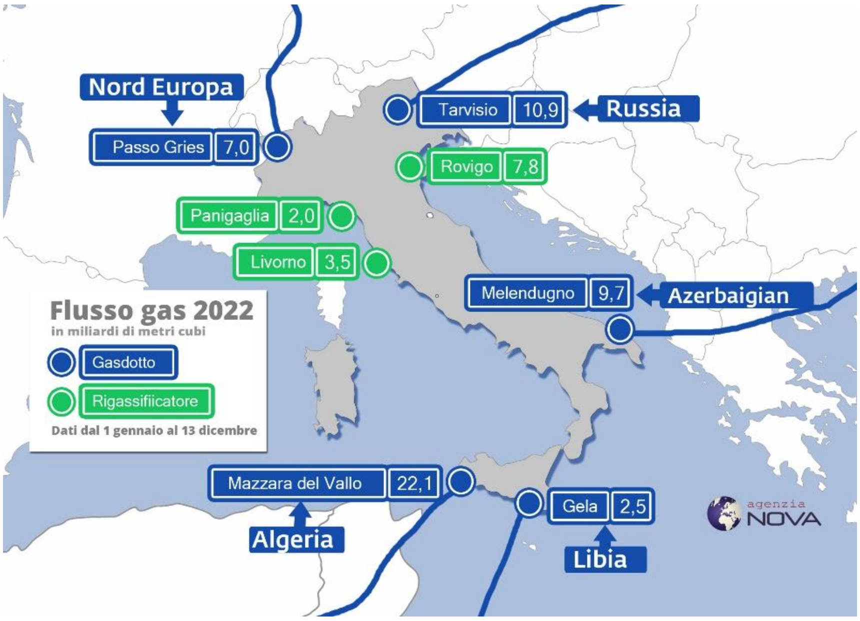

Figure 7: natural gas entered Italy in 2022

The map shows how natural gas entered Italy in 2022 (in billion cubic meters), distinguishing pipeline imports (blue) and LNG regasification terminals (green): the largest pipeline flow came from Algeria through Mazara del Vallo (22.1 bcm), followed by gas from Russia via Tarvisio (10.9 bcm), from Azerbaijan via Melendugno (9.7 bcm), from northern Europe through Passo Gries (7.0 bcm), and from Libya through Gela (2.5 bcm); in addition, liquefied natural gas arriving by ship was regasified at the terminals of Panigaglia (2.0 bcm), Livorno (3.5 bcm) and Rovigo (7.8 bcm), showing that in 2022 Italy relied on a diversified mix of pipeline supplies and LNG imports.

1.5 Gas Storage

Because natural gas processes, including exploration, production, and transportation, are time consuming and because all of the produced natural gas is not always needed at various destinations, a part of the extra gas is injected into storage units, which usually are located near market centres and are usable for unlimited periods. Gas storage is one of the new and critical steps of the natural gas network process that must respond to the demands of different periods of the year.

Traditionally, during summer months, natural gas was stored to respond to increased demands during the coldest months, but nowadays natural gas demand in summer has increased because special users such as power-generation companies must produce electricity for air conditioners during summer. In addition, natural gas storage plays a critical role in unexpected events such as natural disasters, which may affect production and transportation.

In general, some of the main reasons behind using storage along the natural gas network are its capability to respond to cyclic fluctuations when temperatures vary and consumption is high, improving services to all customers, keeping market shares competitive with other sources of energy, and achieving operations with high load factors. Natural gas storage can be done in different ways, but underground reservoirs are the most important method. The storage deals with pipelines, local distribution companies, producers, and pipeline shippers.

Country	Annual Consumption (Billion m³)	Storage Capacity (Billion m³)	Storage Capacity relative annual consumption	Days Storage
UK	103	4	3-4%	14
Germany	101	19	19%	69
Italy	81	13	16%	59
France	46	11	24%	87
USA	631	114	18%	66

Table 2: *Annual gas consumptions and gas storage volumes in some European countries and USA*

The table shows that **Italy** has a medium position among the listed countries in terms of gas storage security. Italy consumes about 81 billion m^3 per year and has around 13 billion m^3 of storage capacity, equal to about 16% of its annual consumption, or roughly 59 days of supply. This is clearly better than United Kingdom, which has very limited storage, but weaker than both Germany and France, which have higher storage ratios and longer coverage in days. Compared with the United States, Italy's storage-to-consumption ratio is relatively similar, even though the overall size of the U.S. gas market is much larger.

1.5.1 Underground Storage:

The first experience with storing gas underground in depleted oil fields, and particularly depleted gas fields, as well as in water-bearing reservoirs (so-called aquifer formations) and in artificially constructed salt caverns, had already begun during the town gas era.

Deep underground geological formations are particularly attractive for the storage of gas because it can be stored at high pressures deep underground, unlike the large tanks on the surface which are limited to relatively low pressures. Another advantage of underground gas storage is that very large geometrical storage volumes can be created. The combination of high pressures and large volumes are the factors which enable gas storages to achieve extremely high energy storage capacities, even though the density of the gases, even after compression, is relatively low compared to liquid or solid fuels.

The operation of underground gas storage facilities usually involves injecting the gas into the storage cavern under pressure and withdrawing it at a later date by releasing the pressure. This means that underground storage is not only possible in open cavities—such as artificially constructed caverns (see oil storages) but also in natural reservoirs consisting of a matrix of countless interconnected microscopic pores. A special feature of storage operations involving compression and pressure release is that the operational injection and production pressures must stay within a range between a minimum and a maximum operating pressure. The storage capacity achievable within this range is called the working gas. The residual gas which remains in the storage below the minimum pressure is called the Cushi

Advantages	Disadvantages
Use of existing reservoir	Low deliverability per well
Excellent knowledge of reservoir (geology, performance)	Max.(0.5–1)% daily withdrawal of total capacity
Low investment costs for conversion	Max. 1–2 turnovers per annum; low deliverability and injectivity
Possibility of reusing existing wells	High percentage of cushion gas

Table 3: *Advantages and disadvantages of gas storages in depleted oil and gas fields.*

1.5.2 Underground Gas Storage Mechanisms

Salt caverns, aquifers, and depleted gas reservoirs are common locations for underground gas storage. Because of their established infrastructure and demonstrated geological integrity, depleted reservoirs are the most utilised. Gas is compressed and kept under high pressure during injection times. Gas expands during withdrawal periods, which results in temperature drops because of Joule-Thomson cooling effects. Gas must be heated and dehydrated before being delivered into transmission networks due to this thermodynamic behaviour. Temperature stability, withdrawal rate, cushion gas volume, and reservoir permeability all affect storage efficiency.

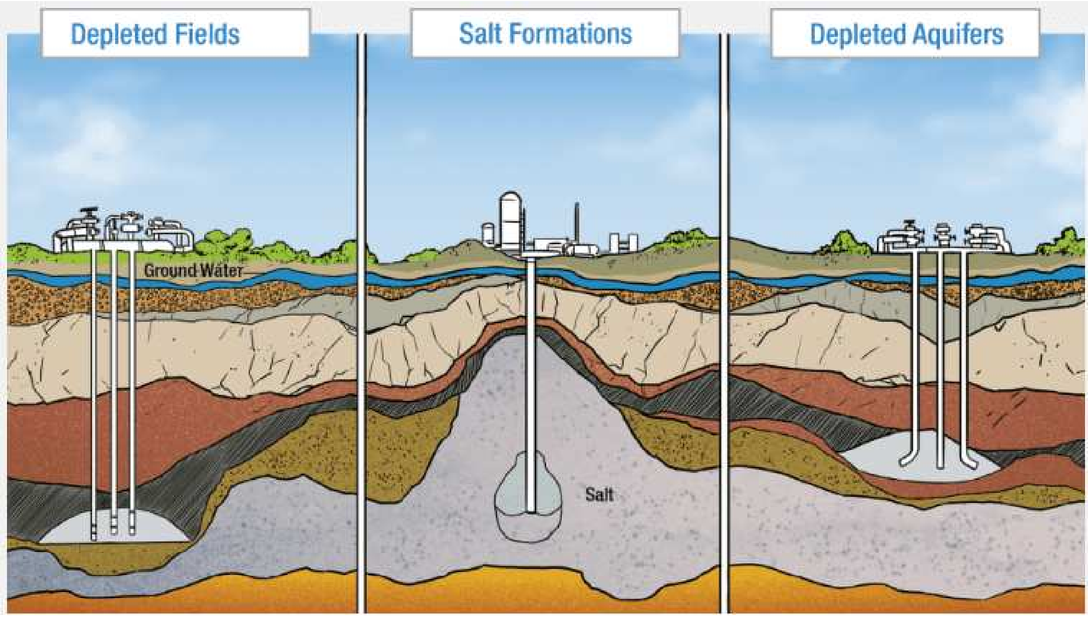

Figure 8 :Underground Gas Storage Types

Storage Type	Capacity	Cost	Response Speed	Typical Use
Depleted Reservoir	High	Medium	Medium	Seasonal
Aquifer	Medium	High	Slow	Long-term
Salt Cavern	Low	Low	Fast	Peak shaving

Table 4: *Storage Type Comparison*

1.5.3 Seasonal Gas Storage Systems

Excess gas can be kept underground in the summer and removed in the winter thanks to seasonal gas storage. Salt caverns, aquifers, and depleted gas reservoirs are common forms of storage.

In contrast to gas removed in the winter, which is typically colder and frequently saturated with moisture, gas injected into storage is typically warm and dry. Treatment procedures like separation, dehydration, and reheating become necessary as a result.

To control these seasonal fluctuations and guarantee gas quality prior to pipeline injection, low-temperature separation (LTS) and heat recovery systems and low temperature valves are frequently employed.

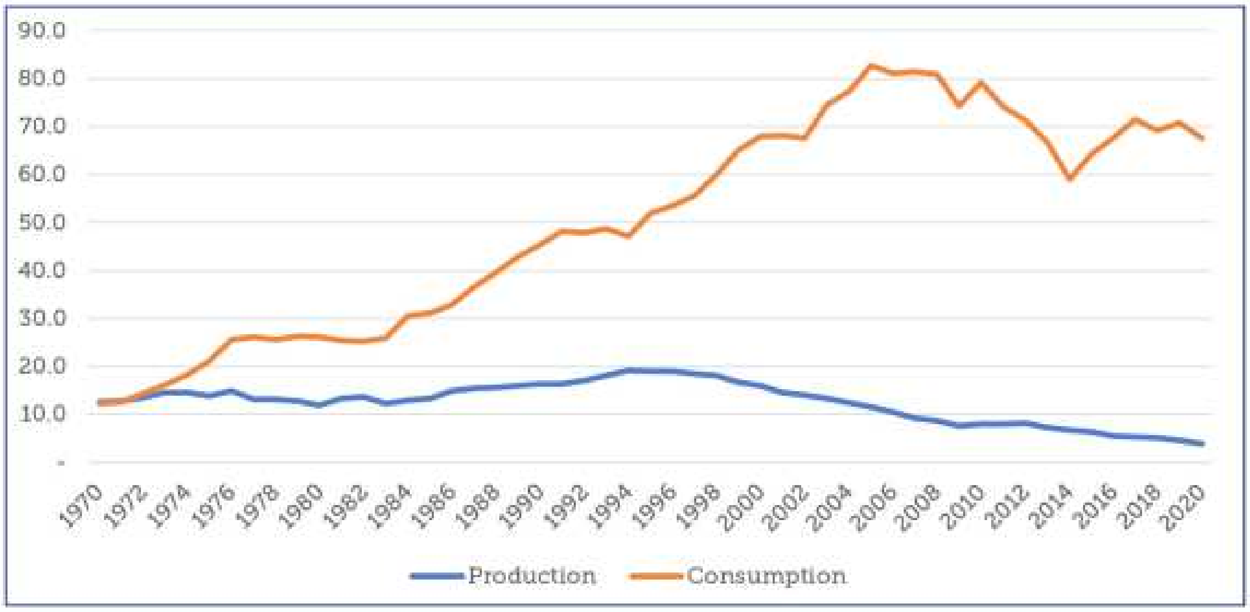

Figure 9: Italy natural gas production and consumption chart

The chart in **Figure 9** shows the long-term trend of natural gas production and consumption in Italy between about 1970 and 2020. Gas consumption grows steadily from the early 1970s, accelerates strongly during the 1990s, and reaches its highest level in the mid-2000s. After around 2008, consumption declines noticeably and then fluctuates at a lower but still relatively high level up to 2020.

By contrast, domestic gas production remains much lower throughout the whole period. It rises only modestly until the mid-1990s, peaks around that time, and then falls continuously afterward. As a result, the gap between consumption and production becomes wider over time. This clearly shows that Italy has shifted from partial selfsufficiency in the past to a much stronger reliance on imported natural gas in recent decades.

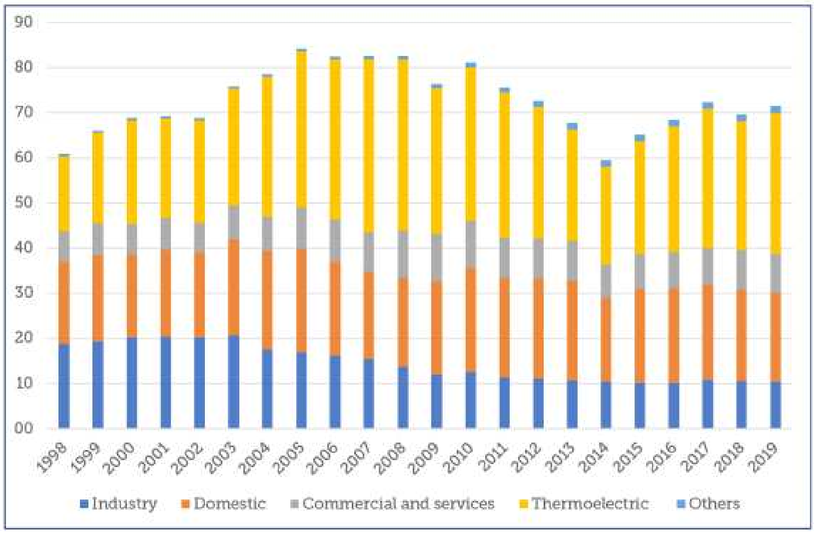

Figure 10 : natural gas consumption by sector from 1998 to 2019

1.6 Conclusion and scope of the Thesis

In conclusion, natural gas is an efficient and environmentally favourable energy resource. Understanding and properly processing it is essential for safe and reliable network operation. This research aims to develop a steady-state Aspen HYSYS simulation of a gas treatment facility to analyse processes, ensure quality standards, identify operational issues, and support optimization.

Chapter -2

RESEARCH OBJECTIVES

This thesis aims to provide an analysis, a model, and ultimately improvements to a natural gas storage and treatment system, using steady-state process simulation to demonstrate how to analyse and improve the efficiency of a typical seasonal gas storage and treatment system.

The main goal of this thesis is to gain an understanding of how natural gas behaves thermodynamically when it is taken out of the ground. Additionally, operational challenges with a typical seasonal gas storage and treatment system will be identified in this thesis. Finally, this thesis will propose a way to optimize the operation of such a system in a technical way to meet NGPN (National Gas Pipeline Network) requirements.

This research combines the basic principles of gas processing with advanced process simulations using Aspen HYSYS v11.

Aspect	Description
Objective	Analyze and optimize seasonal natural gas storage and treatment system using steady-state simulation.
Scope	Study gas behavior during withdrawal and processing to identify operational challenges.
Method	Develop a steady-state model in Aspen HYSYS v11.
Goal	Improve efficiency and ensure compliance with NGPN pipeline requirements.

Table 5: *Thesis Definition Table*

2.1 Objective 1 – System Understanding and Modelling

The first objective of this thesis is to fully understand the Gas Storage & Treatment System and to represent that system using an accurate, steady-state Process Model for the Gas Storage & Treatment System. This involves, among other things, determining all major components of the process, what each of their respective functions are and what their thermodynamic function is in relation to the overall gas system.

The specific points of this objective include:

- Defining the entire gas treatment process from the point of storage withdrawal until the delivery of the treated natural gas to the NGPN.
- Understanding how pressure, temperature and composition change in each step of the gas storage and treatment system.
- Mapping the change in the natural gas's phase behaviour at each step of the gas treatment process (separation, cooling, expansion, and mixing).
- Creating an accurate correlation between the gas operating conditions and the resulting gas treatment performance.
- Completing this first objective provides a solid foundation for continuing development of analysis and gas storage and treatment system optimizations.

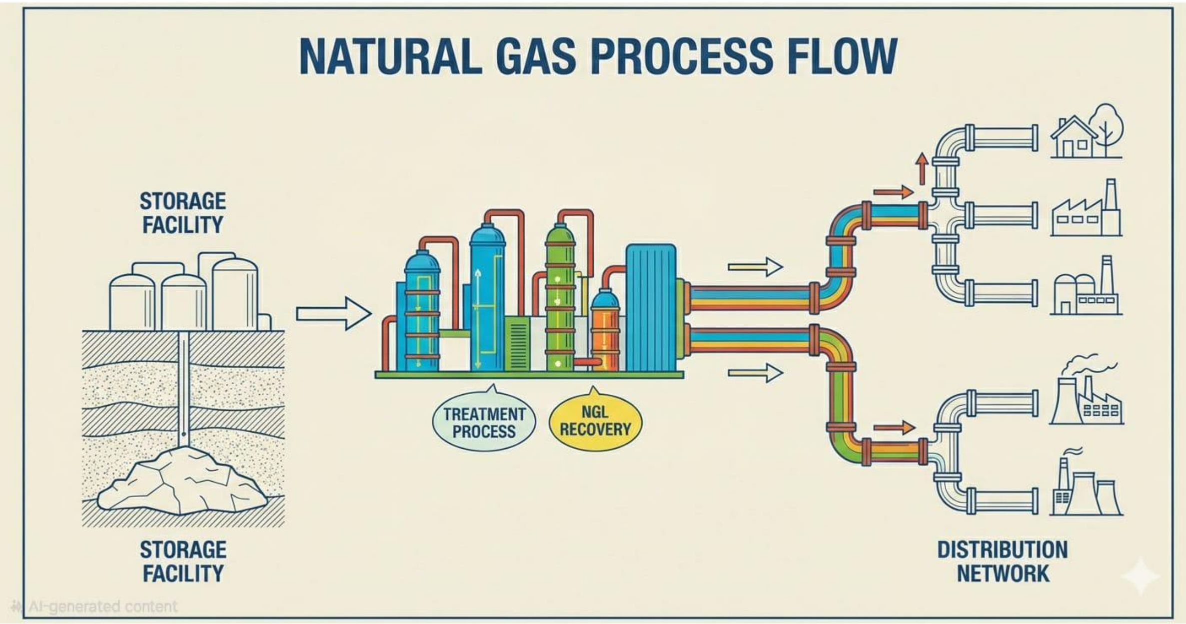

Figure 11: Natural gas process Diagram

2.2 Objective 2 – System Improvement and Optimization

1. The 2nd objective of this thesis focuses on identifying and resolving a significant amount of operational limitation that was discovered during the baseline gas treatment process. The baseline simulation at steady state started revealing that after undergoing Joule-Thomson Expansion and Low-Temperature Separation Processes, the gas temperature was down to about -10 degrees Celsius at the plant outlet. Not only does this violate NGPN-117 standards but also increases the chances of hydrate forming inside the pipeline.

To solve this problem, the following steps have been undertaken:

- An analysis on why the gas cooled excessively in the JT-LTS section.
- A process modification proposal that increases the outlet gas's temperature while still allowing for safe and stable operation will be proposed.
- The proposed solution will be implemented using Aspen HYSYS software to evaluate performance.
- The baseline results will be compared with and without the process modification for outlet temperature, pressure, and phase behaviour.

Requirement	Target condition in this thesis
Outlet temperature	≥ +5°C
Gas dryness	No free water
Hydrocarbon dew point	Within pipeline limits
Outlet pressure	~34 bar
Stable flow rate	~100,000 m^3/day

Table 6: *Target Process Conditions and Regulatory Requirements*

Chapter 3

REAL SYSTEM UNDERSTANDING

3.1 Seasonal Gas Storage in real Systems

Gas storage during seasonal extremes plays a key role in the infrastructure for natural gas in many parts of the world. Countries that have wide-ranging seasonal variations in energy needs (such as Italy) greatly depend on underground geological formations to store excess gas.

These underground geological formations (including depleted reservoirs, aquifers, and salt caverns) serve as natural storage for large quantities of gas at very high pressures.

As gas consumption increases dramatically during the winter months (for heating purposes), the stored gas is taken from the underground geological formations. However, there are some differences between the properties of gas stored and that being removed during this time of year. In most cases, injected gas will have been warmed up and dried out when it is stored; but when gas is taken out of storage, the thermodynamic states of the gas will have changed, and in the winter months, this gas will have absorbed heat from the surrounding rock, leading to cooler (more saturated with water and heavier hydrocarbon) gas.

Consequently, extracted gas cannot be sent directly to the transmission network; it needs to undergo additional conditioning processes (pressure reduction, phase separation, dehydration, and/or reheating) to restore the qualities of the gas to acceptable levels for transport through the pipelines.

To effectively handle these seasonal fluctuations, storage facilities frequently incorporate heat recovery networks and low-temperature separation (LTS) systems. To guarantee that the gas supplied to the National Gas Pipeline Network (NGPN) is dry, safe, and compliant with regulations, these systems combine Joule-Thomson expansion, phase separation, and thermal control.

3.2 Natural Gas Treatment and Conditioning Process

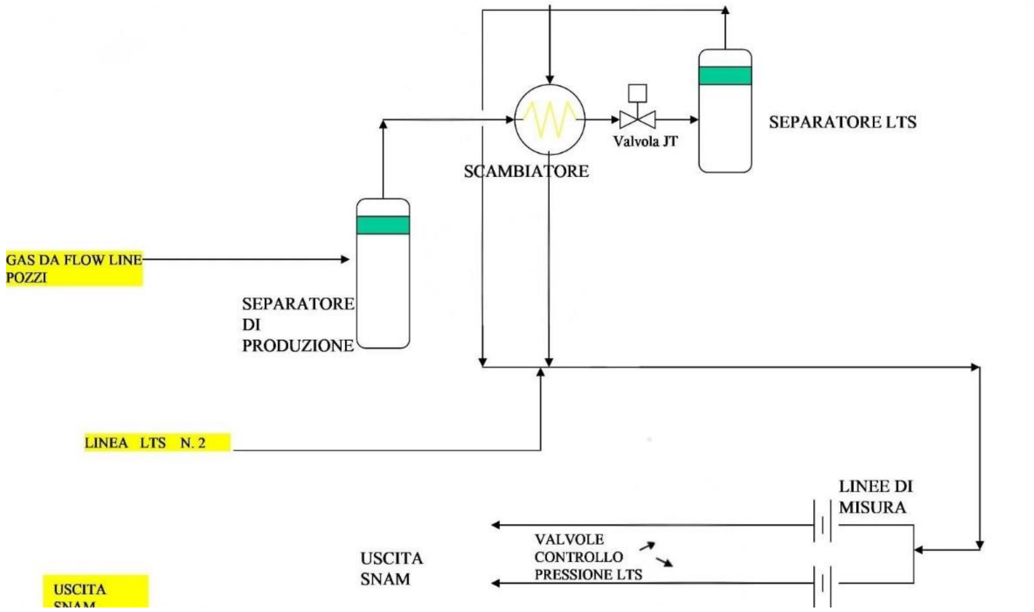

Figure 12:Process Flow Diagram

This diagram represents a natural gas treatment process using a Low Temperature Separation (LTS) system. The natural gas enters from the flow line coming from the wells, and it is mixed with impurities such as water, condensates, and possibly solid particles. First, the gas passes through the production separator, where bulk liquids (free water and condensate) are removed.

After that, the gas flows to a heat exchanger, where its temperature is reduced through heat exchange. Then, the gas expands through a Joule–Thomson (JT) valve, which causes a further temperature drop due to pressure reduction. This cooling promotes condensation of heavier hydrocarbons and remaining water.

The cooled stream then enters the LTS separator, where condensed liquids and water are separated from the dry gas. Finally, the treated gas goes to the measurement lines and pressure control valves before being sent to the export line .

main component names shown in the diagram:

1. **Production Separator**
2. **Heat Exchanger** (Scambiatore)
3. **Joule–Thomson (JT) Valve**
4. **Low Temperature Separator (LTS Separator)**
5. **Measurement Lines**
6. **Pressure Control Valves** (Valvole Controllo Pressione LTS)

3.3 Gas Specifications and Design Basis

The trimodal gas treatment and storage design presented in this thesis is developed from the typical operational constraints of a representative Italian Gas Storage Facility, where these characteristics would be the basis of the steady state simulation in the Aspen HYSYS software.

The gas being withdrawn from storage is assumed to be primarily composed of methane, with minor components of heavier hydrocarbons and inert gases. This is consistent with the normal composition of European gas storage.

The presence of heavy hydrocarbons and trace amounts of water demands special care to ensure that these substances do not condense into liquid form, form hydrates or corrode downstream pipelines.

For simulation purposes, we will assume the gas is non-corrosive, provided there is no moisture present. Conversely, any moisture in the system, coupled with carbon dioxide, could potentially cause localized corrosion/rusting if the gas were to condense on certain areas. Therefore, we consider dehydration and the use of corrosion-resistant materials to be critical aspects in the design of a trimodal gas treatment and storage facility.

There are five primary design parameters which define the operating envelope of a trimodal gas treatment and storage facility and provide guidance for process design and equipment selection: 1) Inlet Pressure; 2) Inlet Temperature; 3) Gas Composition; 4) Flow Rate; and 5) The Target Outlet Conditions Required by the National Gas Processing Network.

Common Name	*Chemical Name (IUPAC)*	*Chemical Formula*
Methane	**Methane**	CH_4
Ethane	**Ethane**	C_2H_6
Propane	**Propane**	C_3H_8
i-Butane	**2-Methylpropane (Isobutane)**	C_4H_{10}
n-Butane	**Butane (n-Butane)**	C_4H_{10}
i-Pentane	**2-Methylbutane (Isopentane)**	C_5H_{12}
n-Pentane	**Pentane (n-Pentane)**	C_5H_{12}
n-Hexane	**Hexane (n-Hexane)**	C_6H_{14}
CO_2	**Carbon Dioxide**	CO_2
Nitrogen	**Dinitrogen**	N_2
Helium	**Helium**	**He**
H_2O	**Water (Oxidane)**	H_2O

Table 7: *Initial Natural Gas Composition for Simulation Feed*

3.4 Equipment Description

A complete description of seasonal gas storage and treatment systems will be provided within this section for the main process units. Every process unit will be described according to function and operation principles, and also their relatedness to the complete process of seasonal storage and treatment of gas. The equipment selected for this section represents normal operating practices within the gas processing industry, and the equipment design is typical of many European gas storage facilities.

3.4.1 Production Separator

The First Stage Separating Product Separator or Production Separator is designed to prevent overloading, hydrate formation and filing on critical components such as heat exchangers, valves and low-temperature production separators, which increases process reliability and safety.

From a green engineering perspective, the Production Separator allows hydrocarbons to be recovered that would have been lost as a result of the process and treated seawater for reuse or re-injection to eliminate environmental discharges. assistance to engineers and designers, regarding the design and operation of gas conditioning plants associated with underground natural gas storage.

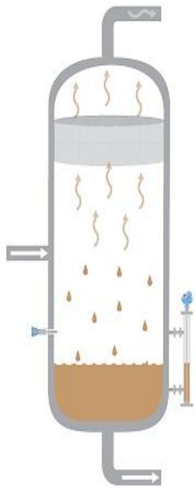

Figure 13 : Production separator

3.4.2 Heat Exchanger

Heat exchangers serve several functions throughout the treatment process, including as a cooler for gas prior to Joule-Thomson expansion during dehydration and as a means of heating gas during winter withdrawals before final delivery.

Two different types of heat exchangers are commonly used:

- The Printed Circuit Heat Exchanger (PCHE) is compact, has high efficiency, and is also best suited for use in high-pressure applications.
- The Shell-and-Tube Heat Exchanger is designed for harsh environments as it is both robust and highly resistant to corrosion.

By integrating the heat from the hot streams and the cool streams together, it is possible to greatly lower the total amount of energy used and reduce the amount of CO_2 being produced, typically by between 10% and 20%

Figure 14: : exploded view of a printed circuit heat exchanger

3.4.3 JT Valve (Joule–Thomson Expansion Valve)

The Joule–Thomson (JT) Valve is essential in providing cooling to gases by means of adiabatic expansion. As high-pressure gases travel through the JT Valve, they will undergo a Joule–Thompson effect upon expansion when this occurs, a cooling will take place and this cooling will cause condensation of heavier hydrocarbons and water vapour below the LTS. While operating is enthalpically, the JT Valve does not add or remove work to the process when the gas reaches atmospheric temperature.

Figure 15: : Pneumatic Actuated Globe Control Valve

3.4.4 Low Temperature Separator (LTS)

A Low-Temperature Separator (LTS) is a type of machine that separates out all of the moisture and water in treated gas. The objective of a low-temperature separator is to create a clean gas that meets both pt. and dew point specifications for pipeline entry. The operation of LTS operating at temperatures below 40°F will result in improved separating performance. Liquid carryover from low temperature separators to the transmission system is minimized when the separation efficiency is improved by the operation of low temperature separators through the recovery of heat exchange.

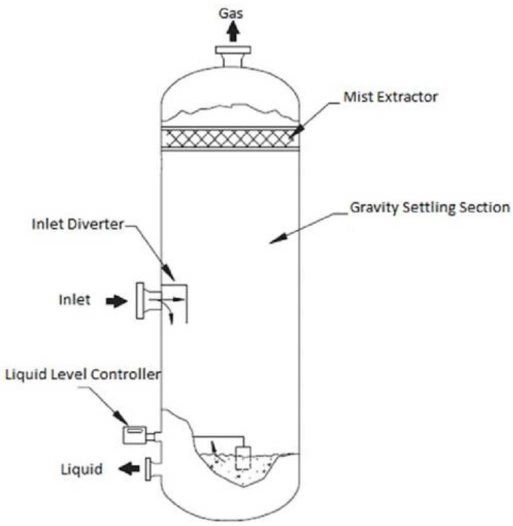

Figure 16: Schematic of a Vertical Gas-Liquid Separator

3.4.5 Pressure Control Valves

Pressure Control Valves control and maintain a consistent operating pressure within a Treatment and Export System, protecting downstream equipment from overpressure damage while providing reliable and safe gas delivery to the NGPN.

Properly maintaining consistent pressure during gas processing has the added benefit of reduced compressor energy costs, lower mechanical stresses on pipelines, and decreased chances of methane emissions resulting from pressure fluctuations

Figure 17: Electric Actuated Control Valve with Manual Override Handwheel

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3.5 Production Separator Design and Working Principle

Production separators are pressure vessels that separate gas, liquids, and water using gravity, centrifugal action, and residence time. Factors that affect the efficiency of the separation include inlet velocity, separator vessel geometry, time available for droplet settlement, and internal separation devices such as diverters, mist extractors and baffles.

Gas-liquid separation is achieved through gravity acting on heavier liquid droplets, causing them to settle while gas will flow upwards under the influence of buoyancy. Proper sizing of a separator provides the necessary residence time for droplet coalescence, so they may fall into the liquid section. When separators are sized improperly, there is an increased likelihood of liquid carryover into gas pipelines where it can cause damage to compressors and hydrate blockages.

Separation efficiency can be estimated from the terminal settlement velocity of droplets, which is determined by the droplet size, the difference in densities of the fluids and the viscosity of the gas. For natural gas processing facilities, separators are key components to remove free liquid prior to downstream cooling and expansion.

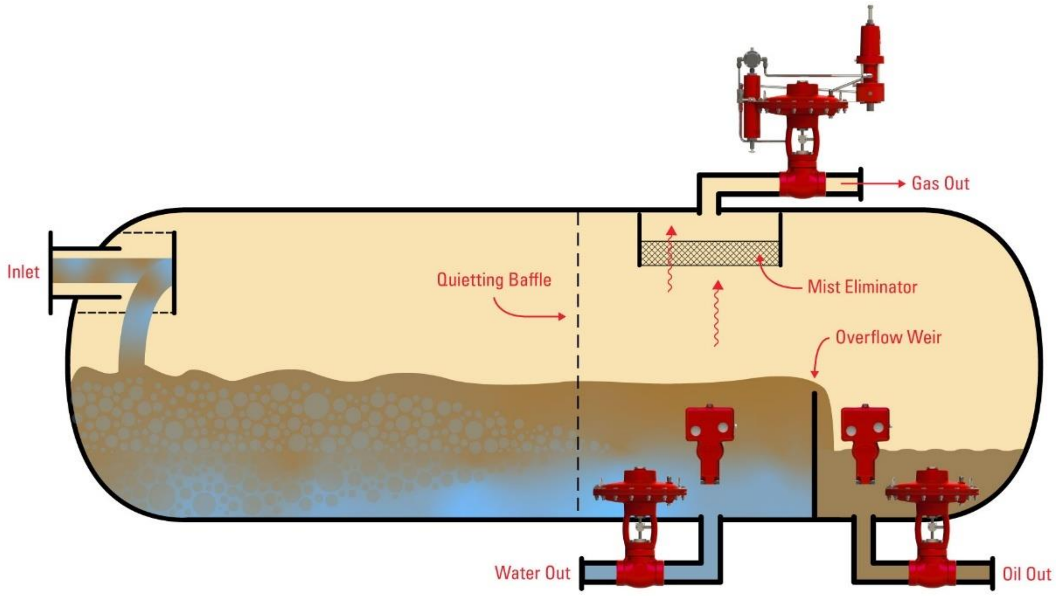


Figure 18: Separator Internal Layout

Parameter	Typical Value	Function
Operating Pressure	20–110 bar	Phase stabilization
Gas Velocity	3–6 m/s	Prevent liquid carryover
Residence Time	2–5 minutes	Liquid separation
Droplet Cut Size	150–300 µm	Removal efficiency

Table 8: *Separator Design Parameters*

3.6 Heat Exchanger Design Considerations

Process streams utilize a heat exchanger as a method of transferring heat energy from one stream to another for temperature regulation, in order to avoid problems with excessive cooling during compression, expansion or separating process steps.

Excessive cooling may cause the formation of hydrates or cause condensation of hydrocarbons in the gas treatment stream.

The main design parameters that must be considered in the design of heat exchangers include the heat transfer coefficient, temperature differential, fouling factor, and the allowable pressure drop. The Shell and Tube and Printed Circuit Heat Exchanger are two of the most common types of heat exchangers due to their efficiency, reliability, and strength.

The thermal performance of a heat exchanger is governed by the energy balance equation:

$$Q = \dot{m} \cdot C_p \cdot \Delta T$$

where Q is heat duty, $\dot{m}$ is mass flow rate, C_p is specific heat capacity, and ΔT is temperature change.

Figure 21: *Heat Exchanger Temperature Profile*

Parameter	Typical Range
Inlet Gas Temperature	−5°C to 27°C
Outlet Gas Temperature	5°C to 9°C
Heat Duty	0.5–5 MW
Pressure Drop	< 0.5 bar

Table 9: *Heat Exchanger Performance Metrics*

3.7 Joule–Thomson Valve Thermodynamics

Through the concept of the Joule-Thomson (JT) principle, gas is allowed to escape from a high pressure to a lower pressure at constant enthalpy, which generates a change in temperature as compared to the initial state. The cooling generated by the JT expansion of methane-rich natural gas at pipeline operating conditions.

Many factors affect the amount of cooling generated by the JT expansion including, but not limited to, the gas composition, the inlet pressure, and the inlet temperature. Improperly controlling the temperature of gas entering the JT stage may cause excessive JT cooling, resulting in liquid hydrocarbons and/or hydrates forming in the JT valve.

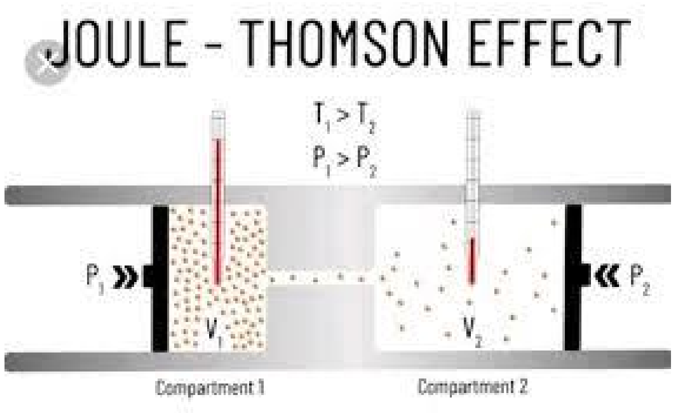


Figure 19: Joule–Thomson Cooling Effect

3.8 Low Temperature Separator (LTS) Functionality

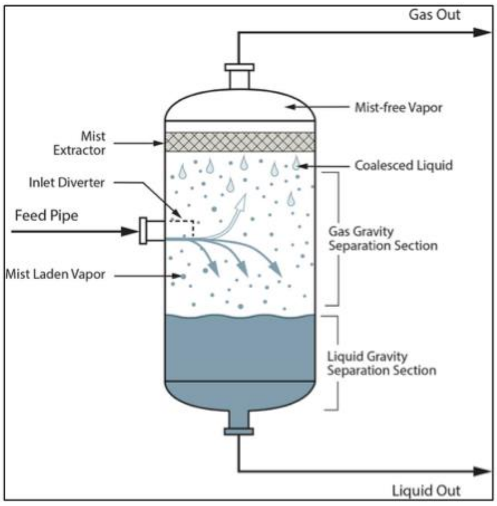


Figure 20: LTS Operating Principle

The Low Temperature Separator (LTS) is used to remove any condense liquids that were created after the JT cooling process so that the downstream gas pipelines do not receive liquids such as hydrocarbons and/or water.

It includes equipment such as demisters, vortex breaks, and insulated walls which help to regulate the LTSs' temperature. The operator must maintain the correct temperature in order to optimally recover condensed liquids while preventing hydrocarbon hydrate formation.

Parameter	**Typical *Range***
Operating Temperature	*−20°C to 5°C*
Operating Pressure	*20–70 bar*
Liquid separation	*85–95%*
Gas Dew Point Reduction	*10–25°C*

Table 10: *LTS Operating Conditions*

3.9 Pressure Control Valve Behaviour

Pressure control valves help to establish flow and prevent unstable pressure fluctuations due to improper tuning. An ideal setting will allow for consistent delivery of gas at a stable rate and limit pressure surges that can result in JT overcooling.

In addition to controlling flow, control valves also provide a safeguard through the ability to control the blowdown process and to control the reduction in pressure during an emergency situation.

Chapter 4

PROCESS MODELING IN ASPEN HYSYS v11

4.1 Introduction:

To accurately replicate the design and analysis processes of gas processing systems today, engineers are utilizing modelling tools to provide accurate thermodynamic predictions for phase equilibrium (physical phases existing together) and energy interactions under all realistic operating conditions. The cost, time and complexity of testing a gas treatment plant of industrial size is extremely high. Because of this, simulation of your processes with modelling tools is a very important aspect of optimizing and designing your processes.

In this thesis, Aspen HYSYS v11 has been selected to perform a steady-state (steady) model simulation of a gas treatment and storage facility. The model consists of several key process units used for the conditioning of gas during the withdrawal phase of the process, including Separation, Heat Exchange, Joule-Thomson Expansion, Low Temperature Separation and Final Mixing before Transportation by Pipeline to Market.

The simulation is more than a graphical representation of a process. It is a virtual laboratory for evaluating and graphically displaying thermodynamic variables like pressure, temperature, molecular make-up and phase behaviour of the physical product throughout the entire operation of the facility. In addition to providing the ability to simulate the processes, the model also provides a mechanism for evaluating high priority issues within Gas Conditioning processes, including temperature drop across the JT Valve, liquid formation in the Low Temperature Separator, and effectiveness of Heat Integration strategies.

Objective	Expected outcome
Thermodynamic accuracy	Realistic prediction of temperature and pressure profiles
Phase behaviour analysis	Clear understanding of condensation and separation
Baseline model	Reference for optimization
Scenario simulation	Ability to test different operating conditions
Documentation	Model suitable for academic and technical reporting

Table 11: *Simulation objectives and expected outcomes*

4.2 Objectives of the Simulation

A steady-state simulation in Aspen HYSYS is developed to achieve the following technical objectives:

1. Thermodynamic Accuracy - Ensure that the model accurately represents the behaviour of natural gas, including phase changes, during the operation of all major process units under industrial operating conditions.
2. Phase Behaviour Analysis - Determine the effects of pressure drop and cooling on gas-liquid equilibrium with respect to the Joule-Thomson (JT) valve and Low Temperature Separator (LTS).
3. Baseline for Optimization - Provide a "validated" reference case against which modifications will be made for enhanced operation, heat integration and emission reductions.
4. Predictive Capability - Simulate a variety of operating conditions associated with seasonal underground gas storage withdrawals.
5. Documentation and Repeatability - Establish a structured simulation model, which can be used for the purposes of academic reporting, education and possible industrial applications.

4.3 Why Aspen HYSYS v11?:

The choice of Aspen HYSYS version 11 as the selected simulation software for this study was made for its very high industrial application capability, superior thermodynamic modelling capability, simplicity to use.

The program is extensively used within the petroleum and gas industries when simulating systems related to gas processing, gas separation and gas transportation networks.

Aspen HYSYS is known as the standard software program for modelling and simulating gas processing in upstream and midstream gas processing operations. There are many end-users, including operator companies, engineering consulting firms, and research facilities that use this software program to create/design and analyse both existing designs and new designs of facilities used for gas treatment (such as gas processing plants) similar to the locations modelled in this thesis.

4.4 Detailed Description of the Natural Gas Processing Steps Shown in the Process Flow Diagram:

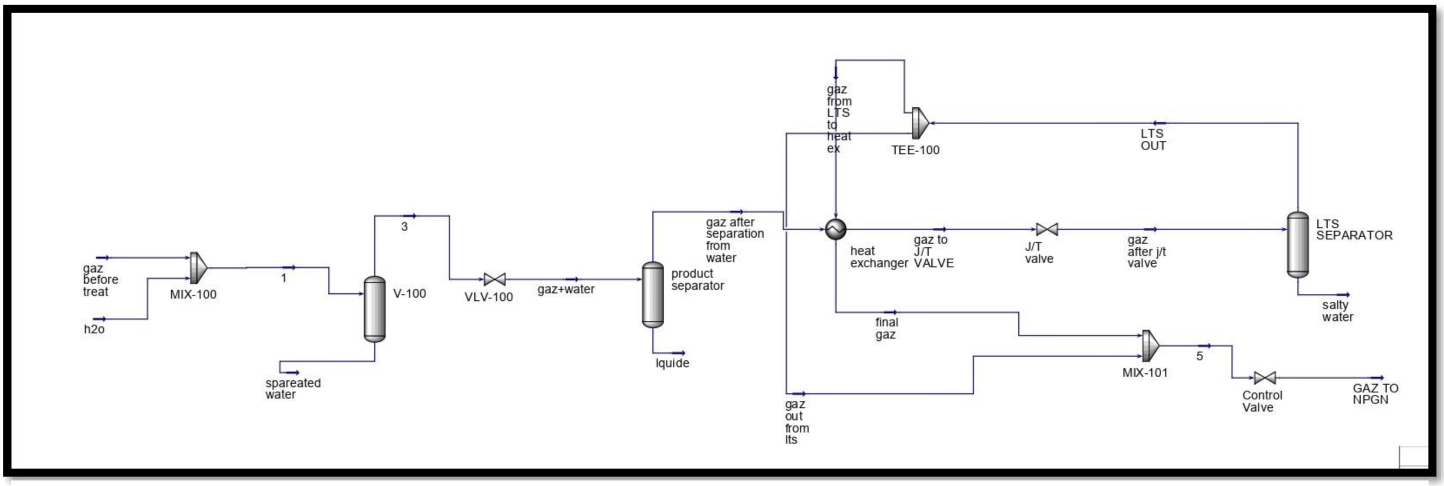


Figure 21: Complete Process Flow Diagram (PFD) for Natural Gas Processing and Separation

Description of the Natural Gas Processing Flow Diagram

Flow Diagram illustrates the natural gas treatment process through several sequential stages. We assume that the gas is mixed with water because we are simulating the gas as it exists inside the reservoir (well), where natural gas is normally accompanied by water and liquid phases due to high pressure and temperature underground.

The process begins with the gas–water mixture entering the **MIX-100** unit, where the flow is homogenized before treatment. The mixture then moves to **V-100**, which operates as a primary separator, allowing free water to settle and leave from the bottom while the gas exits from the top to continue through the process.

After the first separation stage, the gas passes through the pressure control valve **VLV-100** and enters the Product Separator, where remaining liquids and entrained water are removed. The separated liquid leaves from the bottom, while the gas flows to a Heat Exchanger, where it is cooled using cold gas returning from the Low Temperature Separation (LTS) section. This cooling promotes additional condensation of heavier hydrocarbons.

Next, the gas passes through the **Joule–Thomson (J/T) valve**, where a sudden pressure drop causes a significant temperature decrease. As a result, the gas enters the **LTS Separator**, where salty water and condensed liquids are separated at low temperature conditions. In the final stage, part of the processed gas is mixed in MIX101 and then passes through a control valve before being sent to the gas transmission network.

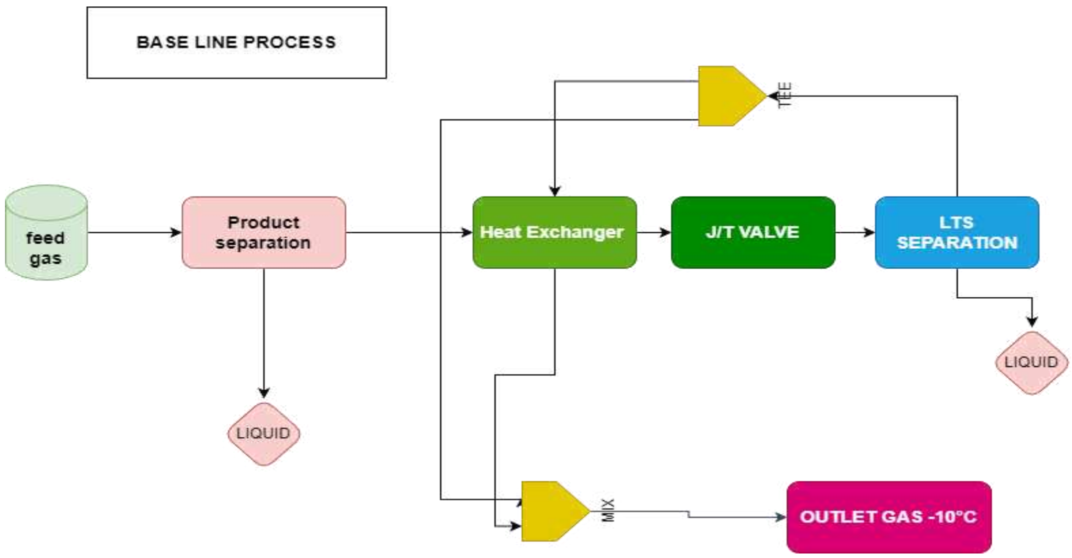


Figure 22: Process Flow Diagram

4.5 Initial simulation setup for Gas treatment process:

4.5.1 Input gas characteristics:

Parameter	Value
Inlet pressure	110 bar
Inlet temperature (baseline)	25°C
Outlet pressure	34 bar
Gas flow rate	~100,000 m^3/day

Table 12: *Input gas characteristics for the HYSYS Model*

The natural gas enters the system at a pressure of 110 bar and a temperature of 25 °C, which represent the normal upstream supply conditions.

The flow rate is approximately 100,000 m^3 per day, indicating a continuous and moderate natural gas throughput.

4.5.2 Choosing thermodynamic Property Package – Peng Robinson EOS (PR-EOS):

To simulate gas processing systems that include phase change and condensation, a thermodynamically reliable model must be utilized in order to ensure accurate results. In the present research, we will use the PR-EOS as our primary thermodynamic property package. PR-EOS is particularly well suited to hydrocarbon systems because it accurately predicts both vapor and liquid phase behaviour for both light and heavy hydrocarbon components. The natural gas industry actively uses PR-EOS in the modelling of gas separation processes and in flashing operations.

The key advantages of PR-EOS include:

- Accurate prediction of vapor-liquid equilibrium conditions during JT expansion.
- Reliable performance at low temperatures resulting from throttling.
- Validated in both academic publications and actual industrial applications

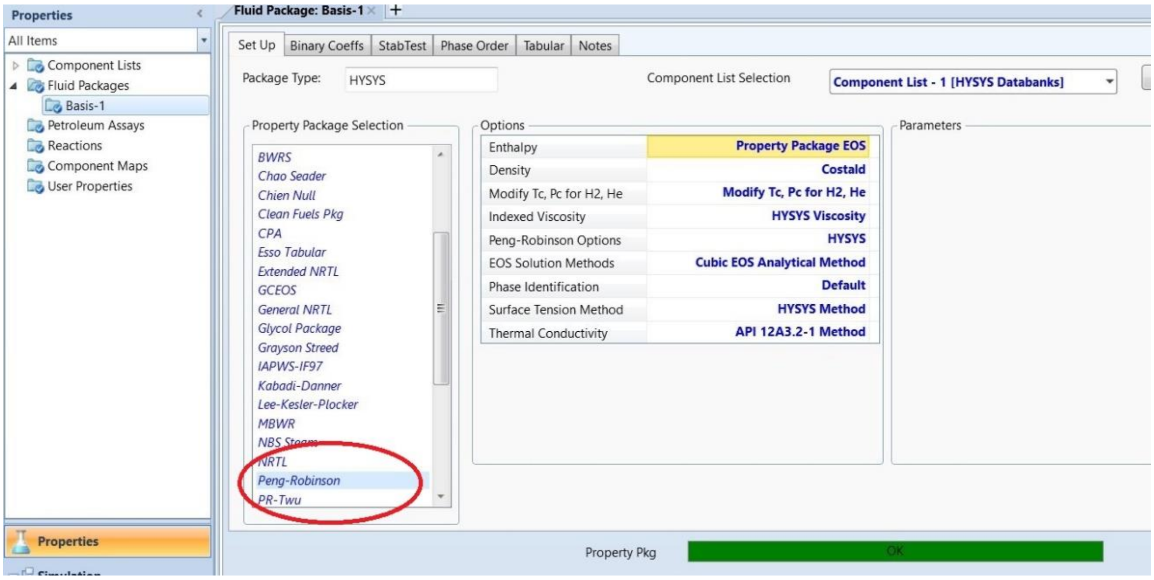


Figure 23: Fluid Package Configuration for Thermodynamic Modelling

Criterion	PR-EOS performance
Hydrocarbon range	Accurate for light and heavy components
Flash calculations	Reliable during JT expansion
Low-temperature stability	Suitable for sub-zero conditions
Industry acceptance	Widely validated and trusted

Table 13: *PR-EOS performance evaluation criteria*

4.5.3 Component Selection:

The following components were selected from the Aspen HYSYS Databank to represent a realistic natural gas mixture pulled from subsurface storage. The components chosen comprise: light hydrocarbons, heavier hydrocarbons, and inert gases commonly present in gas pipeline streams from the storage tanks.

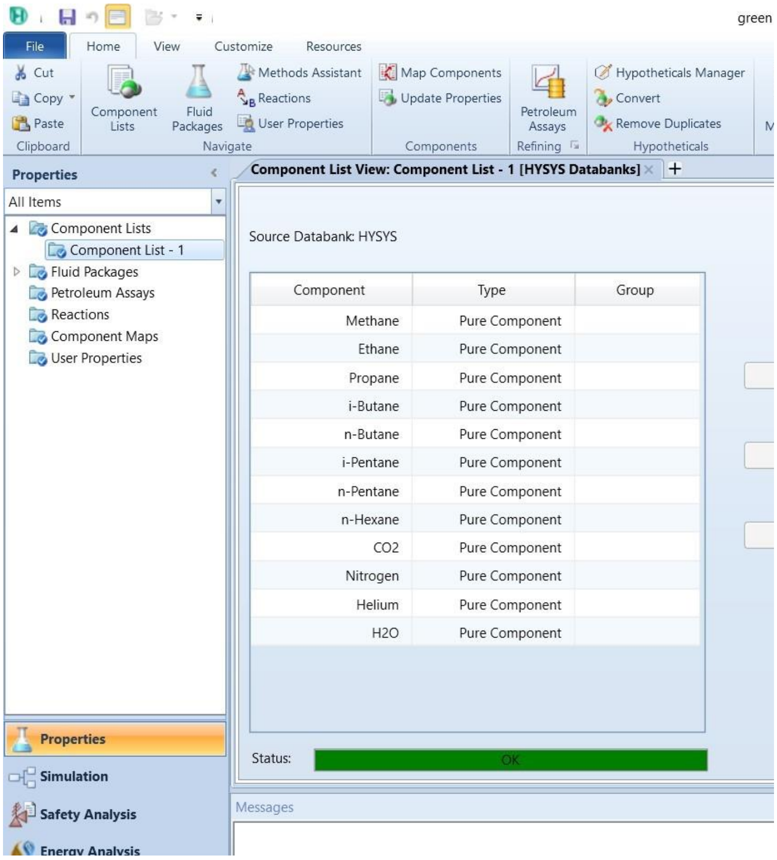


Figure 24: Component List Selection for Natural Gas Mixture

4.5.4 Feed Gas Stream Setup:

In order to accurately represent the gas being discharged from underground storage, the first step in Aspen HYSYS was to set up two separate gas and water streams. These streams were then combined with a mixer block, simulating the combined stream of saturated gas that would be providing the feed stream for treatment.

The gas component of the feed stream was represented using mole percent based on the average of common industry standards to represent natural gas and the saturation point of water, which gave a total composition of 1.000 for both gas and water. The inlet conditions for the feed stream were provided in Table 3.2 for the design.

This method provides the ability for the model to determine the effects of the gas and water phases, allowing for more accurate prediction of the formation of hydrates, the separation of gas and water, and the condensation of water.

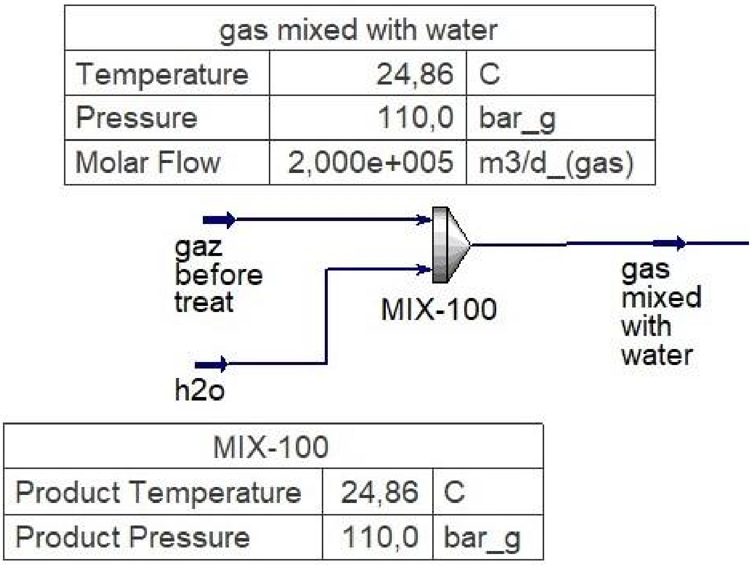


Figure 25: Process Flow Diagram (PFD) for Initial Stream Mixing

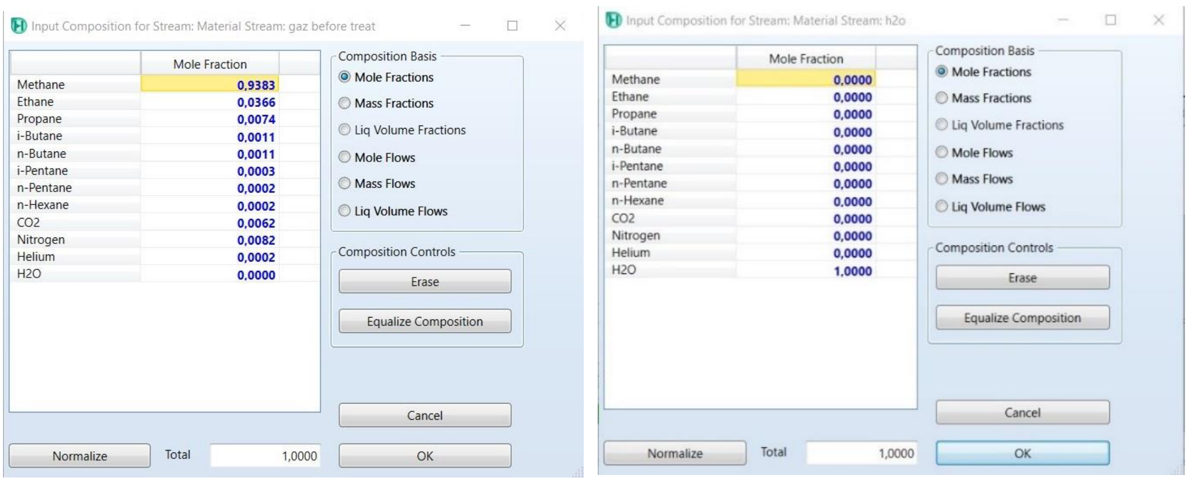


Figure 26: input mole fraction for each composition both streams

4.5.5 Production Separator:

The Production Separator is designed as a two-phase separator with an intermediate operating environment, close to ambient temperature and high pressures. The purpose of this equipment is to separate free liquid from gas before it goes through the remaining cooling and expanding stages of production.

During the simulation, the gas–liquid mixture was subjected to two consecutive separation stages with an intermediate pressure reduction in order to improve liquid removal efficiency. Initially, the feed stream entered **Product Separator 1** at a pressure of **110 bar(g)** and a temperature of **24.86 °C**, with a gas flow rate of **100,000 m³/d**. At these conditions, free liquids and water were separated by gravity, allowing the liquid phase to be withdrawn from the bottom while the gas phase exited from the top of the separator.

The separated gas then passed through the control valve **VLV-100**, where the pressure was reduced from **110 bar(g)** to **82 bar(g)**. This pressure drop caused a temperature decrease from **24.86 °C** to **14.59 °C** due to the drop pressure effect, leading to additional condensation of heavier components and residual water vapor.

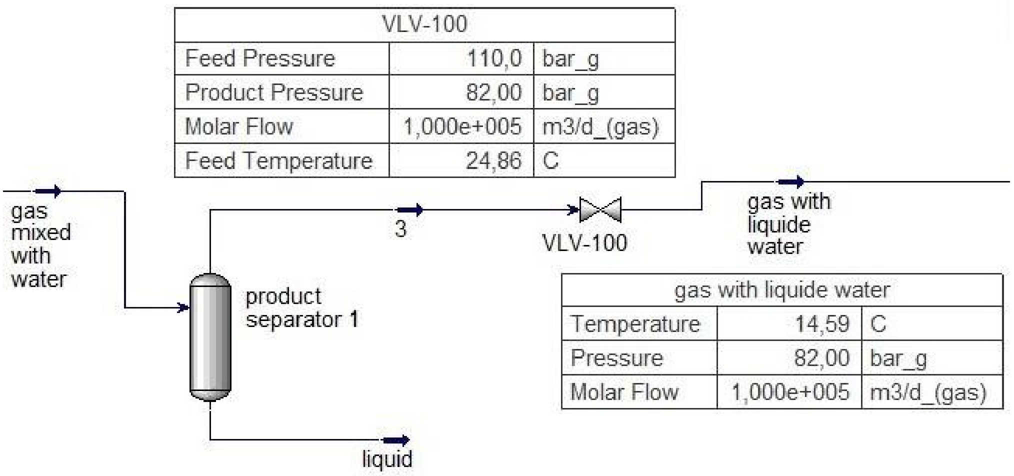


Figure 27: flow sheet of first separation and lowering the pressure

Following the pressure reduction, the cooled gas stream entered **Product Separator 2**, operating at **82 bar(g)** and **14.59 °C**. Under these lower temperature conditions, the newly condensed liquids were separated from the gas phase. The separator removed approximately **15.91 m³/d (gas equivalent)** of liquid, resulting in a significantly drier gas stream suitable for downstream transport to the next treatment stage.

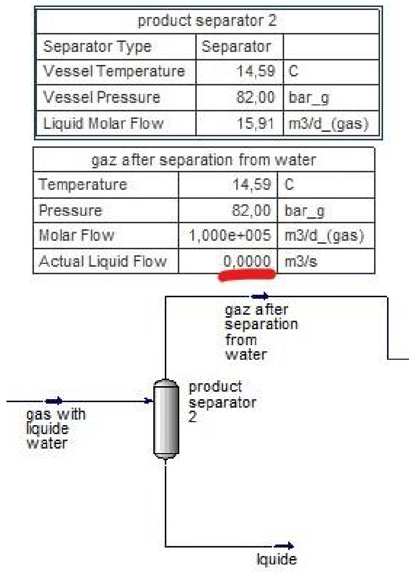


Figure 28: flow sheet of product separator 2

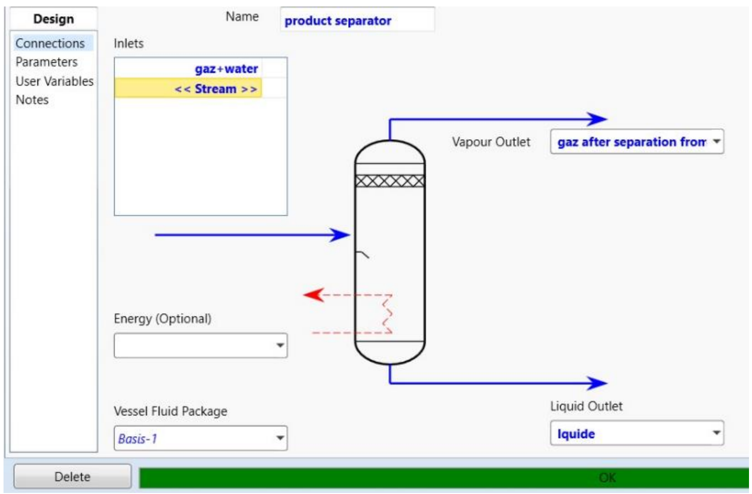


Figure 29: Configuration of Product Separator for Phase Splitting

4.5.6 Pre-Cooling Heat Exchanger and cold-recovery loop:

The heat exchanger helps improve dehydration and hydrocarbon liquids removal, reduces hydrate risk, and improves the overall efficiency of the low-temperature separation process without using an external refrigeration system.

The loop around the heat-exchanger its self-refrigeration loop using the J-T valve and the LTS separator

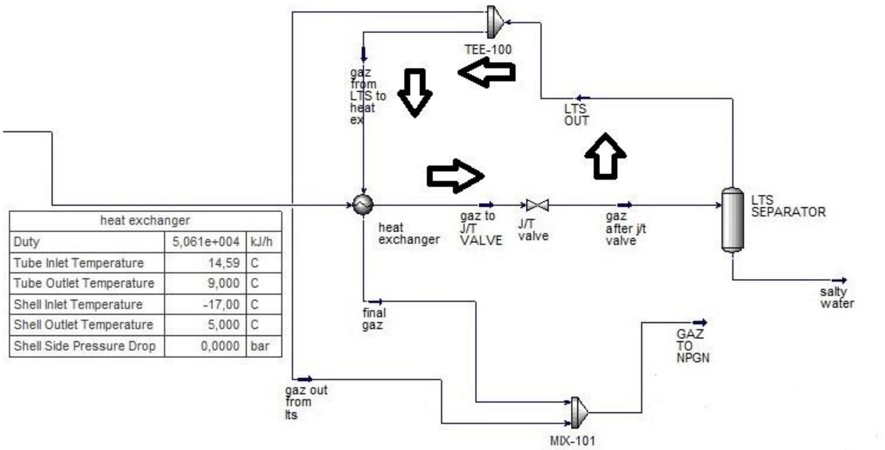


Figure 30: flow sheet of Pre-Cooling Heat Exchanger and cold-recovery loop

Gas enters the heat exchanger

The warm high-pressure gas coming from second separator enters the tube side of the heat exchanger.

From the table we can see that

Tube inlet ≈ 14.6 °C

Tube outlet ≈ 9.0 °C

So, this stream is being cooled inside the exchanger.

At the same time, a cold stream coming from the LTS system flows through the shell side of the exchanger.

From the table we can see also

Shell inlet ≈ –17 °C

Shell outlet ≈ 5 °C

So, the shell outlet stream is warming up by cold-recovery to tube outlet

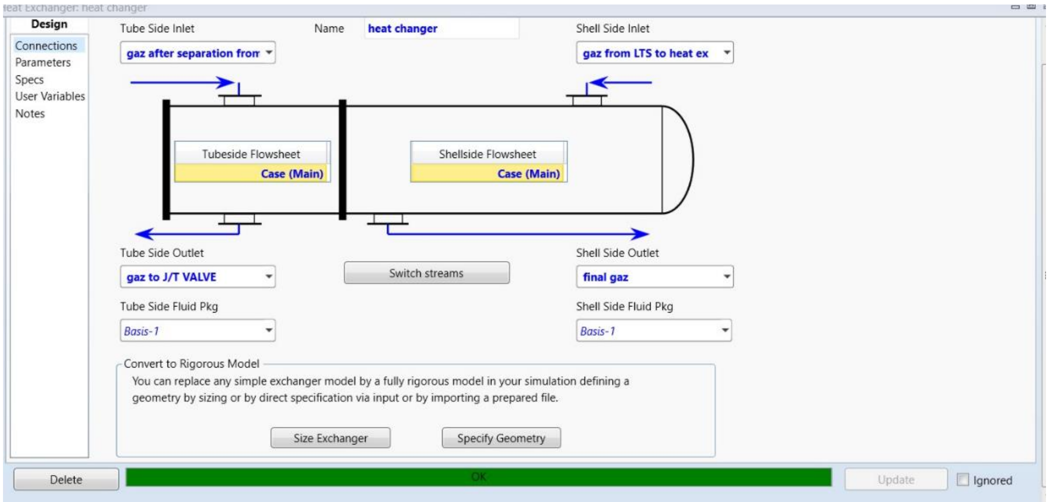


Figure 31: Shell and Tube Heat Exchanger Configuration

4.5.7 JT Valve – Joule–Thomson Expansion:

Natural gas pipelines have strict specifications. If the gas is too rich in heavy hydrocarbons (like propane, butane, pentane), these can condense into liquids inside the pipeline during winter or high-pressure transport, causing blockages and equipment damage.

By cooling the gas to -17°C at the plant, you force these heavy components to condense into liquids now.

J/T valve		
Feed Pressure	82,00	bar_g
Product Pressure	33,98	bar_g
Molar Flow	1,000e+005	m3/d_(gas)
Feed Temperature	9,000	C
Product Temperature	-17,00	C

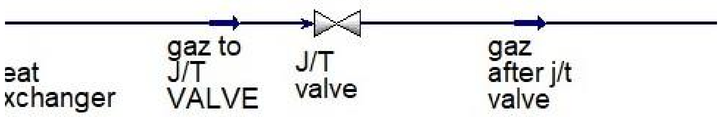


Figure 32: Flow sheet and Analysis of JT valve

4.5.8 LTS Separator:

At -17°C, water and heavy hydrocarbons can no longer stay as a gas, they turn into liquid.

Separation: The liquids are heavier than the gas, so they fall to the bottom.

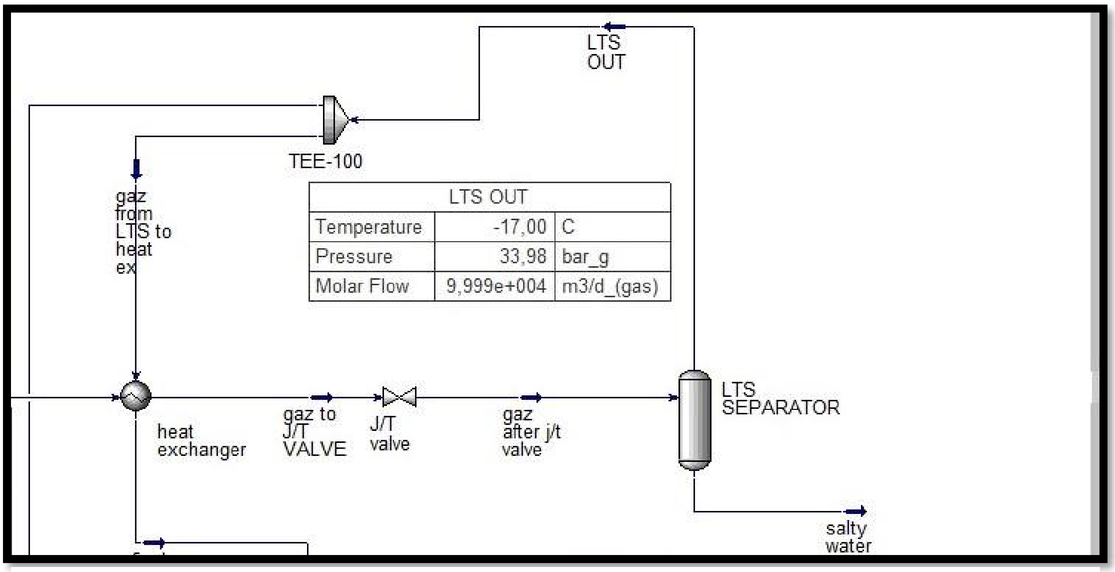


Figure 33: Flow sheet and Analysis of JT valve

4.5.9 LTS OUTLET & TEE-100 Splitter:

The LTS OUT stream consists of the dry, processed gas exiting the top of the LTS SEPARATOR at a temperature of -17°C and a pressure of 33.98 bar_g. This cold gas is directed toward TEE-100, which serves as a junction to route the flow within the system. From this point, the gas is sent to the heat exchanger to act as a cooling medium for the warm incoming feed. This configuration creates a thermal recovery loop, where the cold energy from the LTS OUT stream pre-chills the "gas to J/T VALVE," allowing the plant to reach cryogenic temperatures more efficiently before the final expansion occurs at the J/T valve.

The other stream that bypasses the heat exchanger and goes directly to the gas network is typically

By splitting the stream at TEE-100, you are essentially managing the balance between process efficiency and product requirements. One portion of the cold gas is sent to the heat exchanger to "recycle" the cold energy and keep the plant running at

-17°C, while the other portion is sent directly to the gas network to ensure you are delivering the required volume of high-quality, dry gas

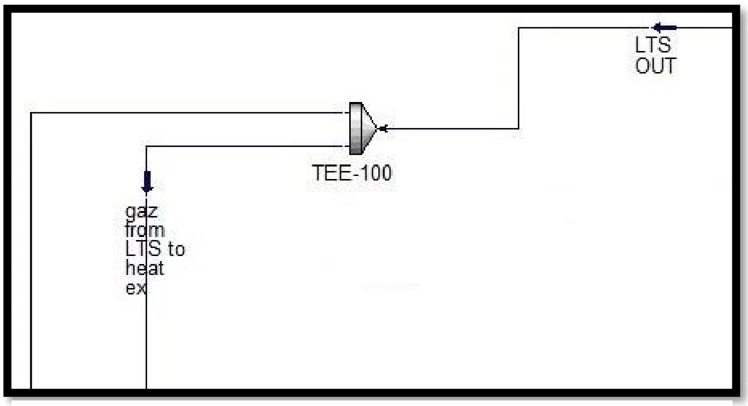


Figure 34: Flow sheet TEE

4.5.10 Mixer and the final stream

Before being delivered to the NGPN, the MIX-101 mixer unifies the gas streams from the heat exchanger and LTS into a single, uniform stream. The mixer stabilizes the final gas properties and guarantees consistency in the mass and energy balance.

The resulting mixture, labelled **GAZ TO NPGN**, meets the final delivery gas for the network:

- **Temperature:** The final temperature is settled at **-10,19°C**. This is warmer than the separator temperature of -17°C because it has absorbed heat while cooling the incoming feed in the heat exchanger but It does not meet the network requirement.
- **Pressure:** The pressure remains stable at **33,98 bar_g approx. 34 bar_g**.
- **Liquid Content:** Crucially, the **Actual Liquid Flow is 0,0000 m3/s**. This confirms the "quality" you mentioned—the process has successfully removed all water and heavy hydrocarbons, ensuring only high-quality dry gas enters the network.

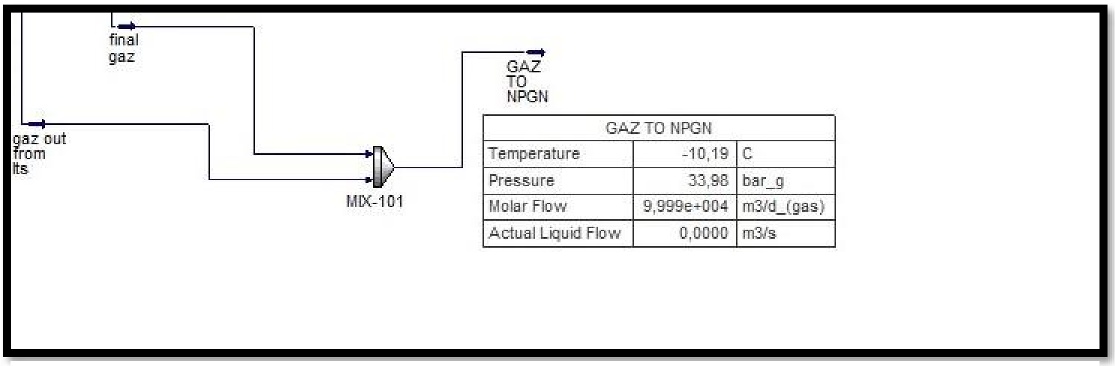


Figure 35: Final Recombination of Gas Streams via MIX-101

Chapter 5

SYSTEM IMPROVEMENT AND OPTIMIZATION

5.1 Problem Statement

During typical operations, Natural Gas conditioning systems that utilize the Joule - Thomson (JT) Expansion Process and Low Temperature Separations (LTS), will see significant cooling as a result of two thermodynamic processes. The first, Isenthalpic Expansion, occurs as the gas flows through the JT Valve, while the second is through the removal of Latent Heat during the Condensation of heavier hydrocarbons in the LTS.

Although this cooling effect is beneficial to Liquid Separation in Natural Gas Conditioning Systems, it poses severe Operational and Safety Issues if not carefully managed. For example, the baseline steady state simulation of the Natural Gas Treatment Plant showed that the Gas Outlet Temperature post JT - LTS section had fallen to approximately -10 Degrees Celsius.

Figure 36: Hydrate Formation in the Gas Stream. Gas Hydrates

Gas Outlet Temperature at such a low level signifies a dramatic increase in the likelihood of Hydrate Formation in the Gas Stream. Gas Hydrates, which are Crystal-Like Structures that form when Pressure & Temperature are low enough to induce the combination of Water & Methane, could potentially lead to Blocked Pipelines, Valves, & Instrumentation due to their Crystallization. Additionally, extremely low Gas Outlet Temperatures can result in Operational Difficulties, Excessive Material Stress, and Non-Compliance with National Gas Pipeline Network Delivery Specifications.

These observations clearly concluded that the original configuration of the Natural Gas Treatment Process did not and could not provide safe and compliant delivery of Natural Gas to the Pipeline and needed to be Optimized to raise the Gas Outlet Temperature to a safe and compliant level.

5.2 Compliance Requirement with the National Gas Pipeline Network (NGPN):

Gas transported through National Gas Pipeline Network (NGPN) systems must meet very high-quality and operating standards before entering the system. One of the most important operating conditions requires that the gas is delivered at a temperature above a certain level; generally, at least 5 degrees Celsius.

There are several reasons why maintaining this temperature is important:

- Hydrates will not form within pipelines and valves.
- Heavy hydrocarbons do not condense inside the pipelines, thus preventing damage to our pipelines and valves.
- The transport of gas will have stable thermodynamic properties while being transported.
- Reduced likelihood of interruptions of safe operation of the Transmission System.

For these reasons, all gas treatment facilities connected to the NGPN must be designed and managed to ensure that gas meets or exceeds the specified operating temperature, pressure, and quality constraints.

5.3 Root Cause: JT and LTS Cooling Effect

The extreme drop in temperature shown in the baseline simulation arises from two primary thermodynamic principles:

1. Thermally balanced expansion through the JT Valve - When natural gas expands through the JT valve, it is at a state where no heat is added or taken away (Isenthalpic); the natural gas has a positive Joule-Thomson coefficient (the ability to cool down on expansion), which translates into lowering the temperature of the gas stream at the operating point. Because the gas expands is enthalpically, the temperature of the gas stream will drop dramatically.
2. Condensation of heavier hydrocarbons in LTS - With the condensation of heavier hydrocarbons in the Low Temperature Separator (LTS), heat in the form of latent heat is extracted from the gas stream. This "latent heat" will cause the temperature of the gas stream to decrease even further.

These thermodynamic principles of JT–LTS process configuration are less about adjusting how the gas expands but rather about how to adjust the thermodynamic conditions of the gas before it reaches the JT valve.

5.4 Proposed Solution 1: Heating in the Output point

A heater (Heater – E-101) was installed on the gas export line before sending the gas to the network in order to increase the gas temperature and improve operating conditions. The gas enters the heater at a low temperature of approximately −10.19 °C and passes through it, where thermal energy of about 31.04 kW/h is supplied. As a result, the gas temperature increases to approximately 5.00 °C before being delivered to the gas network, while the pressure remains nearly constant at 33.98 bar(g)

Installing a heater upstream of the gas network is a sound engineering practice that ensures the gas is delivered at an appropriate temperature, maintains equipment integrity, and supports stable and reliable operation with reasonable operating costs.

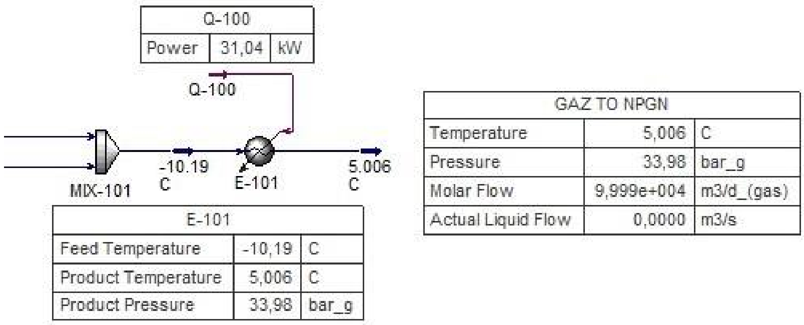


Figure 37: Heater Configuration for outlet stream

5.5 Proposed solution 2: Heat recovery from separated water to increase gas temperature:

To overcome this issue, another solution based on the principle of heat integration was developed by utilizing the thermal energy already available within the process rather than relying on external heating sources. The water separated in the first separator, which would otherwise be considered an underutilized side stream, was employed as a heat source to increase the temperature of the gas in the final stage of the process. To maximize heat recovery, two heat exchangers were installed in series, allowing efficient and gradual heat transfer from the separated water to the cold gas stream.

The implementation of this modification significantly improved the operating conditions of the treated gas by increasing its temperature to a safer level and reducing the likelihood of hydrate formation. As a result, the final gas stream delivered to the NPGN unit achieved a temperature of approximately 8.03°C at a pressure of 33.98 bar, demonstrating the effectiveness of the proposed heat recovery system. Furthermore, this approach offers a cost-effective and sustainable solution, as it recovers and reuses thermal energy available within the process without requiring additional fuel consumption or external heating utilities. Consequently, it enhances the overall thermal efficiency of the plant, reduces operating costs, and provides a practical long-term engineering solution.

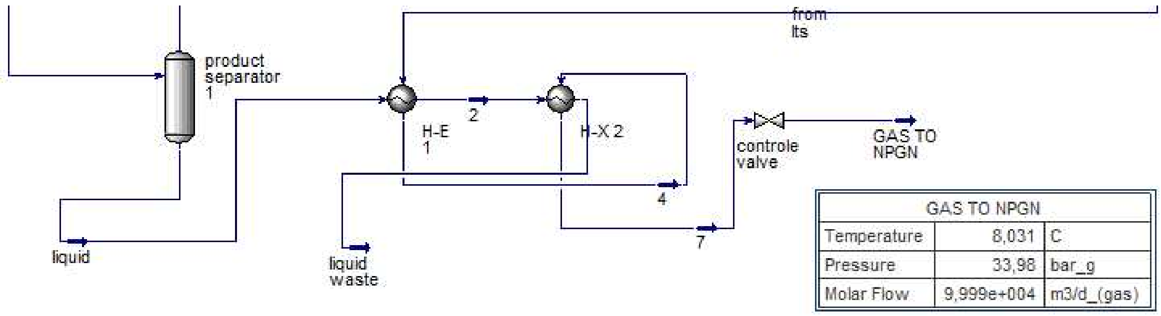
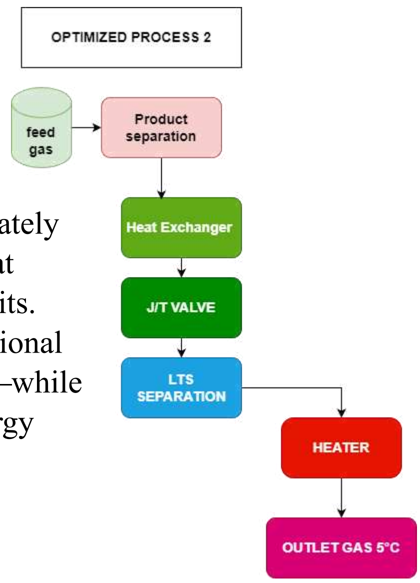


Figure 38: Heat Integration Using Dual Heat Exchangers

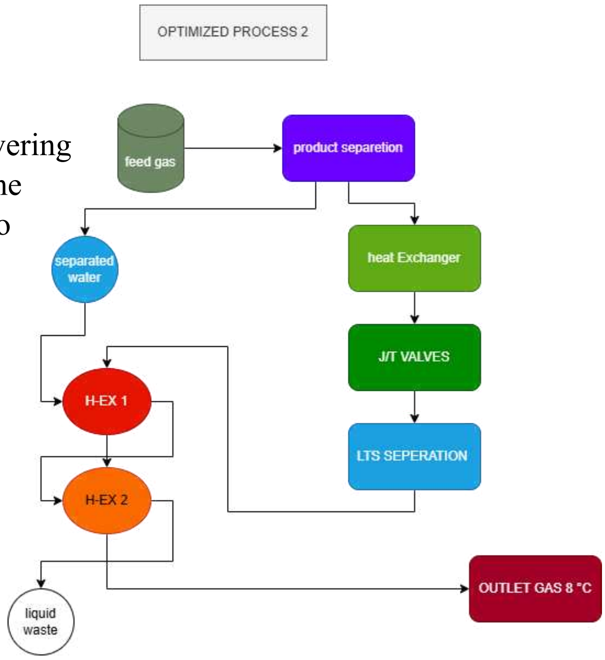
5.6 Comparison between the two Optimization

5.6.1Technical Comparison

A comparison between the two systems shows a clear difference in engineering efficiency and energy performance based on the heating location and required power consumption. In first solution, heating is applied only before delivering the gas to the network, increasing the temperature from −10.19 °C to 5.006 °C using approximately 31.04 kW of heating power, while maintaining the pressure at about 33.98 bar(g) without affecting upstream processing units. This controlled and limited heating achieves the main operational objective—preventing hydrate formation and condensation—while maintaining safe delivery conditions with relatively low energy consumption.



the second solution utilizes heat integration by recovering thermal energy from the water stream separated in the first separator. Two heat exchangers were installed to transfer this available thermal energy to the cold gas stream before its final delivery. This configuration increased the gas outlet temperature to approximately 8.03°C without the need for a dedicated external heater. Consequently, the heat integration approach provides a more energy-efficient and economically attractive solution



5.6.2 Economic Comparison

Alternative 1: External Heater	
Equipment	**Cost (USD)**
Mixer (MIX-100)	8,000
Separator 1	75,000
Separator 2	75,000
Low Temperature Separator (LTS)	95,000
Main Heat Exchanger	85,000
JT Valve	10,000
Control Valve	6,000
Heater E-101	65,000
Piping & Fittings	40,000
Instrumentation & Control	45,000
Total Equipment Cost	**504,000**
Total Installed Cost:	655,000 USD
Total Capital Cost:	720,000 USD
Total Utilities Cost:	92,000 USD/year
Total Operating Cost:	128,000 USD/year
Desired Rate of Return:	15%/year

Table 14: *External Heater costs*

Alternative 2: Heat Integration Using Two Heat Exchangers	
Equipment	**Cost (USD)**
Mixer (MIX-100)	8,000
Separator 1	75,000
Separator 2	75,000
Low Temperature Separator (LTS)	95,000
Main Heat Exchanger	85,000
Heat Exchanger H-E1	55,000
Heat Exchanger H-X2	55,000
JT Valve	10,000
Control Valve	6,000
Piping & Fittings	50,000
Instrumentation & Control	50,000
Total Equipment Cost	**564,000**
Total Installed Cost:	760,000 USD
Total Capital Cost:	840,000 USD
Total Utilities Cost:	18,000 USD/year
Total Operating Cost: 42,000 USD/year	42,000 USD/year
Desired Rate of Return:	15%/year

Table 15: *Heat Integration Using Two Heat Exchangers costs*

The economic evaluation showed that the external heater alternative required a lower initial investment, with a total capital cost of approximately **720,000 USD** compared to **840,000 USD** for the dual heat exchanger configuration. However, the annual operating cost of the heater-based design was estimated at **128,000 USD/year**, nearly three times higher than the **42,000 USD/year** required for the heat integration alternative. Similarly, utility costs were reduced from **92,000 USD/year** in the heater case to only **18,000 USD/year** when two heat exchangers were used.

From a technical perspective, both alternatives successfully prevented hydrate formation by increasing the gas outlet temperature to safe operating conditions. However, the dual heat exchanger system achieved this objective by recovering thermal energy from the separated water stream, thereby reducing external energy requirements and improving overall process efficiency.

Assuming a project lifetime of 10 years, the cumulative operating cost of the heater alternative would reach approximately **1.28 million USD**, whereas the heat integration alternative would require only about **0.42 million USD**. This represents a saving of approximately **860,000 USD** over the project lifetime. Therefore, despite its higher initial capital cost, the dual heat exchanger configuration offers superior long-term economic performance, lower energy consumption, and improved process sustainability, making it the preferred design option.

5.7 Conclusion of Optimization Study

The baseline model indicates a serious temperature control problem within the gas cleaning unit due to which the outlet temperature dropped to roughly -10°C and was therefore out of specification per NGPN. Both proposed alternatives successfully increased the gas outlet temperature and effectively prevented hydrate formation. Therefore, they provide safe and reliable solutions for maintaining stable gas processing conditions.

This enhanced configuration meets all NGPN requirements, eliminates hydrate formation, and increases operational stability of the overall process.

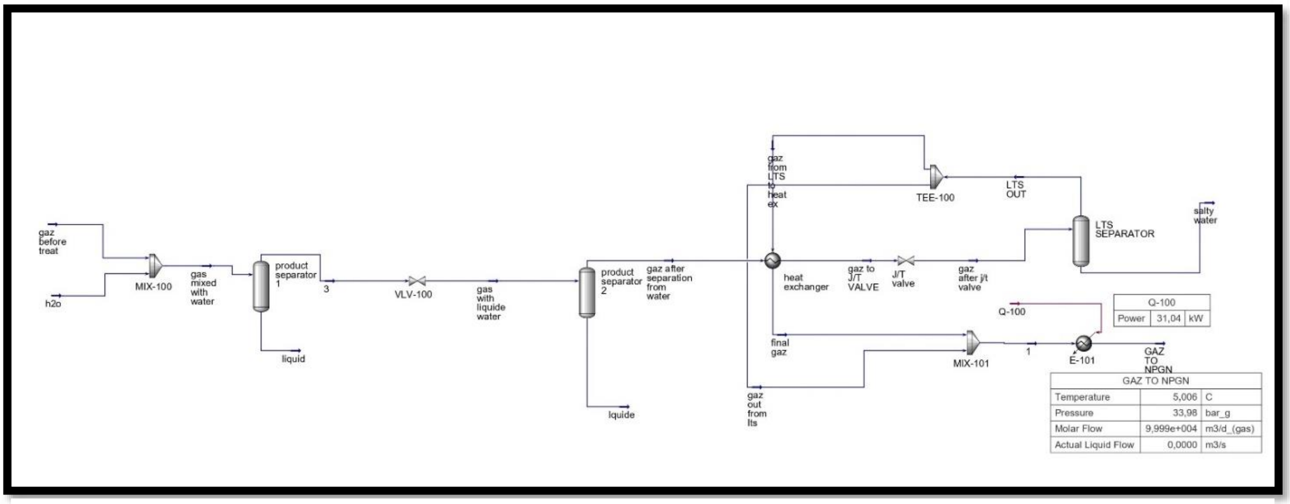


Figure 39: Full Process Flow of optimised Diagram of adding heater

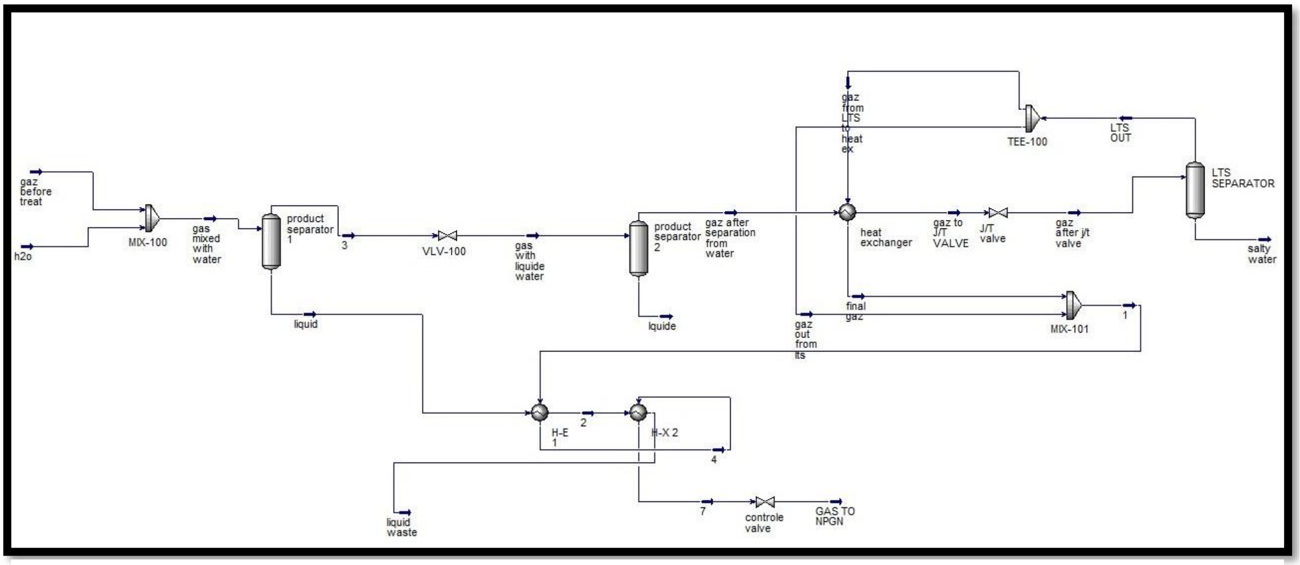


Figure 40: Full Process Flow of optimised Diagram of adding 2 heat exchanger

Important Note
Both alternatives effectively prevented hydrate formation. The dual heat exchanger system reduced energy consumption and operating costs; however, its performance depends on the availability, flow rate, and temperature of the separated water, which may vary under different operating conditions. In contrast, the outlet heater provides a more reliable and practical solution for real industrial applications.

5.8 Final Gas Conditions Delivered to NGPN

Based on the optimized HYSYS simulation results, the final gas delivered to the NGPN has the following conditions:

- Temperature: +5°C/+8°C
- Pressure: 34 bar aprox
- Flow rate**:** approximately 100,000 m^3/day
- Actual Liquid Flow is 0,0000 m3/s

These values are not arbitrary; they are specifically chosen to satisfy typical NGPN entry specifications for temperature, pressure, and flow stability.

5.9 Why These Conditions Match NGPN Requirements

5.9.1 Gas Must Be Dry (No Free Water)

The system ensures dryness through:

- Water removal in the Production Separator.
- Deep cooling and condensation in the JT–LTS section.
- Final liquid removal in the LTS.

As a result, the delivered gas contains no free water and complies with NGPN moisture limits.

5.9.2 Gas Must Not Contain Heavy Hydrocarbons

Heavy hydrocarbons can condense in pipelines and cause operational issues. The LTS effectively removes:

- Condensed hydrocarbons
- Liquid water
- Trace contaminants

This ensures that the hydrocarbon dew point remains within acceptable pipeline limits.

5.9.3 Temperature Must Be Above Pipeline Minimum

To prevent condensation or hydrate formation, NGPN mandates that the gas entering the pipeline is not too cold. This requirement is met by the optimised process, which produces should be more than +5°C.

5.9.4 Pressure Must Be Within NGPN Operating Range

The gas is supplied at 34 brag, which is within the normal pressure range that the NGPN permits for entry points. This enables direct injection without the need for extra compression.

5.10 Baseline vs. Optimized Natural Gas Treatment Process

5.10.1 Baseline Simulation Performance Analysis

According to this study's baseline simulation scenario, the gas storage and treatment plant is functioning at its unoptimized pre-optimization state. The simulation confirmed that a significant decrease in gas outlet temperature occurred because of the Joule-Thomson expansion stage. This decrease in temperature results in an increase in the potential for both hydrocarbon and hydrate formation within the plant, thereby lowering both pipeline safety and compliance with NGPG Gas Input Standards.

Parameter	Baseline Value
Inlet Pressure	110 brag
Outlet Pressure	34 brag
Inlet Temperature	25°C
Outlet Temperature	−10°C
Hydrate Risk	High
NGPN Compliance	No

Table 14: *Baseline operating conditions and key results*

5.10.2 Optimization Strategy

Before heating, the gas temperature dropped to approximately −10°C after the pressure reduction stage, creating conditions favourable for hydrate formation and potentially affecting process reliability. After the heating stage, the gas temperature increased to approximately 5–8°C, providing safer operating conditions, minimizing the risk of hydrate formation, and ensuring that the treated gas met the required specifications for delivery to the NGPN.

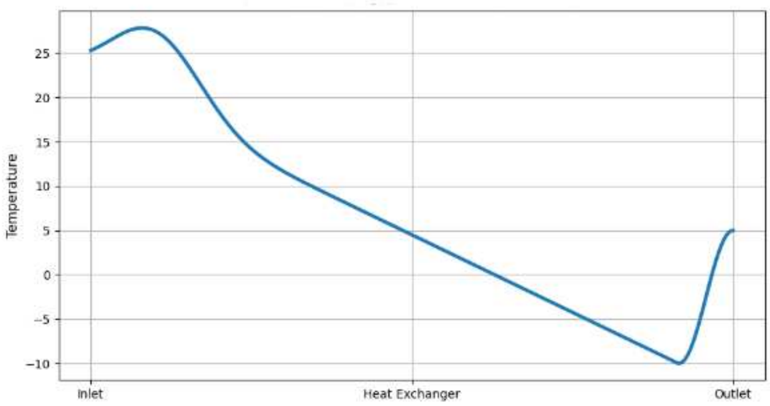


Figure 41: optimized temperature Chart

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Parameter	Baseline Value
Inlet Pressure	110 bar_g
Outlet Pressure	34 bar_g
Inlet Temperature	25°C
Outlet Temperature	+5/8°C
Hydrate Risk	Very low
NGPN Compliance	yes

Table 15: *optimized operating conditions and key results*

5.10.3 Baseline vs. Optimized

When evaluating the performance of baseline systems versus those optimized through change(s), there is evidence of improved processing capability from the change(s) made within both systems. An increase gas temperature is achieved in optimal configurations of both systems, while maintaining steady state pressure and flow to eliminate the formation of hydrate(s) and achieve pipeline delivery specifications.

This improvement indicates that thermal conditioning is one of the most important operational considerations for stored gas treatment during high withdrawal periods. It also suggests that during periods of high withdrawal, the effect of thermal drop(s) is at its greatest.

Performance	Baseline	Optimized
Outlet Temperature	−10°C	5/8°C
Hydrate Formation Risk	High	Low
Energy Efficiency	High	Medium
Operational Stability	Low	High
NGPN Compliance	No	Yes

Table 16: *Baseline vs optimized performance comparison*

5.11 Engineering Interpretation of Results

Based on the findings of the simulation, we can conclude that steady-state modelling is an effective means of evaluating real-world systems used to store and treat gases. The optimization implemented within this study clearly illustrates the potential impact that even minor modifications to processing will have on safety, reliability, and the ability to meet regulatory requirements. The findings presented in this research add credence to the existing views about how important the process simulation is to the modern practice of gas engineering and allow for engineers to identify potential challenges before they occur, thereby implementing technical solutions to mitigate those difficulties.

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CONCLUSION

To analyse the capability of existing natural gas storage and treatment systems, this thesis models the withdrawal phase of a natural gas storage system using Aspen HYSYS version 11 as well as examines gas-conditioning during the withdrawal phase. The modelling includes all major units of a typical natural gas storage and treatment plant including production/separators, heat exchangers, JT expansion, low temp separation, pressure controllers and final blending of gases.

The baseline simulation has identified an important operational post-JT & LTS, the gas temperature drops considerably, posing a greater likelihood of hydrate formation, hydrocarbon condensation and in many cases not complying with NGPN delivery standards. As a means of resolving this issue, 2 methods are created to the system while maintaining constant upstream pressure. This change increased gas temperature of the process system thus providing a compliant gas and helping eliminate hydrate hazards while continuing to provide for a steady state flow rate, gas quality, pressure, etc., that meets regulatory requirements. The modelling results confirm that the process system will perform safely and reliably without requiring significant amounts of additional equipment modification.

This study demonstrated that steady-state process simulation can be an effective tool for diagnosing operational deficiencies in natural gas treatment systems and for identifying ways to make systematic improvements to process performance. This study provides additional insight into the operation of gas storage and treatment systems, as well as a base for future research in the areas of dynamic simulation, optimization of controls, energy efficiency improvements and economic analysis in the natural gas industry.

APPENDIX A

ENVIRONMENTAL IMPACT OF STORED NATURAL GAS PROCESSING

Appendix A.1 Environmental Impact of Stored Natural Gas Processing and Mitigation Strategies

Environmental impacts related to the atmosphere, energy use, and the generation of waste are all products of the processing of Natural Gas taken out of underground storage. This is due to the operations involved with compressing, drying, venting, and treating Natural Gas.

Several strategies may be implemented to mitigate these impacts including improved monitoring of leaks, vapor recovery units (VRUs), energy efficient compressors, and low emitting technologies. The EU Methane Strategy and OGMP 2.0 provide regulatory frameworks to promote best practices for reducing the environmental impact of Natural Gas processing.

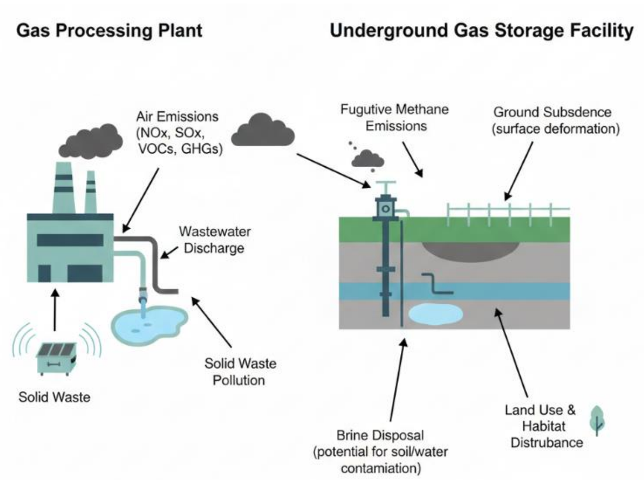

Figure 41: *Main environmental impact sources in gas storage processing*

Appendix A.2 Assessment of Emissions from Stored Natural Gas Processing

Gas Processing and Storage Facilities emit a variety of substances, including; methane (CH_4): which is of particular interest because it is a powerful greenhouse gas compared to CO_2; carbon dioxide (CO_2); nitrogen oxides (NO_x), and Trace Volatile Organic Compounds (VOCs). The major sources of these emissions are compressor exhausts, pressure relief systems, fugitive leaks, and flaring. Quantifying these emissions is important for meeting environmental reporting and regulatory compliance requirements.

Emission Type	Main Source	Environmental Impact
Methane (CH_4)	Fugitive leaks	Greenhouse effect
CO_2	Combustion	Climate change
NO_x	Compressors	Air pollution
VOCs	Valves & seals	Smog formation

Table 17: *Typical emissions from gas storage processing facilities*

Appendix A.3 Environmental Risk Analysis of Stored Natural Gas Storage and Processing

Environmental hazards from the storage and treatment of gas include the possibility of an accidental discharge, contamination of land or soil as well as contaminated groundwater and air pollution. Environmental risk assessment begins with establishing failure scenarios and estimating their likelihood followed by determining the various possible environmental impacts of each failure scenario.

To minimize risks, you can implement safety measures that utilize automated control systems, continuous monitoring of the gas and an emergency shutdown procedure along with secondary containment systems.

Appendix A.4 Impact of Stored Natural Gas Processing on Air Quality

The emissions from methane, carbon monoxide, nitrogen oxides, and other pollutants from gas storage and processing facilities can impact the air quality in proximity to these facilities, often resulting in respiratory health issues from exposure to the pollution over an extended period of time, as well as degradation of air quality across a region. Air Dispersion Modelling is frequently used to determine the concentration of the pollutants and to evaluate whether the facilities are in compliance with the applicable environmental air quality standards, specifically the World Health Organization (WHO) guidelines and the European Union's (EU) Air Quality Directive.

Appendix A.5 Environmental Management of Emissions and Wastes in Stored Natural Gas Processing

Environmental management practices for gas storage operations must focus on producing less pollution by properly handling waste and maximising energy use.

Waste materials produced during a gas storage operation include degraded glycol from dehydrators, sludge from separator operations and treated wastewater.

To achieve effective disposal practices, best practices will include recycling waste materials where possible, the disposal treatment of hazardous wastes, the use of methane recovery systems and the development of environmental monitoring tools to meet the required requirements of ISO 14001.

Waste Type	Source	Management Strategy
Produced water	Separation units	Treatment & reuse
Spent glycol	Dehydration	Regeneration
Solid sludge	Filters	Safe disposal
VOC emissions	Valves & vents	Vapor recovery

Table 18: *Waste streams and management strategies in gas process*