Republic of Yemen

Emirates International University

Engineering and IT Faculty

Chemical Engineering

الجمهورية اليمنية

الجامعة الاماراتية الدولية

كلية الهندسة وتقنية المعلومات

قسم الهندسة الكيميائية

EMIRATES INTERNATIONAL UNIVERSITY

FACULTY OF ENGINEERING AND INFOMRATION TECHNOLOGY

CHEMICAL ENGINEERING

Simulation of YLNG Project IN RASS ISSA

A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR DEGREE IN CHEMICAL ENGINEERING

DONE BY:

ABDUALRAHMAN TAHA AL-MAGRAMI

HAIL SAEED MOHAMMED SAIF

AYMAN FAKHRI MOHAMMED AL-MEHDHAR

MALAK AMER ALNAFESH

MOHAMMED HAMID AL-QADASI

MOHAMMED SALEH AL-QUBARA

SUPERVISOR:

PROF. MOHAMMED ALTAYEB

CO-SUPERVISOR:

ENG. JAMAL SAEED

2022-2023

DECLARATION

We hereby declare that this Bachelor's project is that the result of our own work, except for quotation and summaries, which have been duly acknowledged.

Name: **ABDUALRAHMAN TAHA AL-MAGRAMI** Signature
Date:

Name: **HAIL SAEED MOHAMMED SAIF** Signature
Date**:**

Name: **AYMAN FAKHRI AL-MEHDHAR** Signature
Date**:**

Name: **MALAK AMER ALNAFESH** Signature
Date:

Name: **MOHAMMED SALEH ALQUBARA** Signature
Date:

Name: **MOHAMMED HAMID AL-QADASI** Signature
Date:

APPROVAL

This is certified that the project titled **SIMULATION OF YLNG PROJECT IN RASS ISSA** has been read and approved for meeting part of the requirements and regulations governing the award of the Bachelor of Engineering (Chemical Engineering) degree of Emirates International University, Sana'a, Yemen.

Project supervisor: **PROF./** ***MOHAMMED ALTAYEB***

Date: …………

Signature: ……………………

Project co-supervisor: **ENG./** ***JAMAL SAEED***

Date: …………

Signature: ……………………

ABSTRACT

Simulation of Liquefied Natural Gas (LNG) Processes

The global use of natural gas is growing quickly. This is primarily attributed to its favorable characteristics and to the environmental advantages. it enjoys over other fossil fuels such as oil and coal. One of the key challenges in supplying natural gas is the form (phase) at which it should be delivered. Natural gas may be supplied to the consumers as a compressed gas through pipelines. Another common form is to be compressed, refrigerated, and supplied as a liquid known as *liquefied natural gas (LNG)*. When there is a considerable distance involved in transporting natural gas, LNG is becoming the preferred method of supply because of technical, economic, and political reasons. Thus, LNG is expected to play a major role in meeting the global energy demands. This work addresses the simulation and optimization of an LNG plant. First, the process flowsheet is constructed based on a common process configuration. Then, the key units are simulated using ASPEN HYSYS to determine the characteristics of the various pieces of equipment and streams in the plant. Next, process integration techniques are used to optimize the process.
These activities are carried out using a combination of graphical, compute raided, and mathematical programming techniques. A case study on typical LNG facilities are solved to examine the benefits of simulation and integration of the process. The technical, economical, and environmental impact of the process modifications are also discussed.

DEDICATION

TO

OUR PARENTS

OUR BROTHERS AND SISTERS

OUR FRINDS AND COLLEAGUES

WITH LOVE

ACKNOWLEDGEMENTS

All the praises are due to Allah, the most beneficent and the most merciful for blessing us with the ability to pursue my graduate studies and seek knowledge.
There are many people who have helped us in this research.
We have been honored by working together. Our endless help have been one of the most important key factors that always motivate us to work and do our research. Also, we are thankful to all my graduate and undergraduate studies instructors. Special thanks are due to Dr. Mohammed Altayeb, my academic Supervisor, and T. Jamal Saeed our co-supervisor.
We are personally indebted to everyone for his advises and concerns.
I would like to extend my appreciation to my committee members, Dr. Hani Dammag and Dr. Ibrahem Farea, for serving in our research committee and for their comments and valuable time.
Thanks, are extended to all my colleagues, for their support and help.

Examiner Committee

Project Title:………………………………………………………………

Supervisor

No	Name	Position	Signature
1			
2			

Examiner Committee

No	Name	Position	Signature
1			
2			
3			
4			

Department Head

……………………

INDEX

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

YLNG: Yemen Liquified Natural Gas

LNG: Liquefied Natural Gas

NGL: Natural Gas Liquids

LPG: liquefied petroleum gas

FLNG: Floating Liquified Natural Gas

MCHE: Main Cryogenic Heat Exchanger

TEG: Tri-Ethylene Glycol

STC: Specific Temperature Consumption

IFP: Institut Francais du Petroil

POC: Phillips Optimized Cascade

C3MR: Propane Precooled Mixed Refrigerant

PFHE: plate-fin heat exchanger

SWHE: Spiral Wound Heat Exchanger

PMR: Parallel Mixed Refrigerant

MFC: Mixed Fluid Cascade

APCI: Air Products and Chemicals International

LHV: Lower Heating Value

HHV: Higher heating Value

Btu: British Thermal Unit

MMSCFD: Million Standard Cubic Feet Per Day

(psi): pounds per square inch

Ib_m: Pound Mass

Mt: metric tons

kpa: Kilopascal

mol: Mole

KJ: Kilo Joule

atm: Atmosphere

BP: Boiling Point

MW: Mega Watt

ppm: Part Per Million

HX: Heat Exchanger

CNG: Compressed Natural Gas

Mt: Metric Ton

Approx: Approximation

J−T: Joule−Thomson

GTL: Gas-to-Liquids

VLV: Valve

PFD: Process Flow Diagram

DOF: Degrees Of Freedom

MTBE: Trimethyl butyl ether

MTPA: million tons per annum

Max: Maximum

tot: Total

M.Wt: Molecular Weight

MR: Mixed Refrigerant

FIG: Figure

Km: Kilometer

%Mol: mole percent

kg: Kilogram

MDEA: Methyl Di-Ethanol Amine

DME: Di-Methyl Ether

MMT: Materials and Manufacturing Technology

TCF: Totally Chlorine Free

BOG: Boil-off Gas

AD: Anno Domini

Psig: Pounds Per Square Inch Gauge

MPa: Mega Pascal

SYMBOLS

°F: Degrees Fahrenheit

°C: Degrees Celsius

%: Percent

lb: Pound

$_{(L)}$: Liquid

$_{(g)}$: Gas

g: Gram

m^3: Cubic Meters

s: Second

n_i: Mole

y_i: Mole Fraction

i: Component

M_i: Molecular Weight

m_i: Mass

a: Annual

D: Day

x_i: Mass Fraction

F: Feed

$\sum$: Summation

$\dot{m}$: Mass Flowrate

h: Hour

C_{5+}: Pentane, ……etc.

$CH_2=CH_2$: Ethylene

NOx: Nitrogen Oxides

H_2S: Hydrogen Sulfide

He: Helium

C1(CH_4): Methane

C2(C_2H_6): Ethane

C3(C_3H_8): Propane

n-c4(C_4H_{10}): Normal Butane

i-c4 (C_4H_{10}): Iso Butane

ΔH_v: Standard Enthalpy of Vaporization

$\Delta H°C$: Standard Enthalpy of Combustions

O_2: Oxygen

CO_2: Carbon dioxide

N_2: Nitrogen

C: Carbon

H: Hydrogen

Na_2CO_3: sodium carbonate

Na: Sodium

Hg: Mercury

H_2O: water

NaHS: Sodium hydrosulfide

$NaHCO_3$: sodium bicarbonate

CHAPTER 1: INTROUCTION

1.1: Introduction

In this project, we will talk about natural gas in Yemen, liquefied natural gas, and building a facility in Rass Issa to liquefy natural gas next to the Balhaf station due to, its suspension. The main idea of our project was to draw attention to the Tehama basins that are full of natural gas. Many studies have been done by foreign companies; gas has been discovered. And according to Yemen's agreements with foreign companies, they found that there is no interest to them in natural gas in Yemen, so they have been closed.

1.2: Objectives of the Study

First: Applying what has been studied in chemical engineering through the natural gas liquefaction project.

Second: Simulation of the Belhaf project with the proposed project in Rass Issa, drawing attention to the basins of natural gas in Tihama.

Benefiting from the country's natural resources to cover the local energy need.

Third: Subscription of natural gas is not the subscription of natural gas only, but also consumption locally in petrochemical industries and energy sources in factories.

Fourth: Economic reasons, including raising the country's economy through liquefied natural gas, given the global need, and opening a European and African market for liquefied Yemeni gas.

1.3: Location of the Study Area

Yemen - Hodeidah - Al Jazirah 6JR6+6P."Rass Issa" Next to Rass Isa oil facilities.

1.4: Research Questions

What is LNG – liquefied natural gas?

Liquefied Natural Gas (LNG) is natural gas chilled to -160°C or -260°F. While changing it from gas state into a liquid state, that is 1/600th of its original volume. This dramatic reduction allows LNG to be shipped safely and efficiently aboard specially designed LNG vessels.

1.5: Organization of the Project

This project talked extensively about liquefied natural gas, the most important basic and general information. According to international and local standards, and was divided into seven parts, including the following:

- The first chapter: was a preliminary introductory overview of the project, then dealt with the definition of liquefied natural gas, its components, and properties. Also, it talked about the properties and components of the incoming natural gas, the main goal of the liquefaction process, its most important uses, advantages and disadvantages, the differences between the types of oil gases, the global exporting countries, LNG in Yemen, and the outlook for LNG. The conclusion of this part was a quick description of the process.
- The second chapter: talked in general about the natural gas liquefaction cycle from the preparation of the incoming natural gas and started the liquefaction and refrigeration process with talking about the sections of the liquefaction operations, the different methods, the equipment and determining the methods used in the project.
- The third chapter: was concerned with material and energy balances, where full reliance was made on the simulation program for its calculation.
- The fourth chapter: talked about the design of the facility in general, from the sites to the devices used, and we did not touch on all the details of the devices to focus the project on the main goal, which is liquefaction, where the master plan was included with the names of the devices and control devices.
- The fifth chapter: was talking about after the process of liquefaction and the exit of liquid methane gas, how it is stored, transported, loaded, and then exported.
- The sixth chapter: includes safety and environmental considerations and precautions for LNG.
- The seventh chapter: was talking about the economic feasibility of the project, its benefits, and the appreciation of the global markets for natural gas.

1.6: Natural Gas

Natural gas is a vital commodity in the global energy market. The status of primary sources of energy is summarized in Figure 1.1. Clearly, oil is the leading energy source. Next in importance, come coal and natural gas contributing almost 50% of the energy sources (Energy Information Administration 2007).

Once compressed, LNG gas can be loaded on to specially equipped ships and transported overseas for sale into export markets. At its destination the LNG is returned into a gaseous form for use.

Liquefied Natural Gas is colorless, odorless, non-corrosive and non-toxic and less dense than water. If a spill occurs, the natural gas will warm and evaporate, leaving no substances behind.

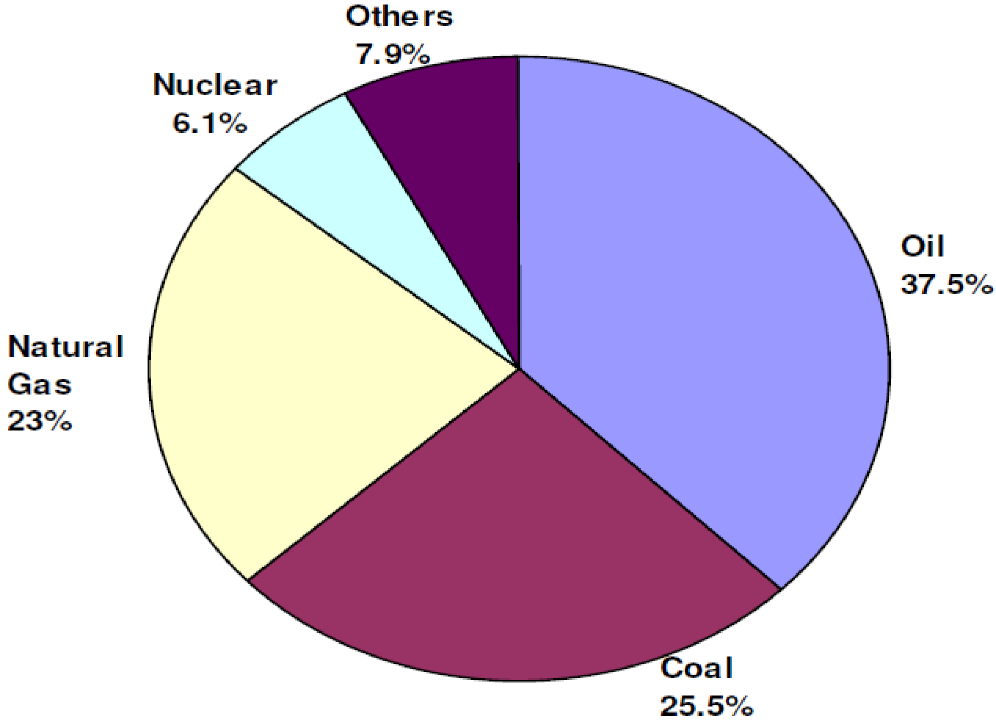


Figure 1: Primary Sources of Energy in the World. Total Energy used was 446.

Natural gas is a clean source of energy, and its popularity is expected to grow rapidly in the future because it presents many environmental advantages over oil and coal. Carbon dioxide (CO_2), a greenhouse gas related to global warming, is produced from oil and coal at rate approximately 1.4 to 1.75 times higher than that produced from natural gas. Also, nitrogen oxides (NOx), greenhouse gas and a source of acid rain, are formed from burning fuel. NOx produced from burning natural gas are less than those produced from burning oil and coal (Kidnay and %20 approximately the worldwide consumption of natural gas was about 100 ,2004 Parrish 2006). In trillion cubic feet and is expected to grow 163 trillion cubic feet by the year 2030**.** **Figure 1.2** shows the projected world total energy consumption by 2030 (Energy Information Administration 2007).

In 2006, the proven reserves of natural gas were reported to be 6,183 trillion cubic feet with most of these reserves being in the Middle East (2,566 trillion cubic feet) and Eurasia (2,017 trillion cubic feet). In fact, Russia, Iran, and Qatar combined account for about 58 percent of the world reserves. For instance, Qatar has a proven reserve (911 trillion cubic feet) of natural gas and the world's third largest supplier of natural gas with 15% of the global production (Energy Information Administration 2007).

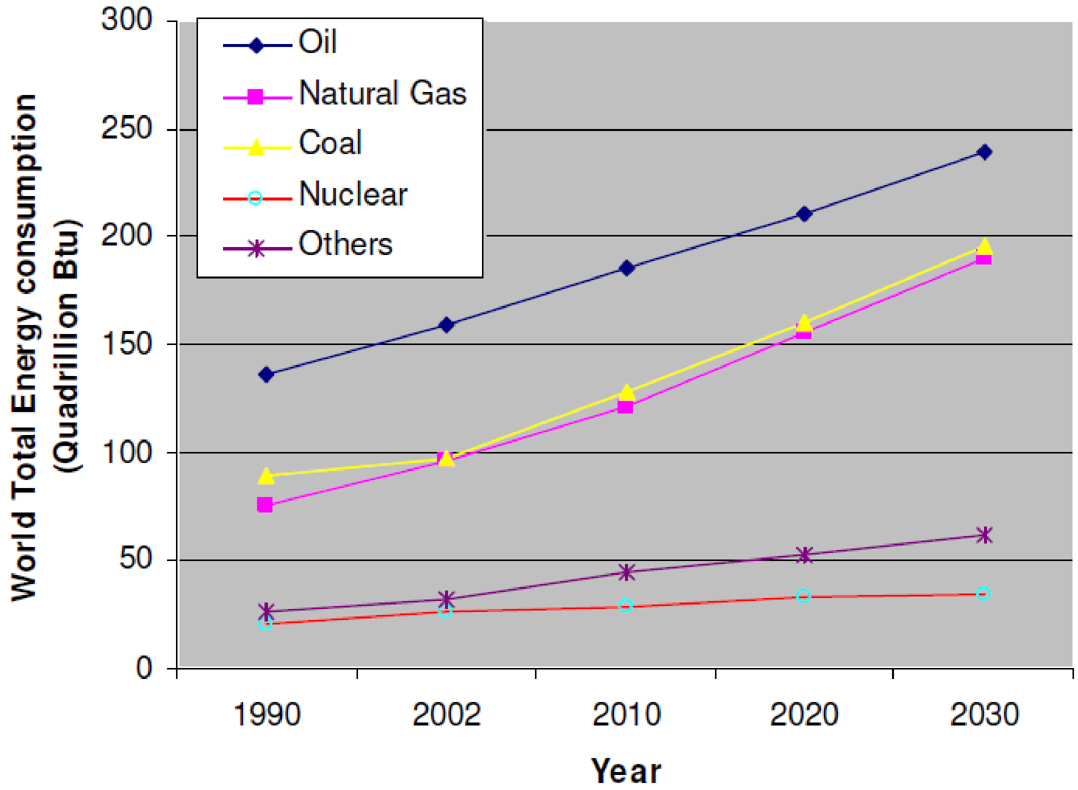


Figure 2 : World Energy Consumption by Fuel. (Data were Extracted from Energy

Table 1: LNG Exporting Countries in 2012.

LNG Importing countries in 2012

Importer	MMT Imported	Total Tons (%)
Japan	88.08	37.3
South Korea	36.77	15.6
China	14.65	6.2
Spain	14.46	6.1
India	13.27	5.6
Taiwan	12.67	5.4
UK	10.38	4.4
France	7.17	3.0
Turkey	5.63	2.4
Italy	5.16	2.2
Mexico	3.52	1.5
Argentina	3.36	1.4
USA	3.09	1.3
Chile	2.77	1.2
Brazil	2.70	1.1
Kuwait	1.99	0.8
Belgium	1.82	0.8
Portugal	1.52	0.6
Canada	1.30	0.6
Dubai	1.05	0.4
Thailand	1.02	0.4
Puerto Rico	0.97	0.4
Dominican Republic	0.92	0.4
Greece	0.76	0.3
Indonesia	0.72	0.3
Netherlands	0.56	0.2
Total Imports	**236.31**	**100**

Table 2 : LNG Exporting Countries in 2012

LNG Exporting countries in 2012

Exported	**MMT Exported**	**Total Tons (%)**
Qatar	76.39	32.3
Malaysia	23.72	10.0
Australia	20.88	8.8
Nigeria	19.58	8.3
Indonesia	18.97	8.0
Trinidad and Tobago	13.48	5.7
Algeria	11.21	4.7
Russia	10.86	4.6
Oman	8.15	3.4
Brunei	6.82	2.9
Abu Dhabi	5.66	2.4
Yemen	4.89	2.1
Egypt	4.74	2.0
Peru	3.86	1.6
Equatorial Guinea	3.62	1.5
Norway	3.31	1.4
USA	0.17	0.1
Total Exports	**236.31**	**100.0**

1.7: LNG Definition:

LNG stands for Liquefied Natural Gas. It is a form of natural gas that has been cooled to a liquid state, reducing its volume by a factor of more than 600 times. This process allows natural gas to be transported over long distances in a liquid form, making it easier to store and handle. LNG is commonly transported by tanker ships or in specialized cryogenic containers and is often used as an alternative to traditional fossil fuels in power generation and transportation.

1.8: Technology Background:

The process of producing LNG involves extracting natural gas from underground deposits, purifying it to remove impurities, and then cooling it to a temperature of

-162°C (-260°F). At this temperature, the gas becomes a liquid and can be stored in specially designed tanks or vessels.

To return the LNG to its gaseous state, it must be warmed up again. This is typically done at a regasification plant, where the LNG is heated and returned to its original state. From there, it can be distributed through pipelines or used directly as a fuel.

LNG technology has made it possible to transport natural gas to areas that do not have access to pipelines and has allowed countries to import and export natural gas more easily. It has also been used as a cleaner alternative to traditional fossil fuels in the transportation sector, as it produces fewer emissions when burned.

1.9: Composition of LNG:

Liquefied natural gas (LNG) is composed primarily of methane, with smaller amounts of other hydrocarbons, such as ethane, propane, and butane. The exact composition of LNG will vary depending on the source of the natural gas and the purification process used to produce the LNG.

In general, LNG is composed of more than 90% methane, with the remaining constituents making up less than 10% of the gas. The other hydrocarbons present in LNG are typically present in much smaller quantities and are known as "trace impurities."

LNG is also typically free of impurities such as water, sulfur, carbon dioxide, and mercury which can affect the performance of the gas in certain applications. These impurities are typically removed during the purification process used to produce LNG.

Table 3 : General Composition of LNG

Component	Short symbol		LNG 1 [%mol]	LNG 2 [%mol]	LNG 3 [%mol]
methane	C_1		96,07	89,18	94,05
ethane	C_2		2,67	7,07	2,77
propane	C_3		0,77	2,5	0,77
n-butane	nC_4		0,18	0,69	0,15
iso-butane	iC_4		0,21	0,46	0,18
pentanes	C_5		0,01	0,01	0,01
nitrogen	N_2		0,01	0,09	2,07
Latent heat of vaporization		[kJ/kg]	508,97	505,31	502,63
Boiling temperature at normal pressure		[K]	111,8	112,6	105,8

1.9.1: The Feed Specifications:

The feed specifications of liquefied natural gas (LNG) refer to the quality and purity standards that the gas must meet to be used as a feedstock for the production of chemicals or other industrial processes.

LNG feed specifications typically include limits on the levels of impurities, such as water, sulfur, mercury, and carbon dioxide, that are present in the gas. These impurities can affect the performance of the gas in chemical production processes and may need to be removed or reduced to meet the required specifications.

Other specifications for LNG feedstocks may include requirements for the gas composition, heating value, and other physical and chemical properties. The specific feed specifications for LNG will vary depending on the end use of the gas and the requirements of the chemical production process.

1.9.2: Product Specification

Table 4: Product Specification for LNG

Parameter	**Value**
Boiling point	-160 °C to -162 °C
Molecular weight	16−19 g/mol
Density	425−485 kg/m^3
Specific heat capacity	2.2−3.7 KJ/kg/°C
Viscosity	0.11−0.18 mPa.s
Higher heat value	38−44 MJ/m^3
Water continents	< 1ppm
CO_2	< 50ppm

Composition (%)	LNG (low)	LNG (medium)	LNG (high)
Methane	98.00	92.00	87.00
Propane	1.40	6.00	9.50
Butane	0.10	0.00	0.50
Nitrogen	0.10	1.00	0.50
Density(kg/m^3)	427.74	445.69	464.83

Table 5: Classification of LNG by Density

1.10: Aim of Liquified Natural Gas

The main aim of liquefying natural gas is to make it easier to transport and store. Natural gas is often found in remote locations that are far from markets, and it can be expensive and difficult to build pipelines to transport the gas over long distances.

Liquefying the gas reduces its volume by a factor of more than 600 times, making it easier to store and transport in tanker ships or specialized cryogenic containers. This allows natural gas to be transported to markets around the world, even if there are no pipelines connecting the two locations.

In addition to making transportation easier, LNG has also been promoted as a cleaner alternative to traditional fossil fuels. When burned, LNG produces fewer emissions than other fossil fuels, making it a potential option for reducing greenhouse gas emissions in the energy sector.

1.11: Uses of LNG:

Liquefied natural gas (LNG) has several uses, including:

- Power generation: LNG can be used to generate electricity in power plants.

- Transportation: LNG can be used as a fuel for vehicles, including buses, trucks, and ships.

- Industrial uses: LNG can be used as a feedstock to produce chemicals, such as ammonia and methanol. It can also be used as a fuel for industrial processes.

- Residential and commercial use: LNG can be used as a replacement for propane at homes and businesses.

- Military use: LNG has been used as a fuel for military vehicles and ships, particularly in situations where access to traditional fuel sources is limited.

Overall, the use of LNG has been growing in recent years as a cleaner alternative to traditional fossil fuels, particularly in the transportation sector. It has also been used to help meet increasing global energy demand and to reduce reliance on oil and coal.

1.12: Advantage & Disadvantages of LNG

There are both advantages and disadvantages to using liquefied natural gas (LNG):

Advantages:

- Cleaner burning: LNG produces fewer emissions when burned compared to other fossil fuels, such as coal and oil. This makes it a potential option for reducing greenhouse gas emissions in the energy sector.

- Abundant supply: Natural gas is a relatively abundant resource, and there are large reserves of it around the world.

- Efficient transportation: LNG can be transported over long distances in a liquid form, making it easier to transport than natural gas in its gaseous state.

- Versatility: LNG can be used in a variety of applications, including power generation, transportation, and industrial processes.

Disadvantages:

- High infrastructure costs: The infrastructure required for LNG production, storage, and transportation can be expensive to build and maintain.

- Safety concerns: LNG is flammable and must be handled with care. There have been some high-profile accidents involving LNG spills and fires.

- Limited distribution: LNG is not widely available in many parts of the world, and it can be expensive to import to areas that do not have a domestic supply.

- Limited availability: The process of producing and transporting LNG can be disrupted by political instability, natural disasters, and other factors. This can lead to shortages and price fluctuations.

1.13: The Difference Between LNG, CNG, NGL. LPG and GTL:

Liquefied natural gas (**LNG**), compressed natural gas (**CNG**), natural gas liquids (**NGL**), liquefied petroleum gas (**LPG**), and gas-to-liquids (**GTL**) are all forms of natural gas or products derived from natural gas. Here is a brief overview of the differences between these terms:

- Liquefied natural gas (**LNG**): LNG is natural gas that has been cooled to a liquid state, reducing its volume by a factor of more than 600 times. This process allows natural gas to be transported over long distances in a liquid form, making it easier to store and handle.

- Compressed natural gas (**CNG**): CNG is natural gas that has been compressed to a pressure of 2,200-3,600 pounds per square inch (psi), making it easier to store and transport in tanks. CNG is primarily used as a fuel for vehicles.

- Natural gas liquids (**NGL**): NGLs are hydrocarbons that are extracted from natural gas and are composed of propane, butane, and other light hydrocarbons. NGLs are used as a feedstock to produce chemicals, as a fuel for heating and cooking, and in other industrial applications.

- Liquefied petroleum gas (**LPG**): LPG is a mixture of hydrocarbons that is produced from natural gas or crude oil. It is composed mainly of propane and butane, and is used as a fuel for cooking, heating, and transportation.

- Gas-to-liquids (**GTL**): GTL is a process that converts natural gas into liquid fuels, such as diesel or jet fuel. The process involves reacting the natural gas with hydrogen to produce a synthesis gas, which is then converted into liquid fuels through a series of chemical reactions.

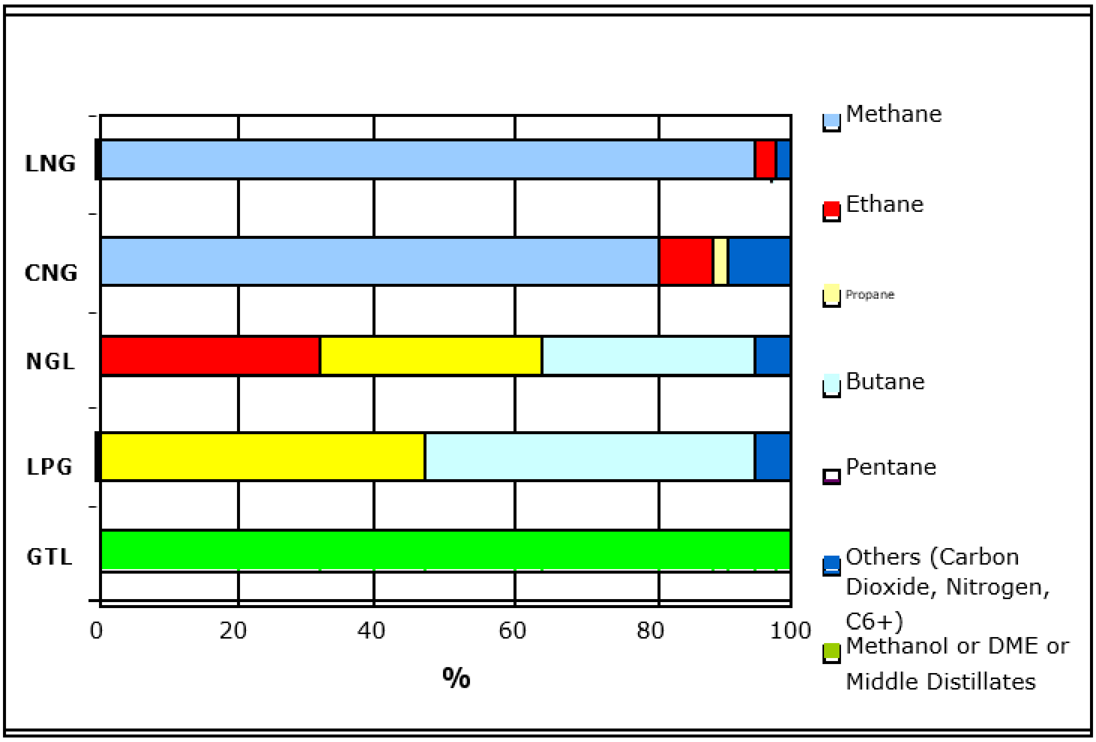


Figure 3 : Summary Comparison of LNG and other Fuels

1.14: LNG Exports by Country:

Liquefied natural gas (LNG) is exported by several countries around the world. Here are some of the top LNG exporting countries:

- **Qatar**: Qatar is the world's largest exporter of LNG, with an annual export capacity of over 77 million metric tons.

- **Australia**: Australia is the second-largest exporter of LNG, with an annual export capacity of over 50 million metric tons.

- **Malaysia**: Malaysia is the third-largest exporter of LNG, with an annual export capacity of over 30 million metric tons.

- **Indonesia**: Indonesia is the fourth-largest exporter of LNG, with an annual export capacity of over 22 million metric tons.

- **Yemen**: Yemen LNG was planned with a capacity of 5.3 MTPA. Yemen LNG was mainly targeting markets in Asia (Korea, Japan, Taiwan, China, and India), but also looked for opportunities in Europe. European LNG markets, however, seemed relatively less attractive than Asian markets in the mid-90s, because of pipe gas competition in Europe. In the US, the LNG market was little more than a tiny niche market as LNG could not compete with natural gas produced domestically or imported from Canada.

Other significant exporters of LNG include Russia, Nigeria, Algeria, and Trinidad and Tobago. The demand for LNG has been growing in recent years as a cleaner alternative to traditional fossil fuels, particularly in the transportation sector.

1.15: LNG in Yemen & Future Vision

The discovery of natural gas in Yemen began to keep pace with oil expenditures in 1984 AD in the Marib-Al-Jawf basin area as gas associated with oil in 1992 AD. New quantities of gas were discovered in the Jannah-Shabwa region. Separate it in the Safer facilities and factories in Marib Governorate, where the daily production of gas is estimated at about (275) billion cubic feet of this amount in the fields at the time to maintain the reservoir pressure to produce the largest amount of oil. A quantity of condensates is produced from processing and processing, estimated at about 2200 per day. This amount is added to crude oil for export to improve its quality. About 1300 tons per day.

Yemen is not a significant exporter of liquefied natural gas (LNG). However, the country does have some domestic production of natural gas, which is primarily used for power generation and as a feedstock to produce chemicals.

In the past, Yemen has exported small amounts of LNG to Japan, South Korea, and other countries in the Asia-Pacific region. However, the ongoing conflict in the country has disrupted production and exports of LNG and other natural resources.

It is worth noting that Yemen is located in a region that has abundant reserves of natural gas, and the development of these resources has the potential to play a significant role in the country's economic development. However, political instability and security challenges have made it difficult to fully exploit these resources.

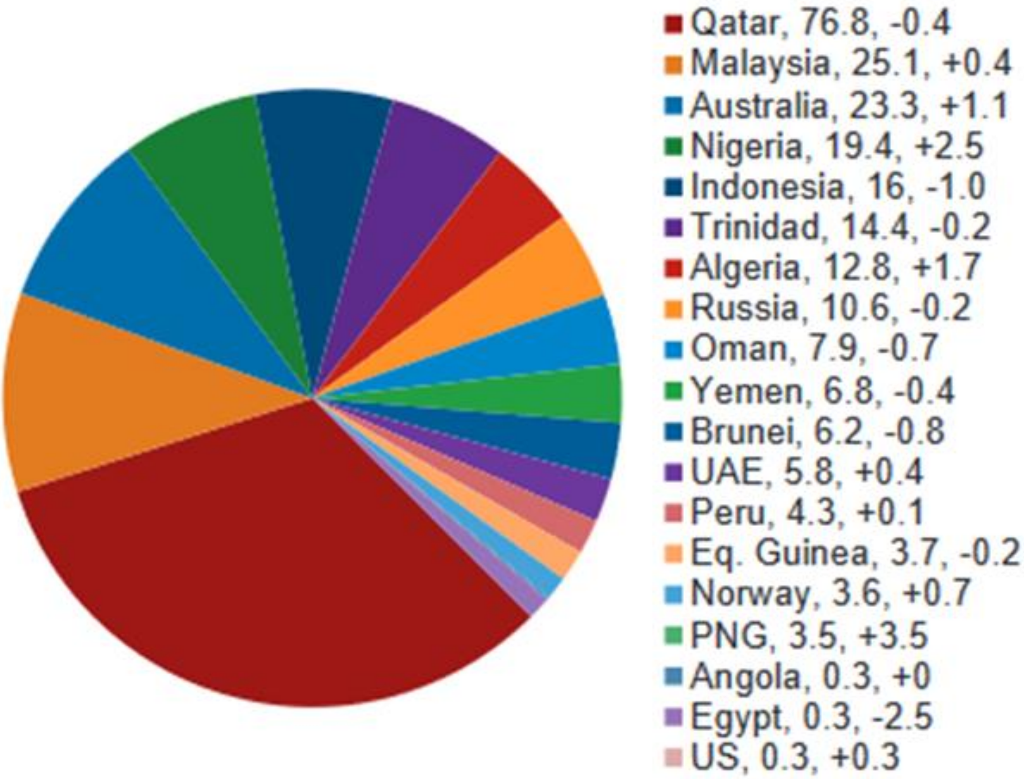


Figure 4 : 2014 LNG Exports by Country and Incremental Change Relative to 2013

The future vision in Yemen LNG:

First: In the production of electric energy using gas

The most expanding sector is the electricity sector at the global level, as the degree of importance of the electrical sectors reached its climax in Asia, and it was recently issued by the Ministry of Energy in India that electric energy is the other basic need. This trend also became in Western Europe when electricity consumption increased at an annual rate of capacity 4.2% compared to an increase in total energy consumption of 5.1% per annum.

The relatively rapid growth in the demand for electric power creates, in turn, a growing market for fuels that are used in the operation of generation stations that were built in response to the increasing demand for electricity, which led to an increase in the demand for natural gas as fuel.

And since the Republic of Yemen does not depend on the production of electric energy in its initial stages, and it still occupies a very large space of attention and encouragement by the state and the government, the issue of producing electric energy has become a high priority, and therefore this sector will be one of the most important sources for the use of natural gas.

Second: Fertilizer production

Natural gas is used in the manufacture of ammonia, urea, and other nitrogen fertilizers. Given that Yemen consumes large quantities of fertilizers and relies on imports of this substance to meet the needs of the local market, it is economically possible to use natural gas to produce urea and ammonia.

Third: petrochemical production

A) Ethylene and polyethylene, which are considered intermediates in the manufacture of industrial detergents, solvents, synthetic fibers, and nylon.

b) Trimethyl butyl ether (MTBE) is used as a substitute for tetraethyl lead to raise the octane number of gasoline and does not pollute the environment.

c) Synthetic rubber and thermoplastics........etc.

d) Vanillin chloride, which is converted into polyvinyl chloride, which has many uses in the manufacture of utensils, tools, and plastic pipes.

Fourth: Production of oil derivatives (converting gas into oil derivatives (Gas Transfer Liquid (GTL))).

GTL: It is the process of converting natural gas into industrial oil, where other operations take place, and it is converted into fuel or other basic hydrocarbon products. In simple terms, the (GTL) process classifies natural gas molecules and reassembles them into a long chain of molecules, such as those that make up crude oil. However, through a special conversion process, the result is quite clear. Industrial crude oil, which is free of any pollutants such as Sulfur, aromatic compounds, and metals. In addition, this industrial crude can be refined into products such as diesel fuel, oil, wax, liquid petroleum products, and special products.

Fifth: As fuel for cars

Most of the operating cars in Yemen have become old, and at that time there is no large transportation fleet among the general public, as the number of vehicles is not large, but in the future, it is expected that the transportation movement in Yemen will improve, and therefore the process of converting cars to work with gas will become feasible.

Sixth: Using gas for cement factories

If the pipeline transporting natural gas reaches Sana'a, it is possible to convert the Amran Cement Factory to work with natural gas, especially after raising its production capacity. There are also newly established factories, such as the "Rass" factory in Hodeidah and the "Arab Cement Company" factory in Hadramout. Natural gas can be used as fuel.

In view of the conditions the Gulf region is going through and the consequent fears of natural gas importing countries and what will result from it for the next ten years, which reflects positive signs and greater opportunities for marketing Yemeni gas to importing countries, which in turn aims to enumerate the sources in energy import, as the liquefaction of natural gas is the most appropriate for our country because it reflects greater financial returns than any local projects, which in turn raises the country's income level.

1.16: Process Description

The process of producing liquefied natural gas (LNG) involves several steps:

1. Extraction: Natural gas is extracted from underground deposits using drilling techniques.
2. Purification: The extracted natural gas is purified to remove impurities, such as water, sulfur, carbon dioxide, and mercury.
3. Cooling: The purified natural gas is cooled to a temperature of -162°C (-260°F), at which point it becomes a liquid and can be stored in specially designed tanks or vessels.
4. Transport: The LNG is transported to market using tanker ships or specialized cryogenic containers.
5. Regasification: When the LNG reaches its destination, it is warmed up again at a regasification plant and returned to its original state as a gas.
6. Distribution: The re-gasified natural gas is then distributed to customers through pipelines or used directly as a fuel.

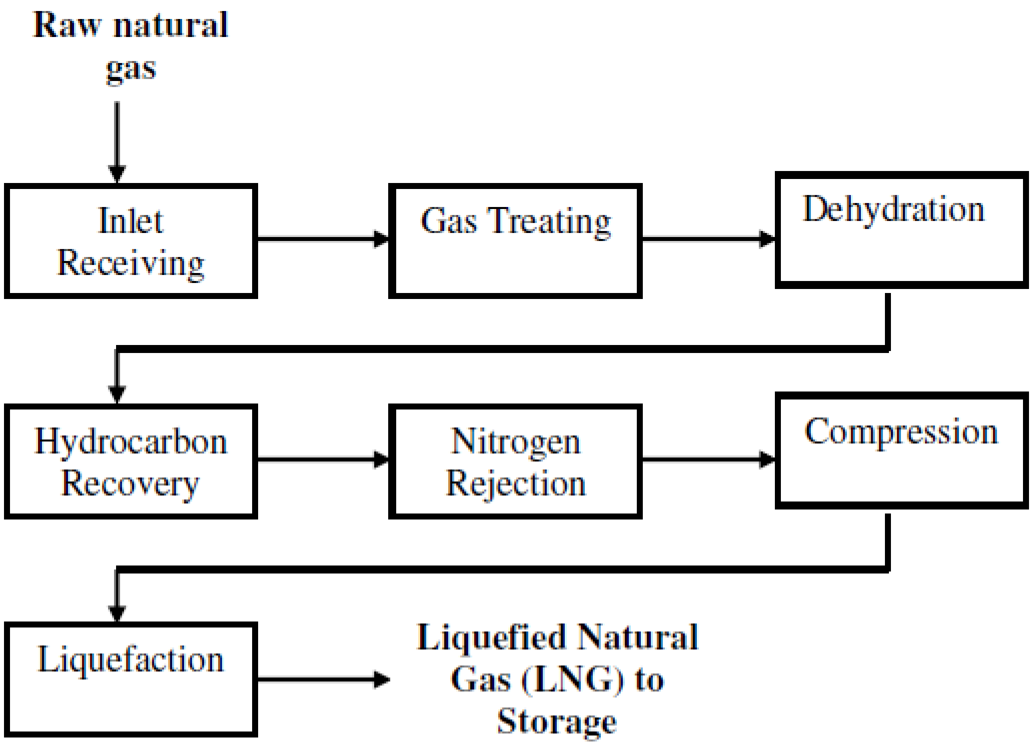


Figure5 : Block Flow Diagram of an LNG Plant

Overall, the process of producing and transporting LNG involves several specialized technologies and processes to extract, purify, cool, and transport the gas. The process is designed to make it easier to transport and store natural gas, and to allow countries to import and export natural gas more easily.

Chapter 2: Liquification

Liquification refers to the process of changing a substance from a solid or a gas to a liquid state. This can be achieved through various methods such as heating, cooling, or applying pressure. The specific process and conditions required to liquify a substance will depend on the properties of that substance. For example, water will freeze at 32 degrees Fahrenheit and boil at 212 degrees Fahrenheit at standard pressure, while other substances will have different freezing and boiling points.

2.1: Feed Preparation Processes Prior to Liquefaction Processes

Natural gas is the most important and popular fossil fuel in the current era and in the future as well.

What is natural gas?

Natural gas is composed mostly of methane (94%), and small amounts of ethane, propane, butane, and pentane.

-Methane, a combination of hydrogen and carbon, is formed when plants and animals (organic matter) are trapped beneath the sedimentary layers of the earth. In its original state, natural gas is odorless and colorless. Distribution companies add an odorant, mercaptan, so that it is easily detectable in the event of leaks for easy storage, chilling it to extremely cold temperatures can liquefy natural gas.

-Formation of Natural Gas Natural gas began with tiny plants and animals that lived more than 200 million years ago even before dinosaurs roamed the earth! These creatures and plants died, and war covered over by mud, sand, and silt. Over millions of years, heat and pressure inside the earth turned their decaying remains into fossils, and then into natural gas.

-In general, natural gas processing includes the following steps:

1. Condensate and Water Removal

2. Acid Gas Removal

3. Dehydration- Moisture Removal

4. Mercury Removal

5.Nitrogen Rejection

6. NGL Recovery, Separation, Fractionation, and Treatment of Natural Gas Liquids

-Natural gas exists in deep underground reservoirs it may contain several non-hydrocarbon components, for example, hydrogen sulfide and carbon dioxide.

-These impurities are undesirable compounds and causal several technical problems, for example, corrosion and environmental pollution, Forms of impurities and sours gases (acids gases) presence in natural gas.

-The cyclone type dust collector (catcher) is designed to purify natural and natural and other gases from mechanical impurities and dropping liquid. The cyclone type dust collector (catcher) is installed on main and process pipelines and is used as the first stage of natural gas purification from mechanical impurities and dropping liquid.

How much mercury is in natural gas?

Mercury can be present in natural gas wells and natural gas production streams, depending upon local geology. Trace levels of mercury may be present in natural gas in either elemental form or in compounds such as chlorides.

Studies have shown that natural gas typically contains a mercury concentration is (<0.01 Microgram/m^3) Mercury removal is a necessity. When natural gas is either processed or liquefied in a gas processing or LNG plant.

Why should acid gases be removed from natural gas before transportation and use?

1. nitrogen N_2: it has as a disadvantage its inert character which decreases the commercial value of gas.

2-carbon dioxide CO_2: it is harmful by its corrosive properties.

3-hydrogen sulfide H_2S: it is harmful by its corrosive properties.

4- helium He: it can be developed commercially.

5-hydrogen sulfide: it is harmful by its corrosive properties.

*Natural gas treatment (purification) methods from acid gases (mercaptans and carbon dioxide).

2.1.1: Sweetening Methods

-Gas sweetening from sour compounds is divided into dry methods (using iron hydroxide and charcoal) and liquid methods by using soda solution ،ethanol-amine or phenates.

-Dry purification (dry method) is one of the old methods for removing sour compounds from industrial gases. It is used in cases that do not require complete separate of hydrogen sulfide under low pressures. Also, the amount of treated gas should be small.

-also cannses The Phenate, such of Na_2 Coz $Na_2CO_3 + H_2S$ <> NaHS + $NaHCO_3$ - With the same principle as the sour gas treatment by the method, which in is the use of countercurrent method, i.e. an absorption and desorption process, the acidic compounds are removed by teams of ethanol-amine.

2.1.2: Gas Dehydration Process

Dehydration is the operation whereby water is removed from gas. Risks of water condensation in the pipe above ambient, the margin of safety is very small to avoid condensation. This is exactly what we want to avoid in gas pipelines. We do not want the water vapor to be condensed.

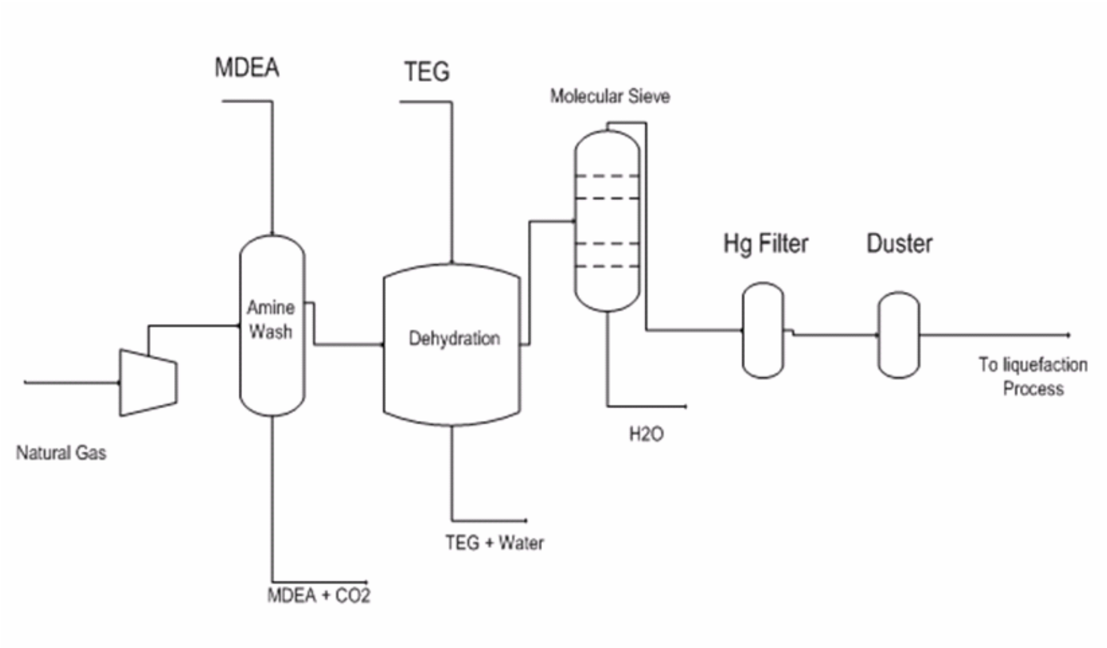


Figure 6 : Flow Chart of Pre-Treatment Processes

There are three potential ways to prevent this:

1- Increase the temperature of the gas It is impossible because the temperature of the gas in the pipe is equal to the temperature of the atmospheric air

2- Decrease the pressure of the gas in the pipe It is impossible too. If the pressure of the gas is decreased, the capacity of the pipe will be decreased too. This is not realistic.

3- Remove water continents:

If the water is taken out of the gas, no risks of condensation are to be expected without increasing the temperature or decreasing the pressure.

This is the best solution to avoid operating problems. Therefore, dehydration is necessary.

Natural gases either from natural production or storage reservoirs contain water, which condense and form solid gas hydrates to block pipeline flow and especially control systems. Natural gas in transit to market should be dehydrated to a controlled water content to avoid hydrate as well as to minimize the corrosion problem.

In general, these standards specify that the natural gas:

1- be within a specific Btu content range (1,035 Btu per cubic feet, +/- 50 Btu)

2- be delivered at a specified hydrocarbon dew point temperature level (below which any vaporized gas liquid in the mix will tend to condense at pipeline pressure)

3- contain no more than trace amounts of elements such as hydrogen sulfide, carbon dioxide, nitrogen, water vapor, and oxygen.

4- be free of particulate solids and liquid water that could be detrimental to the pipeline or its ancillary operating equipment.

Natural gas dehydration is the process of removing associated water from natural gas molecules either by absorption or adsorption. Absorption uses a dehydrating agent to remove water vapor from natural gas while adsorption condenses water vapor out of the gas.

Water must be removed from natural gas because its possible condensation may result in several problems:

-Water (H_2O): Natural gas of a layer is generally saturated with steam. To be exploited, it undergoes a partial dehydration.

Dehydration of natural gas is important for the following reasons:

-Wet gas forms methane hydrate which can plug valves and gas pipelines

-Condensed water in gas pipelines causes restricted flow and corrosion

-Wet gas does not comply with regulatory specifications of 7 lb./MMSCF (max) Natural gas dehydration methods.

There are several methods for natural gas dehydration, but we will focus on three of the most common techniques:

- TEG dehydration Membrane dehydration using adsorbents.

- The three major methods of dehydration are direct cooling, adsorption, and absorption.

Natural gas from wells invariably contains humidity. Gas also becomes wet in the sweetening unit of a gas processing facility when it contacts with the aqueous solution of a solvent, such as methyl diethanolamine (MDEA), used to remove the acid gases contained in the raw gas.

2.2: Liquefaction Cycle

Liquefied natural gas is gas that has been cooled to -260°F (-160°C) and converts to a liquid state. When natural gas is in a liquid form, it takes up approximately 1/600th of the space it would as a vapor, making transportation much more efficient and economical.

What is LNG liquefaction process?

Liquefied natural gas (LNG) is processed natural gas that has been condensed into a liquid form by reducing its temperature to approximately minus 260°F (minus 162°C) at ambient pressure. This process is known as liquefaction.

Gas liquefaction methods generally depend on devising (finding) ways and means to effect severe cooling, including:

1- Use of freezing mixtures:

2- Can be obtained under pressure from a mixture of ice with sodium chloride. By adding calcium chloride to the previous mixture, we get -50° C.

3- Cooling by dielectric expansion of gases for compressed gases (which are under pressure) and devices to liquefy many gases are built on this basis.

4- Rapid evaporation cooling of volatile liquids.

One of the modern methods for liquefaction of permanent gases is based on the concept of the Joule-Thomson effect (1862-1852 AD) (that a small amount of cooling produces compressed gases when it is allowed to diffuse through a porous barrier to a space (space) less pressure than it. The cooling is the result of movement and placement gas particles to liquefy dry natural gases to turn it into a liquid suitable for storage and transportation, especially when transporting over a long distance (Gas heat absorption until liquefaction).

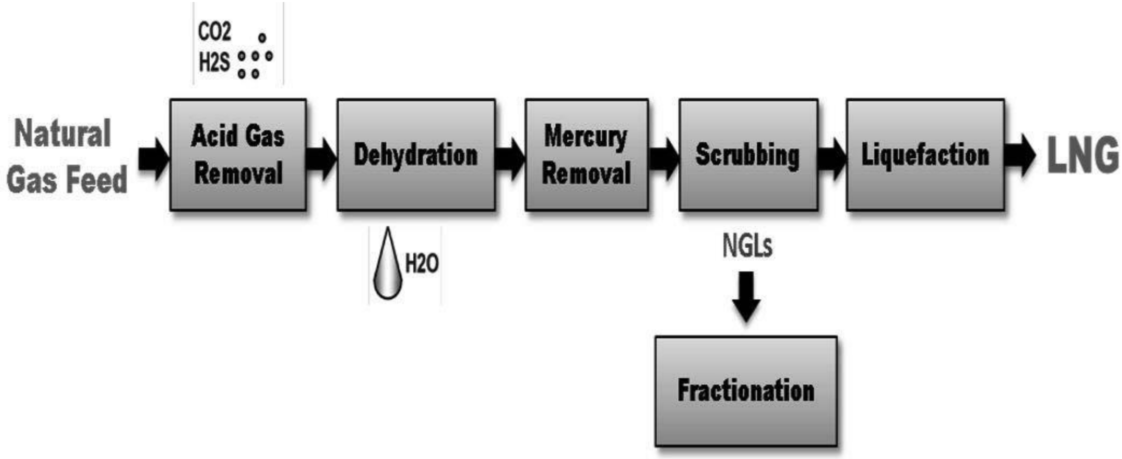


Figure 7 : Block Flow Diagram of a Typical Liquefaction Plant

Table 6: Commonly used LNG Liquefaction Processes

Commonly Used LNG Liquefaction Processes

SN	PROCESS	DEVELOPERS	STC (MTPA)
1.	Phillips Optimized Cascade(POC)	Conoco Phillips	4–9
2.	PRICO	Black and Veatch Pritchard	0.1–2.1
3.	APCI Propane Precooled Mixed Refrigerant(C3MR)	APCI	0.5–6.1
4.	Shell and APCI dual Mixed Refrigerant	Shell and APCI	0.5–8.4
5.	IFP/Axens Liquefin	IFP/Axens	N/A
6.	Parallel Mixed Refrigerant(PMR)	Shell	6–9
7.	Gaz de France Integral Incorporated Cascade	Gaz de France	N/A
8.	APCI AP–X	APCI	5.8–9.0
9.	Statoil Linde Mixed Fluid Cascade(MFC)	Linde in collaboration with Statoil	4.0–6.6

(Weems, P. R., & Hwang, M. (2013). jwt016.)

2.3: Classification of Natural Gas Liquefaction Processes

-Cascade Cycle (Phillips)

-C3-Mixed Ref. Cycle (APCI)

-Single Mixed Ref. Cycle (PRICO)

-Double Mixed. Ref. Cycle (Shell)

LNG industry started with the need of natural gas peak shaving. Cascade cycle we used in the beginning. Later, mixed refrigerant concept was introduced. Phillips Petroleum invented the cascade liquefaction cycle. This cycle utilizes three refrigerants: propane, ethylene, and methane. Air Products applied the mixed refrigerant cycle in the Libya Maras El Braga LNG Plant in 1970.

For many years, propane precooled mixed refrigerant (C3MR) process developed by Shell and APCI (Air Products and Chemicals International) has remained the dominant liquefaction cycle in the LNG industry. The train capacity with Air Products' main cryogenic heat exchanger (MCHE) is up to 5 million tons per annum (MTPA). Natural gas and the mixed refrigerant are precooled by propane refrigerant cycle to -30°C and then liquefied to around -150°C by thermal contact with mixed refrigerant which mainly consists of methane, ethane, propane, and nitrogen in main .cryogenic heat exchanger (MCHE)

Recent improves of the mixed refrigerant cycle, the AP-XTM, can increase train capacity beyond 10 MTPA. Final sub-cooling is not done in the MCHE part and the temperature exiting the exchanger is about -115°C. Final stage of sub-cooling is done using a nitrogen expander loop. However, the AP-X N_2 refrigeration process would not be optimized to perform all three-refrigeration system: precooling, liquefaction and subcooling. Many variables such as the number of expanders, pressure and temperature levels must be optimized for process efficiency.

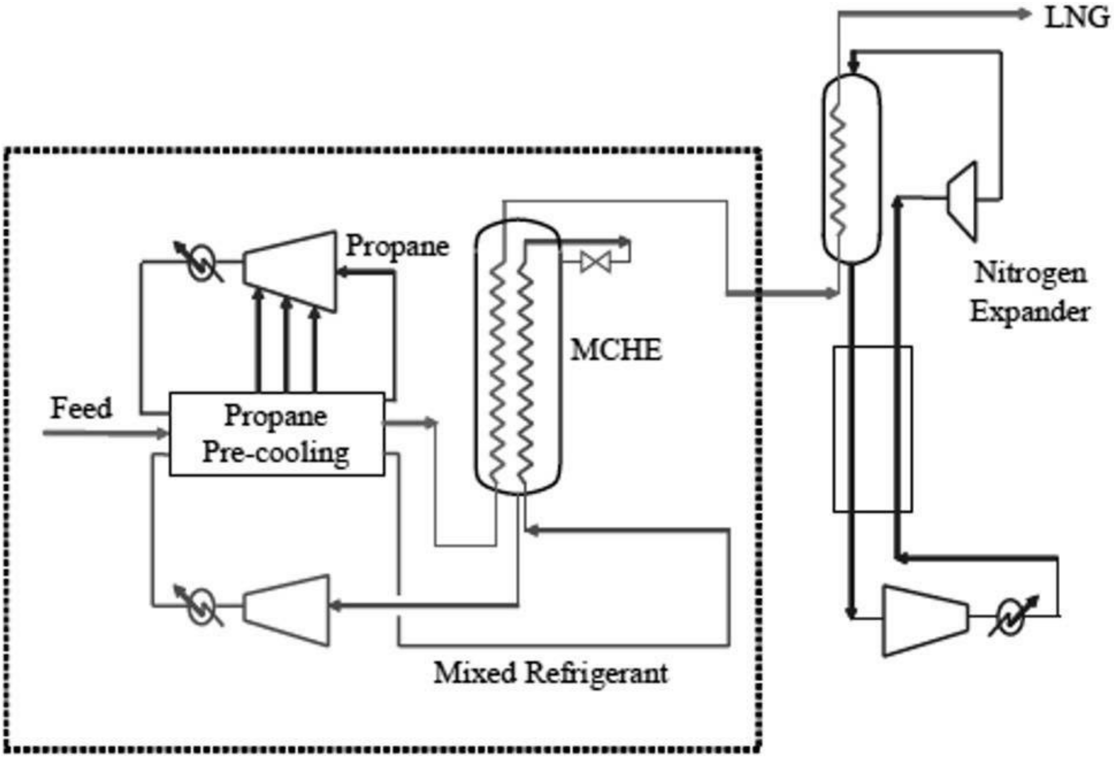


Figure8 : AP-XTM Process

life and operational improvements. Because of environmental issues including global warming, low the CO_2 emissions and the treatment of sour gases and impurities are serious problems that cannot be ignored. An LNG liquefaction plant on a floating platform is similar to an onshore LNG plant but has some important differences. The motion of the LNG vessel by the sea conditions is a key issue. Development of new liquefaction process for safety caused flammable component is a problem awaiting .solution

The reverse Brayton cycle and the single MR cycle are the most remarked process as a FLNG liquefaction process. The reverse Brayton cycle has an object in minimization of flammable inventory for process safety. On the other hand, the single MR cycle is more efficient than the reverse Brayton cycle form the power consumption point of view. It is necessary to consider which system is suitable. LNG vessel design and operating scenarios following the sea conditions are also short of .study and research

2.4: Refrigerant Selection

Multiple refrigeration cycle

Process Description of the technology plan:

This process uses two pure refrigerants-propane and ethylene circuits and a methane flash circuit cascaded to provide maximum LNG production by utilizing the horsepower available from gas turbines. Each circuit uses two 50% compressors with common process equipment.

1- Propane is cooled by compressing it in a propane pressure chamber (propane compressor) - and then passing it (pressurized propane) through a water-cooling device (2), (to get rid of the heat of pressing). Where the propane evaporator pushes propane evaporator (3). Where the pressurized propane is allowed to spread (the pressure decreases) and it cools down intensely, and its cold steam is used to cool the natural gas, pushed (flowing) into the device (3) through heat exchange between the two materials.

2- The cooled propane is drawn out and compressed again at (1) to a pressure higher than the pressure of the initial stage, then it is pushed through the water cooler (2) to be directed to the evaporator (3) and the refrigeration cycle is completed using .propane

3- Natural gas (1) is forced into a propane vaporizer (3) where it is cooled by liquefied or liquefied propane to a temperature of -38°C. This is called the first stage in frost. Propane is used as a refrigerant.

4- In the second stage, ethylene is used ($CH_2=CH_2$) compressed and allowed to spread - by expansion (repeating the same previous steps in the frosting process). In this stage, the natural gas is cooled to -100°C. Using ethylene as a refrigerant by heat exchange.

5- Natural gas has cooled (cooled) to the extent that it can be liquefied under low pressure (methane compressor) (4) and the final cooling to -162° C after the gas has .(5) passed through a methane vaporizer

6- After (5) the liquefied gas is directed to the isolation device (6) to obtain liquefied natural gas (LNG), which is directed to storage or transportation.

End flash gas compressor / Boil off gas compressor:

End flash gas compressors are used to compress the low-pressure vapor which is produced after liquefaction facility or at LNG tank to fuel gas for gas turbine or other process. When the vapor is produced at LNG tank only, those are called Boil off compressor.

By the same principle, LPG is liquefied, but in an easy way (the conditions are simple to convert LPG to liquid), and it generally includes tertiary and quaternary hydrocarbons from propane to propylene, ordinary butane, butylene, isobutylene .... multi-component refrigeration process for liquefaction of natural gas etc.

This invention relates to a process for liquefying a pressurized gas stream rich in methane in which the liquefication of the gas stream occurs in a heat exchanger being cooled by a closed-loop multi-component refrigeration system to produce a methane-rich liquid product having a temperature above about -112° C (-170° F.) and a pressure sufficient for the liquid product to be at or below its bubble point. The liquefied gas product is then introduced to a storage means at a temperature above about -112° C (-170° F.).

The multi-tubes shown at the left of the warm zone in FIG. 4, the feed gas is cooled and partially condensed against a vaporizing refrigerant on the shell side of the bundle. The resulting two-phase flow is directed in the bundles of the cold zone, where it is further cooled and extracted as LNG.

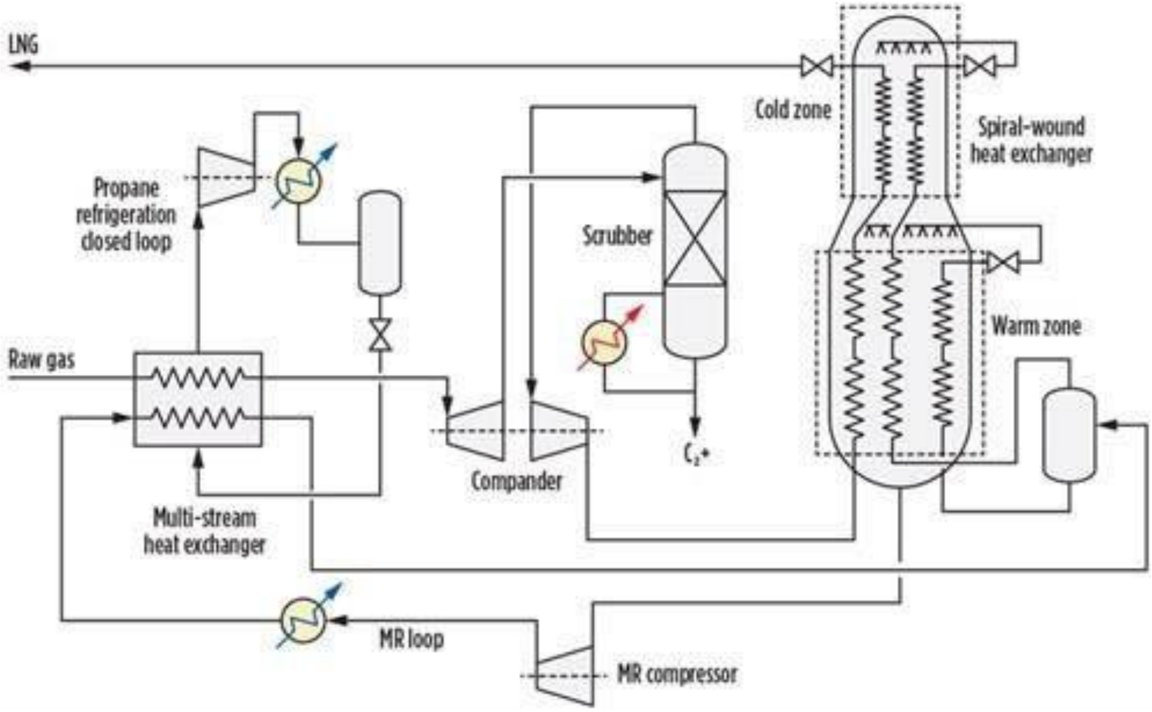


Figure 9 : Propane-precooled SMR Liquefaction Technology

The refrigerant in the shell side is a mixture of light hydrocarbons. After being cooled and partially condensed in the MR refrigeration loop, the two-phase flow is separated in a knockout drum. The liquid from the knockout drum is subcooled in the tubes circuit, shown at the right of the warm bundle, and then throttled and mixed with the refrigerant flowing downward from the cold area. The MR flows downward over the outside of the spool bundle. By vaporizing and warming while flowing downward, the MR provides the refrigeration for cooling the feed gas and subcooling the liquid phase extracted from the knockout drum.

The refrigerant vapor from the knockout drum is cooled in the warm zone and passes through the tube circuit in the cold zone, wherein it is liquefied and possibly subcooled. After pressure reduction, it flows downward on the outer side of the spool bundle and evaporates, thereby providing the refrigeration duty to both the feed stream and the refrigerant vapor coming from the knockout drum. The refrigerant flowing downward in the SWHE becomes totally vaporized upon reaching the bottom.

The exchange configuration previously described is known as “top cold.” The opposite arrangement is “bottom cold.” In the latter configuration, LNG is withdrawn from the bottom rather than from the top.

2.5: Main Cryogenic Heat Exchanger:

The Main Cryogenic HX is the heart of the LNG liquefaction plant and is where NG will be liquefied and sub-cooled. The Main Cryogenic HX will convert the gas temperatures up to -166° C.

2.6: Wound Coil Heat Exchanger:

A type of heat exchanger designed to efficiently transfer heat between two fluids or phases. In the context of LNG, it plays a critical role in the liquefaction and regasification processes.

Here's an explanation of the key features and functions of a Wound Coil Heat Exchanger for LNG:

1. **Coil Design:** The term "wound coil" refers to the design of the heat exchanger. In this design, a coil-shaped tube or series of tubes is used to facilitate the heat exchange. This coiled configuration provides a large surface area for efficient heat transfer while keeping the equipment compact.

2. **Liquefaction Process:** In LNG production, natural gas is cooled to extremely low temperatures (typically around -162 degrees Celsius or -260 degrees Fahrenheit) to convert it into a dense liquid state for easier storage and transportation. The wound coil heat exchanger is a crucial component in the liquefaction process. The hot natural gas is passed through one side of the coil, while a cold refrigerant (usually methane or nitrogen) circulates on the other side. Heat from the natural gas is transferred to the refrigerant, causing the gas to rapidly cool and condense into LNG.

3. **Regasification Process:** Wound coil heat exchangers are also used in the regasification process, where LNG is converted back into gaseous form for distribution and use. In this case, the coil serves the opposite purpose. Cold LNG flows through one side, and a warm fluid (often seawater or heated water/glycol) flows through the coil. Heat is transferred from the warm fluid to the LNG, causing it to vaporize and return to its gaseous state for distribution.

4. **Efficiency:** The coiled design provides efficient heat transfer due to the extended surface area. This efficiency is crucial in LNG applications, as the liquefaction and regasification processes involve extreme temperature differentials and must be energy efficient.

5. **Compact Design:** Wound coil heat exchangers are known for their compact design, which is particularly advantageous in offshore LNG facilities and other space-constrained environments.

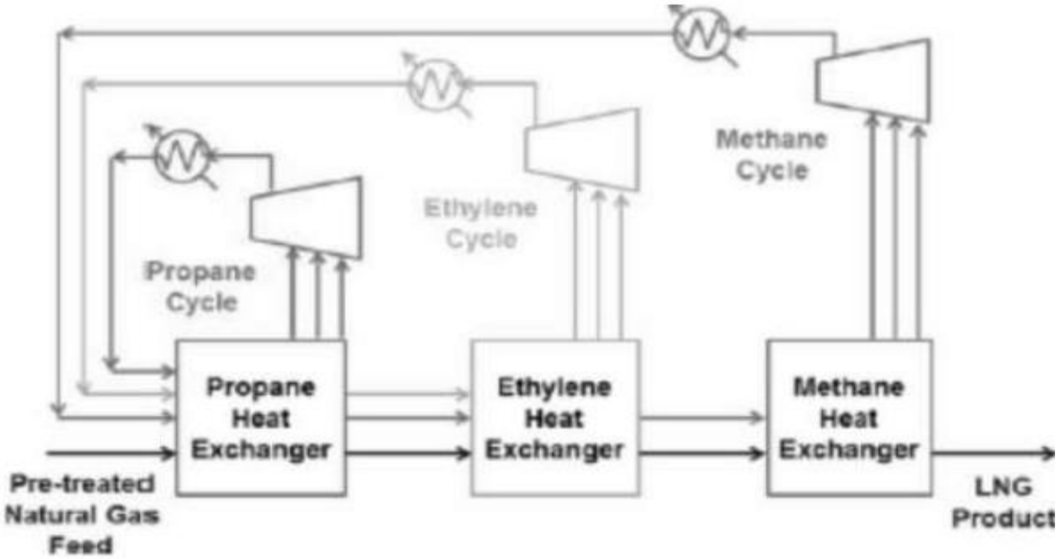
6. **Materials and Insulation:** Because of the extremely low temperatures involved in LNG applications, these heat exchangers are typically made from materials that can withstand cryogenic conditions. Additionally, they are often insulated to minimize heat loss and maintain efficient operation.

In summary, a Wound Coil Heat Exchanger for LNG is a specialized heat exchanger used in the liquefaction and regasification processes of liquefied natural gas. Its coiled design, efficiency, and ability to handle extreme temperature differentials make it a critical component in the LNG industry, enabling the efficient and safe transfer of LNG from its liquid to gaseous state and vice versa.

Figure 10 : Photo of an Unfinished Wound Coil HX

2.7: Classic Cascade Process

Many liquefaction processes have been developed and applied in LNG plants over the last few decades. The processes can be classified into three categories based on the type of refrigeration cycle and equipment used: a cascade process using pure refrigerants, a mixed refrigerant process using refrigerant mixtures, and an expander process using expanders instead of Joule−Thomson (J−T) valves.



Lim, W., Choi, K., & Moon, I. (2013)

Figure 11: Classic Cascade Process

2.8: Phillips Cascade

This process also uses propane, ethylene, and methane cycles, but the single train capacity is 50% greater than that of the three trains at other plant. This process is considered to be the first that employed gas turbine/compressor sets and a plate-fin heat exchanger (PFHE) in each refrigeration cycle.

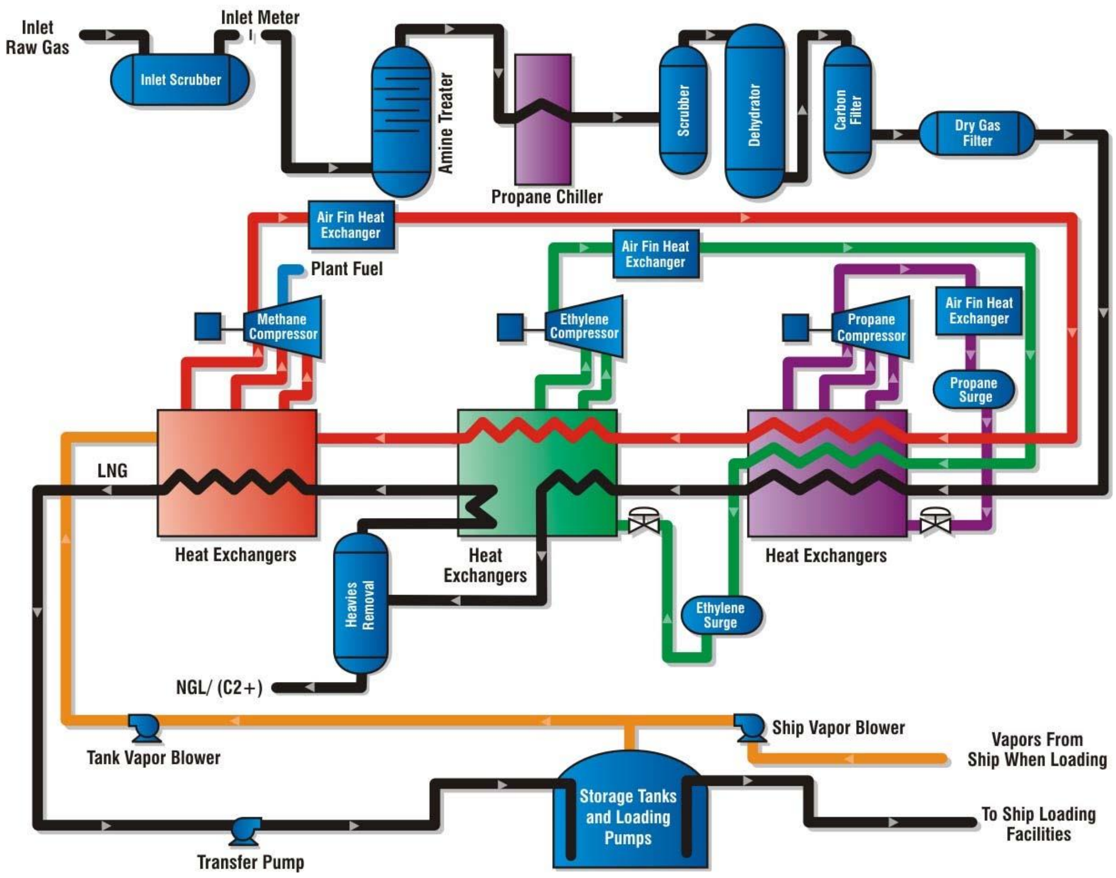


Figure 12 : Schematic of the Conoco Phillips LNG Process

2.9: Study case: (Optimized cascade liquefaction processes)

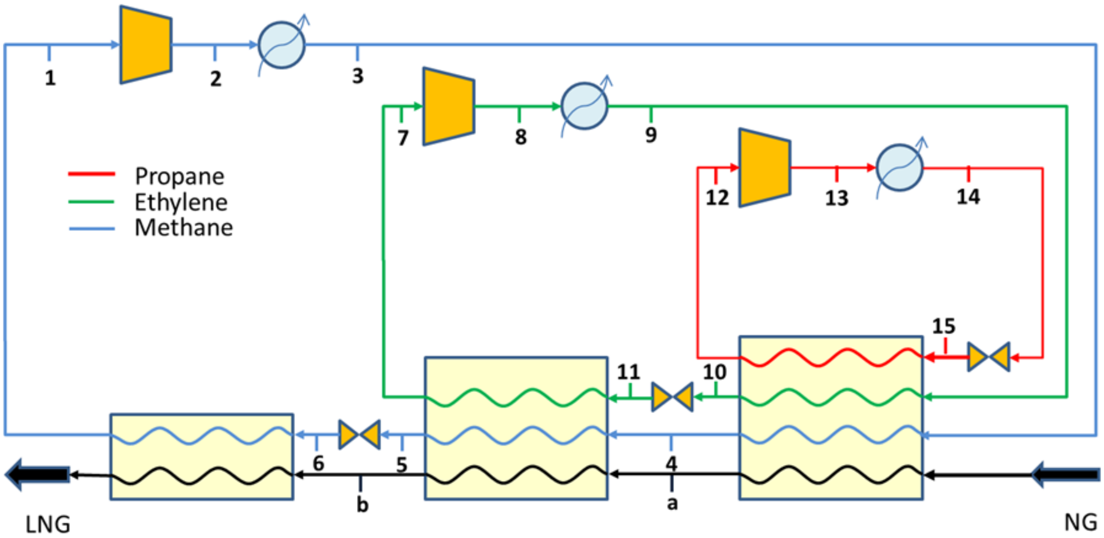


Figure 13: Optimzed Cascade Liquefaction Process

This is a new version of the cascade process and uses three pure refrigerants (propane, ethylene, and methane), and each cycle is operated separately at multiple pressure levels. The process has evolved from the original cascade process because the methane cycle is now an open cycle or a feed-flash system, rather than a closed cycle. This improvement enables a separate fuel gas compressor to be eliminated, as well as allowing stored vapors, the cascade cycles of liquefaction process, utilization of mixed refrigerants made the train capacity grow up to 5 MTPA and more.

Nowadays, dual mixed refrigerant loop or AP-XTM can handle up to 10 MTPA production. The LNG receiving terminal is designed for LNG storage and regasification. During the unloading procedure, efficient BOG handling is required for safety and energy saving. Numerous works on design, modeling, optimization, control, operation, and monitoring of the LNG processing have been published.

Future challenges include the floating liquefaction plants, floating storage and regasification units, gas-to-liquids technology, and combined cycles .a multistage cascade refrigeration cycle applied to a natural gas liquefaction process. Firstly, the process was simulated using commercial software and the results obtained from the simulations were validated with literature data, showing a good agreement. After that, different operational conditions, according to a complete factorial design of experiments, were studied, in order to verify the influence of pressure in six specific points of the cycle. The response variable analyzed is the rate of total exergy destroyed in the cycle. The results showed a new set of operational condition to the refrigeration cycle in which the destroyed exergy rate was reduced by approximately 48% in comparison with literature data.

The classical cascade liquefaction cycle was the first one to be applied in natural gas plants. It is based on a three stage refrigeration cycles, each one operating with a different fluid: methane, ethane (or ethylene) and propane. The mixed refrigeration cycle utilizes only one refrigeration fluid using a mixture of refrigerants, which exegetic optimization of a refrigeration cycle for natural gas liquefaction 441 composition is adjusted to have its evaporation temperature like the natural gas being liquefied, which can change depending on its origin. Because of the high costs involved in construction and operation, the feasibility of an industrial site is strictly related to the efficiency of the process. One possible way of reducing thermodynamic losses of the process is to perform an exegetics analysis, to reduce exergy losses, leading to an optimal operation .The objective of this work is to perform an exegetics analysis of a classical multistage cascade refrigeration cycle applied in the liquefaction of natural gas, in order to propose an optimal operational condition, contributing to reduce the exergy destroyed in the cycle. This analysis will consider the influence of six pressures in different points of the cycle: after the compressor and after the expansion valve of each sub cycle .

2.10: Multistage Cascade Refrigeration Cycle

The multistage cascade refrigeration cycle presents lower energy consumption when compared to the other types, enables flexible operation, as each cycle can be independently operated, and requires smaller heat transfer area in the evaporators. This last characteristic implies in a lower thermodynamic efficiency of the process, which requires higher utilities demand. Another disadvantage is the high installation and maintenance costs, as each cycle has its own compressor and refrigeration fluid storage tank. Figure 1 shows the cascade cycle studied in this paper. For simplification of the figure, only one stage is shown per refrigeration fluid. In this cycle, natural gas is cooled and finally liquefied by a three-stage process. In the real cycle, each refrigeration stage has multiple expansion and condensation steps, being each of them operated at three different evaporation temperatures.

2.11: Process Simulation

The multistage cascade refrigeration shown in (Figure 14) was simulated using Hysys (Aspen Technology, version 3.2), based on the works of Kanoglu (2002) and Filstead (1965). The fluid package chosen to provide thermodynamic properties was the Peng-Robinson equation of state, which is adequate for the refrigerants used in the cycles. Steady state operation and adiabatic equipment were assumed in the simulations. Natural gas molar composition used in the simulation was taken from a Brazilian LNG. Refrigerants selected were methane, ethane, and propane (all 100% pure) .

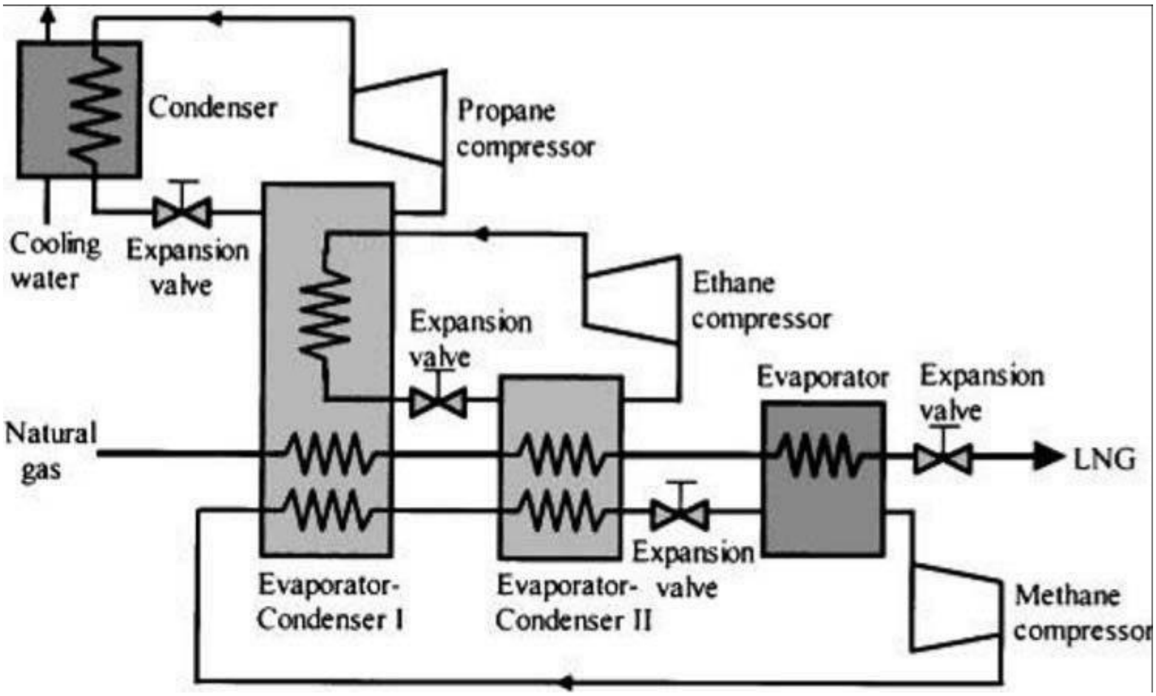


Figure 14: L. Cipolato et al. plant and is: 90.7% CH4, 6.8% C2H6, 1.3% C3H8,442 0.3% C4H10, 0.7% N2 and 0.2% O2

After validation of the simulation by comparison with literature data, obtaining a good agreement, different operational conditions were tested following a full factorial experimental planning. Finally, the results were analyzed by a statistical software, and .an optimal operation condition for the process was proposed

Details of how to perform an exegetic analysis may be found in Szargut (1980). The aim of this analysis is to locate and evaluate quantitatively the effect of irreversibility which reduce thermodynamic efficiency of a process, proposing modifications in order to reduce this irreversibility, by reducing destroyed energy. In this work only the physical component of energy for each process stream was analyzed.

The classical multistage cascade refrigeration cycle applied in the liquefaction of natural gas was studied using an exegetics analysis. The influence of six pressures at six different points of the cycle was evaluated: after the compressor and after the expansion valve of each refrigeration sub cycle. The base case scenario has presented a rate of total destroyed exergy of 19494 kJ/h. Through a full factorial design and a statistical analysis, a new set of operational conditions based on the analyzed factors resulted in a reduction of 48% of this rate, obtaining a new rate of total destroyed exergy of 10096 kJ/h. Using a thermoconform analysis it is possible to check the final benefit of this reduction in the total destroyed exergy. Technically, the modifications proposed are feasible.

CHAPTER 3: MATERAL & ENERGY BLANCE

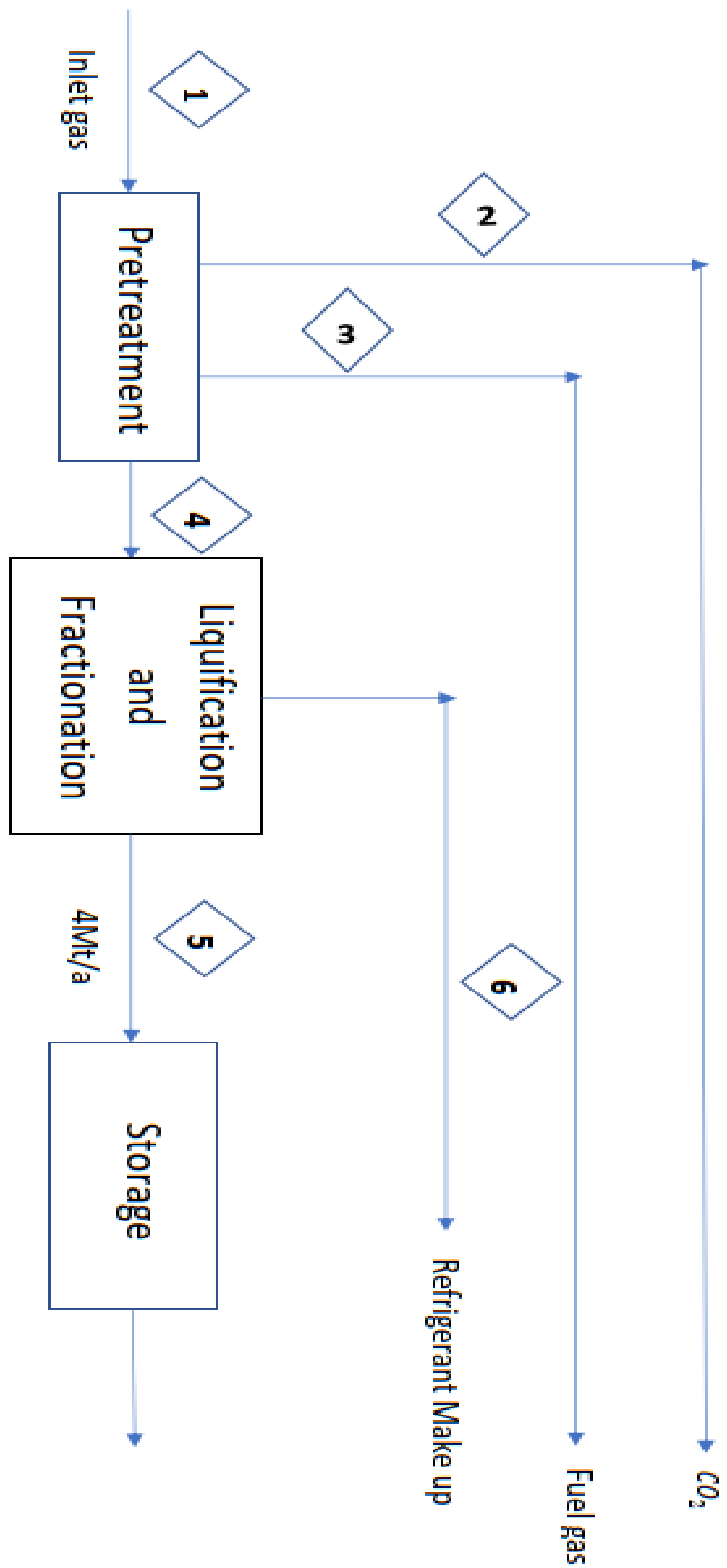


Figure 15: Block Flow Diagram

3.1: Overall Material Balance:

-The purpose of the overall material balance is to know the amount of the inlet gas that must be needed to the plant.

Table 7: Lean Gas from Safeer

STREAMS	1 Gas From Pipeline	2 Acid Gas	3 Make-Up Fuel Gas	4 Liquefaction Feed	5 Liquefaction Fuel Gas	6 Refrigerant Make-Up	7 Fuel Gas from trains	8 Rundown LNG	9 Propane	10 Butane	11 Pentane	12 Boil Off Gas	13 Total Fuel Gas	14 LNG To Carrier	15 Losses	16 Loaded LNG
FLOW RATE (kg/h)	768,111	3,286	70,880	693,945	1,432	2,232	72,311	690,282	DELETED	DELETED	–	8,952	75,320	624,595	2,907	621,688
FLOW RATE (Mt/a) (1)	6.176	0.026	0.570	5.579	0.012	0.018	0.581	5.550	″	″	–	0.078	0.660	5.471	0.025	5.446
FLOW RATE (MMSCFD)	894.1	1.7	82.5	809.9	1.3	1.3	83.8	807.2	″	″	–	11.0	88.0	730.4	3.6	726.6
HHV (kJ/kg) (4)	54,717	2,969	54,717	54,957	53,515	51,290	54,693	54,972	″	″	–	53,638	54,568	54,996	53,844	54,998
HHV (MWa/a)	10,715	2	989	9,723	20	29	1,008	9,674	″	″	–	133	1,142	9,542	43	9,498
HHV (TBtu/yr)	320	0	30	291	1	1	30	289	″	″	–	4	34	285	1	284
HHV (Btu/SCF) (5)	1,069	131	1,069	1,071	1,323	1,972	1,073	1,069	″	″	–	989	1,063	1,070	992	1,070
MOLECULAR WEIGHT	17.25	38.82	17.25	17.20	21.82	33.94	17.32	17.17	″	″	–	16.28	17.19	17.17	16.26	17.18
COMPOSITION (% mole)																
NITROGEN	0.090	0.000	0.090	0.090	0.001	0.019	0.089	0.090	″	″	–	2.041	0.334	0.078	1.809	0.063
CO2	0.170	80.296	0.170	0.002	0.000	0.000	0.167	0.000	″	″	–	0.000	0.146	0.000	0.000	0.000
METHANE	93.211	11.019	93.211	93.378	58.841	24.861	92.671	93.546	″	″	–	97.949	93.333	93.520	98.181	93.482
ETHANE	5.090	0.837	5.090	5.098	41.143	22.803	5.657	5.011	″	″	–	0.009	4.948	5.041	0.010	5.083
PROPANE	1.220	0.170	1.220	1.222	0.015	52.215	1.201	1.142	″	″	–	0.000	1.050	1.149	0.000	1.158
i-BUTANE	0.080	0.003	0.080	0.080	0.000	0.091	0.079	0.080	″	″	–		0.069	0.080		0.081
n-BUTANE	0.110	0.004	0.110	0.110	0.000	0.011	0.108	0.111	″	″	–		0.095	0.112		0.113
i-PENTANE	0.010	0.000	0.010	0.010		0.000	0.010	0.010	″	″	–		0.009	0.010		0.010
n-PENTANE	0.010	0.000	0.010	0.010		0.000	0.010	0.010	″	″	–		0.009	0.010		0.010
HEXANE	0.000		0.000	0.000			0.000	0.000	″	″	–		0.000	0.000		0.000
HEPTANE	0.000		0.000	0.000			0.000	0.000	″	″	–		0.000	0.000		0.000
WATER	0.009	7.672	0.009	< 1ppm	< 1ppm		0.009		″	″	–		0.008			
NOTE	(8)		(8)									(2)			(7)	(3)

3.1.1: Assuming That:

- Fuel gas represent 8% of the inlet gas.
- H_2S isn't existed.
- 30 days for maintenance.
- Hg isn't existed.
- C_{5+}removed in Marib.

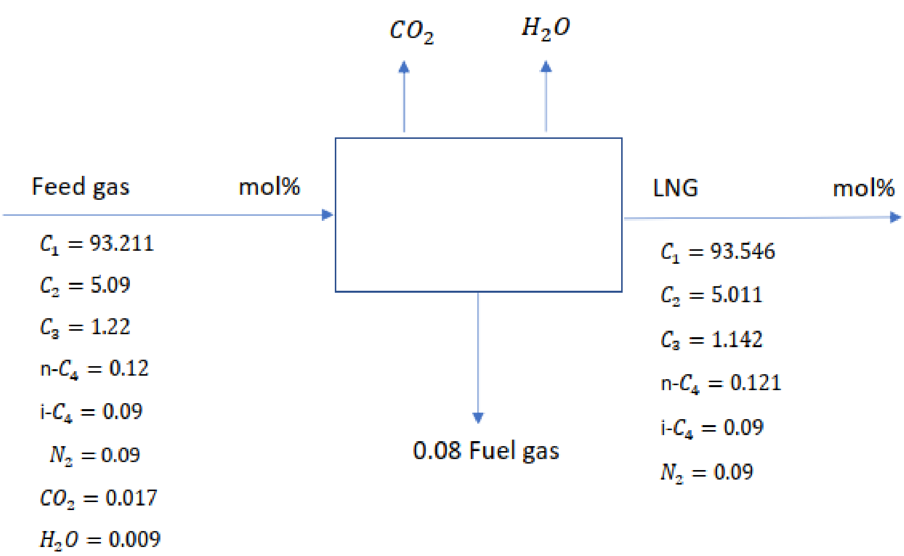


Figure 16: Flowsheet of Overall Material Balance

3.1.2: Overall Material Balance calculations: -

Input = Output

F = 0.0017F + 0.00009F + 0.08F + LNG (kmol/h)

M.Wt for: **C=12 , H=1 , N=14 , O=16 (kg/kmol)**

$$* \sum y_i \ M_i \ for \ output$$

$$= 0.93546(16) + 0.05011(30) + 0.01142(44) + 0.0009(58) + 0.00121(58) + 9 * 10^{-4}(28)$$

= 17.12072 kg/kmol

- Output =

4 Mt	10^6 t	1000kg	annual	1 D
annual	Mt	1 t	335 D	24 h

= 497512.4378 kg/h

➡

497512.4378 kg	kmol
h	17.12072 kg

= 29059.08384 kmol/h

- $\dot{m}$ ((output)) = 497512.4378 kg/h

➡

497512.4378 kg	2.205 Ib_m
h	1 kg

= 1097014.925 Ib_m/h

- Ib_m/h = 110 MMSCFD * M.Wt

➡

1097014.925 Ib_m		kmol
h	110 MMSCFD	17.12072 kg

= 582.503 MMSCFD

- Output = 582.503 MMSCFD

$*M_i \ for \ input$ = 0.93211(16) + 0.0509(30) + 0.0122(44) + 0.0009(58) + 0.0012(58) + $9 * 10^{-4}(28) + 1.7 * 10^{-3}(44) + 0.00009(18)$

= 17.20098 kg/kmol

- F = 0.0017 + 0.00009F + 0.08F + LNG (kmol/h)

  = 0.0017F + 0.00009F + 0.08F + 29059.08384

F – 0.0017F – 0.00009F – 0.08F = 29059.08384

1 – 0.0017F – 0.00009F – 0.08F = 29059.08384

0.91821F = 29059.08384

∴ F = $\frac{29059.08384\ kmol/h}{0.91821}$ = 31647.5358 kmol/h

➡ $\frac{31647.5358\ kmol}{h}\Big|\frac{17.20098\ kg}{1\ kmol}$

= 544368.630 kg/h

➡ $\frac{544368.630\ kg}{h}\Big|\frac{1\ t}{1000\ kg}\Big|\frac{1\ Mt}{10^6\ t}\Big|\frac{24\ h}{1\ D}\Big|\frac{335\ D}{1\ a}$

= 4.377 Mt/a

➡ $\frac{544368.630\ kg}{h}\Big|\frac{2.205\ Ib_m}{1\ kg}$

= 1200332.83 Ib_m/h

∵ Ib_m/h = 110 MMSCFD * M.Wt

➡ $\frac{1200332.83\ Ib_m}{h}\Big|\frac{}{110\ MMSCFD}\Big|\frac{kmol}{17.20098\ kg}$

= 634.389 MMSCFD

3.1.3: The amount of fuel gas = 0.08(F)

=0.08(31647.53558 kmol/h)

=2531.8029 kmol/h

=0.08(544368.630 kg/h)

=43549.5 kg/h

=0.08(4.377 Mt/a)

=0.35Mt/a

=0.08(1200332.83 Ib_m/h)

=96026.63 Ib_m/h

=0.08(634.389 MMSCFD)

=50.75 MMSCFD

3.1.4: Calculation of CO_2 & H_2O: -

CO_2 = 0.0017, H_2O = 0.00009

M.Wt of CO_2= 44 kg/kmol

M.Wt of H_2O= 18 kg/kmol

- F=541429.84 kg/h

$$F=\frac{541429.84\ kg}{h}\left|\frac{kmol}{17.18838\ kg}\right. = 31499.761\ kmol/h$$

3.1.4.1: The Amount of CO_2=31499. 761 * 0.0017

= 53.5496 kmol/h

$$\frac{53.5496\ kmol}{h}\left|\frac{44\ kg}{kmol}\right. = 2356.18203\ kg/h$$

$$\frac{2356.18203\ kg}{h}\left|\frac{1\ t}{1000 kg}\right|\frac{1\ Mt}{10^6\ t}\left|\frac{24\ h}{1\ D}\right|\frac{335\ D}{a} = 0.018944\ Mt/a$$

$$\frac{2356.18203\ kg}{h}\left|\frac{2.205\ Ib_m}{kg}\right. = 5195.3814\ Ib_m/h$$

- $Ib_m = 110\ MMSCFD * M.Wt$

$$\frac{5195.3814\ Ib_m}{h}\left|\frac{1}{10\ MMSCFD}\right|\frac{kmol}{17.20098\ kg} = 30.204\ MMSCFD$$

3.1.4.2: The Amount of H_2O = 31499. 761 * 0.00009

= 2.83498 kmol/h

$$\rightarrow \frac{2.83498\ \cancel{kmol}}{h}\frac{18\ kg}{\cancel{kmol}} = 51.021\ kg/h$$

$$\rightarrow \frac{51.021\ \cancel{kg}}{\cancel{h}}\bigg|\frac{1\ \cancel{t}}{1000\ \cancel{kg}}\bigg|\frac{1\ Mt}{10^6\ \cancel{t}}\bigg|\frac{24\ \cancel{h}}{1\ \cancel{D}}\bigg|\frac{335\ \cancel{D}}{a} = 4.1 * 10^{-4}\ Mt/a$$

$$\rightarrow \frac{51.021\ \cancel{kg}}{h}\bigg|\frac{2.205\ Ib_m}{\cancel{kg}} = 112.50\ Ib_m/h$$

$\because Ib_m = 110\ MMSCFD * M.Wt$

$$\rightarrow \frac{112.50\ Ib_m}{h}\bigg|\frac{1}{110 MMSCFD}\bigg|\frac{kmol}{17.20098\ kg} = 0.0595\ \text{MMSCFD}$$

3.2: HEATING VALUE

The heating value of LNG, which stands for liquefied natural gas, can be expressed in two main ways: Lower Heating Value (LHV) and Higher Heating Value (HHV). These values help quantify the energy content of LNG, taking into account different factors such as the heat released during combustion and the heat required to vaporize any water vapor produced during combustion.

3.2.1: Lower Heating Value (LHV):

LHV, also known as the net heating value or lower calorific value, is a measure of the energy content of LNG when the water vapor produced during combustion is assumed to be in a condensed (liquid) state. It accounts for the heat released during combustion but does not consider the latent heat of vaporization of water. LHV is typically lower than HHV because it assumes that the water vapor remains in a liquid state.

3.2.2: Higher Heating Value (HHV):

HHV, also known as the gross heating value or higher calorific value, is a measure of the energy content of LNG when the water vapor produced during combustion is assumed to be in a vapor (gaseous) state. HHV includes the heat released during combustion and the heat required to vaporize any water vapor produced in the process. HHV is generally higher than LHV because it considers the latent heat of vaporization of water.

In practical applications, the choice between LHV and HHV depends on the specific requirements and standards used in a given context. LHV is often used in the natural gas industry, while HHV is more common in some other applications, including power generation and environmental analyses. It's essential to specify which heating value (LHV or HHV) is being used to avoid confusion when discussing LNG's energy content.

HHV(gross)	LHV(net)
20,000 to 24,000 British thermal units per pound (Btu/lb)	18,000 to 22,000 British thermal units per pound (Btu/lb)
46,540 to 55,680 kilojoules per kilogram (kJ/kg).	41,860 to 51,140 kilojoules per kilogram (kJ/kg).

Table 8: Compering Between HHV & LHV

3.2.3: Heating Value calculations: - Per unit mass of the fuel

- Oxidation of Methane:
  $CH_{4\,(g)} + 2O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2H_2O_{(L)}$
  $\Delta HC° = -890.36_{(g)}$ KJ/mol
- Oxidation of Ethane:
  $C_2H_{6\,(g)} + 7/2\ O_{2\,(g)} \longrightarrow 2CO_{2\,(g)} + 3H_2O_{(L)}$
  $\Delta HC° = -1559.9_{(g)}$ KJ/mol
- Oxidation of Propane:
  $C_3H_{8\,(g)} + 5O_{2\,(g)} \longrightarrow 3CO_{2\,(g)} + 4H_2O_{(L)}$
  $\Delta HC° = -2220_{(g)}$ KJ/mol
- Oxidation of n-Butane:
  $C_4H_{10(g)} + 13/2\ O_{2(g)} \longrightarrow 4CO_{2\,(g)} + 5H_2O_{(L)}$
  $\Delta HC° = -2878.6_{(g)}$ KJ/mol
- Oxidation of i-Butane:
  $C_4H_{10\,(g)} + 13/2\ O_{2\,(g)} \longrightarrow 4CO_{2\,(g)} + 5H_2O_{(L)}$
  $\Delta HC° = -2868_{(g)}$ KJ/mol

***For each mole: *N (non-compositable)**

Table 9: Mole and Mass Fraction

Component i	Mole Fraction y_i	Mole $n_i = y_i * n_{tot}$	M.Wt M_i(g/mol)	Mass (g) $m_i = n_i * M_i$	Mass Fraction $x_i = m_i/m_{tot}$
CH_4	0.93546	0.93546	16	14.96736	0.875
C_2H_6	0.05011	0.05011	30	1.5033	0.0879
C_3H_8	0.01142	0.01142	44	0.50248	0.029371
n-C_4H_{10}	0.00121	0.00121	58	0.07018	$4.1*10^{-3}$
i-C_4H_{10}	0.0009	0.0009	58	0.0522	$3*10^{-3}$
N_2	0.0009	0.0009	28	0.0252	0.0015
Total	1	1	100	17.10812	1

3.2.3.1: HHV (gross) $= \sum y_i \, \Delta HC°$

= (0.93546(890.36) + 0.05011(1559.9) +

0.01142(2220) + 0.00121(2878.6) + 0.0009(2868)

= 942.42604 KJ/mol

$$\rightarrow \frac{942.42604\ kJ}{\cancel{mol}} \Big| \frac{\cancel{mol}}{17.20098\ g} = 54.79\ \text{KJ/g}$$

= 54.79 KJ/g * 1000g

= 54790 KJ/kg

3.2.3.2: LHV (net) = HHV – n_{H2O} $(\Delta H_v)_{H2O}$

*** $(\Delta H_v)_{H2O}$ at 1atm , 25 C° = 44.013**

→ $LHV_{(CH4)}$ = 0.93546((890.36) – 2(44.013))

= 750.5514 KJ/mol

$LHV_{(C2H6)}$ = 0.05011((1559.9) – 3(44.013))

= 71.550 KJ/mol

$LHV_{(C3H8)}$ = 0.01142((2220) – 4(44.01)

= 23.34189 KJ/mol

$LHV_{(n\text{-}C4H10)}$= 0.00121((2878.6) – 5(44.013))

= 3.21683 KJ/mol

$LHV_{(i\text{-}C4H10)}$ = 0.0009((2868) – 5(44.013))

= 2.383142 KJ/mol

∴ $LHV_{(LNG)}$ = 851.0433 KJ/mol

= 49.745 KJ/g * 1000 g = 49745 KJ/kg

Table 10: Final Overall Material Balance of Lean Gas

Streams	1	2		3	4	5	6	7	8
	Gas from pipeline	CO_2 & H_2O Continent		Gas Fuel	Liquification Feed	Random LNG	Refrigerant Make up	Propane	Butane
		CO_2	H_2O						
Flow Rate (kmol/h)	31647.5358	53.5496	2.83498	2531.8029	29059.348	29059.08384	47.4	Del.	Del.
Flow Rate (kg/h)	544368.630	2356.18203	51.021	43549.5	498411.93	497512.4378	1603	-	-
Flow Rate (Mt/a)	4.377	0.018944	$4.1 * 10^{-4}$	0.35	4	4	0.013	-	-
Flow Rate (Ib_m/h)	1200332.83	5195.3814	112.50	96026.63	1098998.32	1097014.925	3535.8	-	-
Flow Rate (MMSCFD)	634.389	30.204	0.0595	50.75	553.375	582.503	0.89	-	-
HHV (KJ/mol)	-	-	-	-	-	942.42604	-	-	-
HHV (KJ/kg)	-	-	-	-	-	54790	-	-	-
LHV (KJ/mol)	-	-	-	-	-	2.383142	-	-	-
LHV (KJ/kg)	-	-	-	-	-	49745	-	-	-
M.Wt	17.20098	-	-	-	-	17.12072	-	-	-

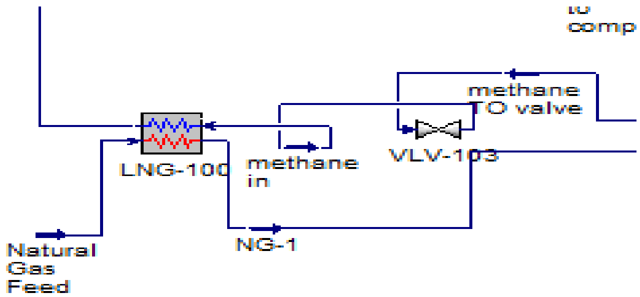
3.3: Base Case

Table 11: Base Case of Simulation LNG

Material Streams												
		distillation feed1	distillation feed 2	distillation feed 3	methan	H.bot-1	ethane	liquids 1	H.bot-2	propane	liquieds 2	H.bot3
Vapour Fraction		0.3280	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Temperature	C	-95.00	20.05	67.48	-83.85	43.23	7.004	7.003	85.35	45.83	45.83	107.6
Pressure	kPa	2500	2790	1690	2275	2310	2275	2275	2292	1585	1585	1655
Molar Flow	kgmole/h	1650	497.0	179.2	1510	140.4	187.8	2.880e-006	309.4	0.0000	103.1	76.06
Mass Flow	kg/h	3.125e+004	2.178e+004	9220	2.509e+004	6154	5857	9.470e-005	1.592e+004	0.0000	4555	4885
Liquid Volume Flow	m3/h	95.51	45.12	16.92	82.77	12.75	15.89	2.449e-007	29.22	0.0000	8.998	7.925
Heat Flow	kJ/h	-1.481e+008	-6.045e+007	-2.318e+007	-1.210e+008	-1.888e+007	-1.675e+007	-0.2929	-3.910e+007	0.0000	-1.212e+007	-1.079e+007
		bottom1	bottom2	M-to cooler	B.M	E-to cooler	B.E	p-to cooler	B.P	Natural Gas Feed	methane in	ethane in
Vapour Fraction		0.0000	0.1940	1.0000	1.0000	1.0000	0.1843	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	C	45.83	64.62	-113.1	-72.00	-20.71	-82.00	29.09	-40.44	25.00	-72.00	-82.00
Pressure	kPa	1585	1655	100.0	100.0	700.0	130.0	600.0	12.50	5870	100.0	130.0
Molar Flow	kgmole/h	103.1	525.9	1510	1510	187.8	187.8	0.0000	0.0000	3.070e+004	3.077e+004	50.00
Mass Flow	kg/h	4555	2.674e+004	2.509e+004	2.509e+004	5857	5857	0.0000	0.0000	5.444e+005	4.937e+005	1503
Liquid Volume Flow	m3/h	8.998	49.90	82.77	82.77	15.89	15.89	0.0000	0.0000	1728	1649	4.227
Heat Flow	kJ/h	-1.212e+007	-6.655e+007	-1.210e+008	-1.189e+008	-1.675e+007	-1.948e+007	0.0000	0.0000	-2.387e+009	-2.409e+009	-4.496e+006
		propane in	pure methane	pure ethane	pure propane	methane to COMP	NG-1	COMP methane	cold methane	M-1	methane TO valve	ethan to comp
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	C	-40.44	-72.00	-82.00	-40.44	19.11	-37.00	-28.00	-160.0	-109.0	-71.61	-42.00
Pressure	kPa	12.50	100.0	130.0	12.50	140.0	5629	81.50	92.00	130.0	140.0	178.3
Molar Flow	kgmole/h	220.0	52.98	50.00	220.0	3.077e+004	3.070e+004	3.077e+004	3.077e+004	3.077e+004	3.077e+004	50.00
Mass Flow	kg/h	9701	850.0	1503	9701	4.937e+005	5.444e+005	4.937e+005	4.937e+005	4.937e+005	4.937e+005	1503
Liquid Volume Flow	m3/h	19.15	2.839	4.227	19.15	1649	1728	1649	1649	1649	1649	4.227
Heat Flow	kJ/h	-2.385e+007	-4.147e+006	-4.496e+006	-2.385e+007	-2.312e+009	-2.483e+009	-2.363e+009	-2.500e+009	-2.447e+009	-2.409e+009	-4.409e+006
		NG-2	COMP ETHANE	COLD ETHANE	ethane TO valve	propane to comp	LNG	COMP PROPANE	cold propane	LNG to sep	Flashs	Final LNG
Vapour Fraction		0.9294	1.0000	1.0000	0.9681	1.0000	0.0000	1.0000	1.0000	0.0177	1.0000	0.0000
Temperature	C	-53.18	-20.34	-87.00	-68.46	-40.00	-160.0	-30.62	-40.00	-160.6	-160.6	-160.6
Pressure	kPa	5318	280.0	110.0	267.9	80.00	5100	100.0	30.00	101.3	101.3	101.3
Molar Flow	kgmole/h	3.070e+004	50.00	50.00	50.00	220.0	3.070e+004	220.0	220.0	3.070e+004	543.8	3.016e+004
Mass Flow	kg/h	5.444e+005	1503	1503	1503	9701	5.444e+005	9701	9701	5.444e+005	8725	5.356e+005
Liquid Volume Flow	m3/h	1728	4.227	4.227	4.227	19.15	1728	19.15	19.15	1728	29.14	1699
Heat Flow	kJ/h	-2.522e+009	-4.361e+006	-4.506e+006	-4.496e+006	-2.398e+007	-2.825e+009	-2.374e+007	-2.385e+007	-2.825e+009	-4.419e+007	-2.780e+009

3.4: Energy Balance Across the Liquefaction Cycle:

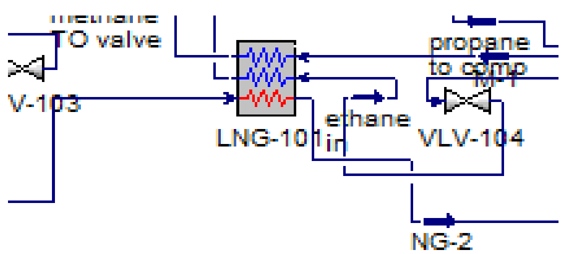
3.4.1: Methane Cycle



NG-1		
Temperature	-37.00	C
Pressure	5629	kPa
Molar Flow	3.070e+004	kgmole/h

Figure 17 : Methane Cycle of Simulation LNG

3.4.2: Ethylene Cycle



ethane in		
Temperature	-82.00	C
Pressure	130.0	kPa
Molar Flow	50.00	kgmole/h

Figure 18: Ethylene Cycle of Simulation LNG

3.4.3: Propane Cycle

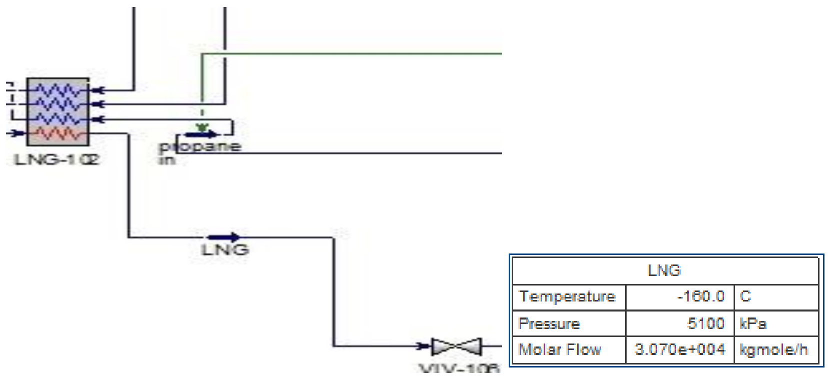
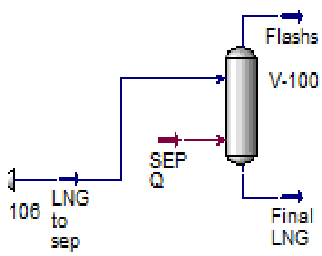


Figure 19 : Propane Cycle of Simulation LNG

3.4.4: Final LNG



V-100		
Separator Type	Separator	
Vessel Temperature	-160.6	C
Vessel Pressure	101.3	kPa
Liquid Molar Flow	3.016e+004	kgmole/h
Duty	-43.61	kJ/h

Figure 20 : Final LNG of Simulation LNG

3.5: Summary of Energy Balance

Table 12: Summary of Energy Balance

Energy Streams									
		heat	Reboiler heat 1	coolers-q1	heat q2	condenser-q2	heat q3	Cooler Duty	Cooler duty2
Heat Flow	Btu/hr	2.100e+006	5.912e+006	4.741e+006	9.108e+006	3.867e+006	4.113e+006	1.987e+006	2.595e+006
		Cooler duty3	comp q1	Cooler q1	COMP Q2	COOLER Q4	comp q4	cooler q5	SEP Q
Heat Flow	Btu/hr	0.0000	1.130e+004	2.224e+005	4.569e+004	1.375e+005	1.187e+005	1.021e+006	-4.133

CHAPTER 4: Plant & Equipment Design

4.1: Plant Design:

4.1.1: Plant Location & Site Selection

The planning of the factory or factory site depends largely on experience combined with the expectations of the human elements in terms of operation and maintenance. One of the most important factors in the factory operation is the accurate establishment and reasonable arrangement of devices, buildings, and pipeline networks, as they are the key to economic construction and safety operation, and since the industry is in continuous development Therefore, the old design of factories is no longer in line with the rapid development of production processes at the present time. Therefore, the factory must be designed to suit industrial conditions at the present time and in the future and facilitate making the necessary adjustments to suit the changes that are added in the production process in the future.

- Among the reasons that require making modifications in building the factory from time to time are:

- The occurrence of fundamental changes in the industrial process as a result of scientific progress, which requires replacing old machines with modern ones in order to face the intense competition in the market.

- The occurrence of fundamental changes in the product market, such as the lack of consumer interest in buying the factory's products, forcing the factory management to make adjustments in the production process.

4.1.2: Site Layout

Choosing the location of the factory is one of the most important decisions, because such a decision is not taken from time to time, but only once, because of the high cost of error in this decision, which cannot be reversed after its implementation. Among the most important factors that are taken into consideration when choosing the factory location are the following:

1. Raw materials.
2. Manpower.
3. Energy.
4. Transportation and communications.
5. Environmental conditions.
6. The abundance of land.
7. Waste disposal.
8. The water required to be provided for the industrial process.

*The following is a brief explanation of the factors mentioned above:

First: raw materials:

When choosing a factory location, its proximity to raw materials must be considered. Also, when there is more than one source of raw materials, it is necessary to study which one is more to stay for a longer period. In general, if the raw materials are spent in large quantities during the industrial process, then in this case the factory must be close to the raw materials to reduce the cost.

Second: Manpower:

The bulk of the cost of the factory is the cost of the labor force, and therefore the choice of the location of the factory depends on the provision of manpower including engineers, technicians, administrators, and workers with high qualifications, because the labor force is considered an essential factor in the production process.

Third: Energy:

Many industrial processes need electrical energy and other types of energy for the purpose of conducting industrial operations. Therefore, the amount of energy required for the industrial process must be known, and the costs of obtaining energy of all kinds must be studied.

Fourth: Transport and communications:

The provision of transportation and various means of transport is one of the main factors that must be considered when choosing the location of the factory, because the process of transporting materials and energy from their sources to their places of consumption, as well as the process of transporting products to their places of use, represents an exorbitant cost.

Fifth: Environmental Conditions:

Although the climate is of particular importance in the comparison between sites, but this importance has become less important at the present time, where it is possible to control reasonable costs of temperature, humidity, ventilation, dust, and smoke inside the factory by using air conditioning devices.

Sixth: the abundance of land:

One of the important factors in choosing the location of the factory, which requires considering the nature of the land and its suitability for constructing buildings on it and bearing the type of machines and equipment that are used in the industrial process, and the provision of land for future expansion must also be taken into account.

Seventh: Disposal of waste and waste:

One of the important factors in choosing the location of the factory or factory is to provide a good drainage network, as the process of getting rid of waste and residues resulting from the industrial process is among the problems facing the factory management, especially since the laws of most countries of the world prohibit throwing these wastes into wells and rivers or burying them in the ground.

Eighth: The water required to be provided for the industrial process:

Water is of great importance in the industrial process, so the factory location must be near water sources in order to ensure the permanent presence of water.

*The use of water in the laboratory is often for the purpose of:

1- It is used in heat exchangers.
2- It is used in the steam boiler.
3- Various uses, for example, for drinking, cleaning, agriculture, and others.

This requires the provision of water free from any impurities or hardness because the presence of such pollutants lead to corrosion of devices that use water continuously (steam boilers). Therefore, it is necessary to build a water desalination plant inside the factory before using the water directly.

In view of the high costs of water treatment, especially used for steam boilers, it is possible to recover or recover a large amount of this water. By installing condensers for the purpose of reusing it again.

Based on these factors and the comparison between the different sites, the Balhaf area was chosen as a place for the establishment of this project, for the following reasons:

1- The availability of raw materials due to the presence of the refinery near it.
2- Availability of manpower.
3- Availability of all kinds of means of transportation, especially marine ones.
4- Availability of suitable space for the establishment of the factory.
5- Availability of services, state strategy and political leadership support for investment and investors in Yemen.

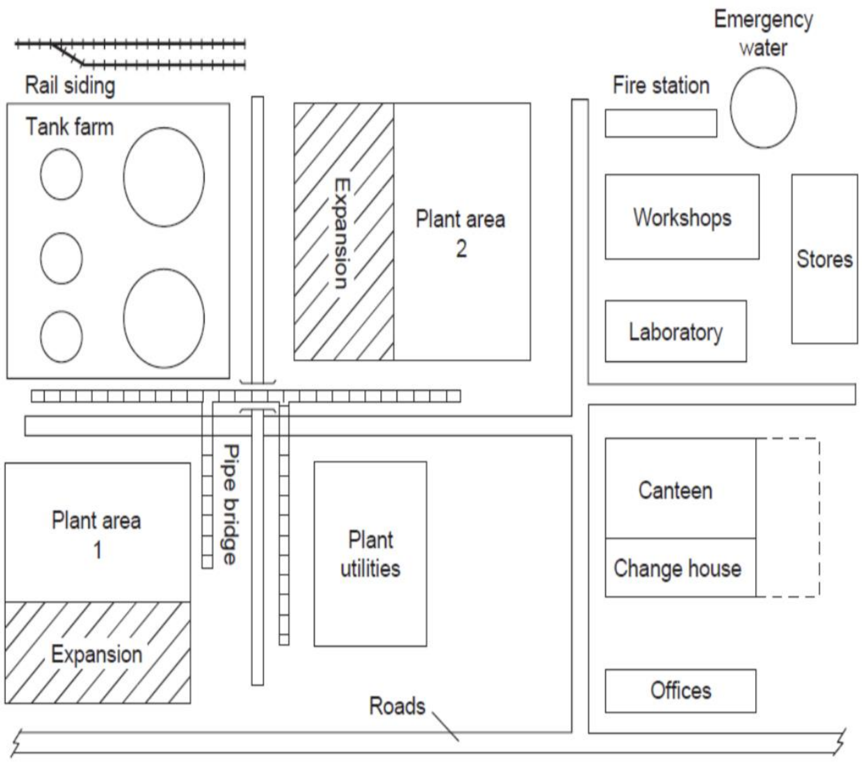


Figure 21: Typical Site Plan

4.1.3: Plant Layout

It means locating production and service departments, specifying operating stations, production centers, waiting areas, storage, and maintenance, which leads to the proper use of the spatial space of machinery, equipment, supplies and various facilities. The best possible use, which leads to ease of movement of workers with the facility and ease of handling raw, semi-finished and finished materials, which leads to achieving the regular flow of production processes between the different departments and stages of production, and which leads to effective interdependence between management, personnel, and materials.

Considerations to be considered when arranging the interior:

1- Type of commodity and service.
2- Follow-up of production and service operations.
3- Line and material handling equipment.
4- Maintenance and services.
5- Equipment and personnel.
6- The amount of output.
7- Control over the type.

4.1.4: Process Flow Diagram (PFD) for the Plant

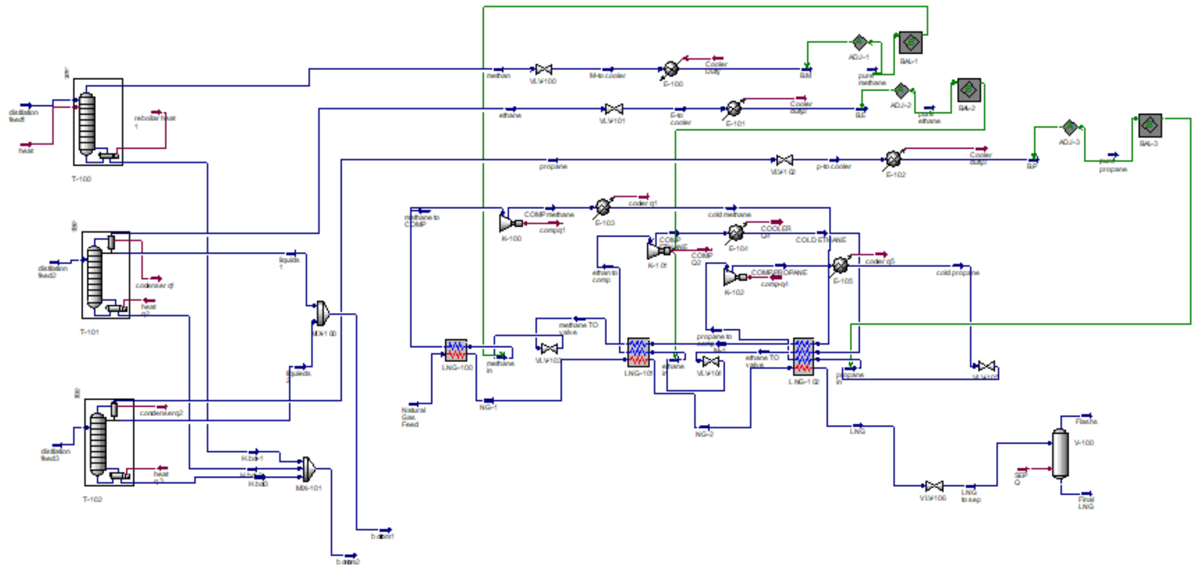


Figure 22: Process Flow Diagram of Simulation LNG

4.1.5: Major Equipment List

4.1.5.1: LNG Exchanger

In LNG production, natural gas is cooled to extremely low temperatures (typically around -162 degrees Celsius or -260 degrees Fahrenheit) to convert it into a dense liquid state for easier storage and transportation. The wound coil heat exchanger is a crucial component in the liquefaction process. The hot natural gas is passed through one side of the coil, while a cold refrigerant (usually methane or nitrogen) circulates on the other side. Heat from the natural gas is transferred to the refrigerant, causing the gas to rapidly cool and condense into LNG.

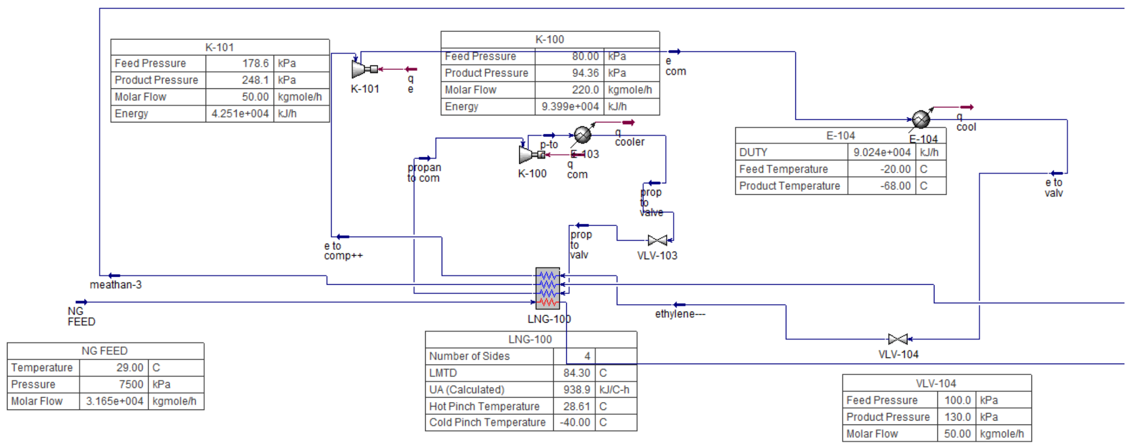


Figure 23: LNG Exchanger of Simulation LNG

4.1.5.2: Compressor

The Compressor centrifugal model is used to simulate a single stage or multistage centrifugal compressors.
To fulfil the DOF of this model several variables should be assigned:

- Pressure specifications
- Efficiencies specifications
- Number of stages

The design and costing mode of the model are also an option. For LNG processes, outlet pressures,
single stage mode and adiabatic efficiency were always the inputs used.

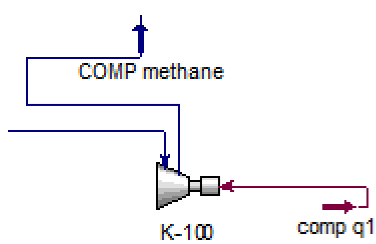


Figure 24: Compressor of Simulation LNG

4.1.5.3: Cooler

The Cooler model is a simplified model of a HX. This model was used to represent the intercooling of the compressors on the simple approach. The user may define the heat duty involved on the unit or the outlet temperature of the stream, the last option was the case for the present project.

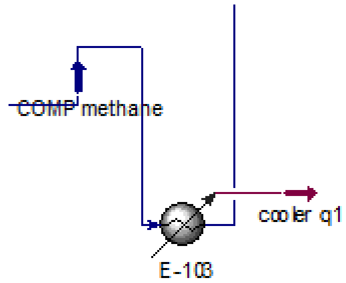


Figure 25: Cooler of Simulation LNG

4.1.5.4: J-T VLV

The JT valve model represents a Joule-Thompson or expansion valve. It is possible to assignment.
pressure specifications, outlet temperatures and vapor pressures. The outlet pressure was always the chosen assignment.

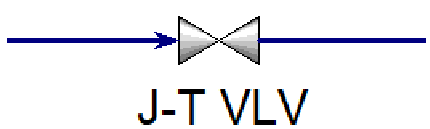


Figure 26: J-T VLV

4.1.5.5: SEPARATOR

The Separator model represents vapor-liquid separating equipment. The user as the option to define removed or added heat, pressure drop and design mode.

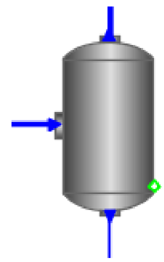


Figure 27: Separator Model

4.1.6: Major Utilities List

1. Electricity.
2. Steam, for process heating.
3. Cooling water.
4. Water for general use.
5. Demineralized water.
6. Compressed air.
7. Inert-gas supplies.
8. Refrigeration.
9. Effluent disposal facilities.

Electricity:

The power required for processes, motor drives, lighting, and general use may be generated on site.

Steam:

The steam for process heating is usually generated in water tube boilers, using the most economical fuel available.

Cooling Water:

Natural and forced-draft cooling towers are generally used to provide the cooling water required on a site.

Cooling towers work by evaporating part of the circulating water to ambient air, causing the remaining water to be chilled. If the ambient temperature and humidity are high, then a cooling water system will be less effective and air coolers or refrigeration would be used instead.

Demineralized Water:

Demineralized water, from which all the minerals have been removed by ion exchange, is used where pure water is needed for process use and as boiler feed water. Mixed and multiple-bed ion-exchange units are used. Water with less than 1 part per million (ppm) of dissolved solids can be produced.

Refrigeration:

Refrigeration is needed for processes that require temperatures below those that can be economically obtained with cooling water.

Compressed Air:

Compressed air is needed for general use and for the pneumatic controllers that are usually used for chemical plant control. Air is normally distributed at a mains pressure of 6 bar (100 psig). Rotary and reciprocating single-stage or two-stage compressors are used.

Inert Gases:

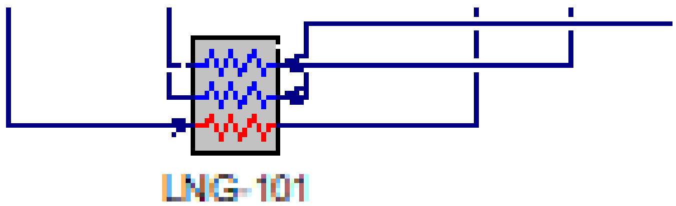
Where a large quantity of inert gas is required for the inert blanketing of tanks and for purging, this will usually be supplied from a central facility. Nitrogen is normally used and can be manufactured on site in an air liquefaction plant or purchased as liquid in tankers.

Effluent Disposal:

Facilities are required at all sites for the disposal of waste materials.

4.2: Equipment Design

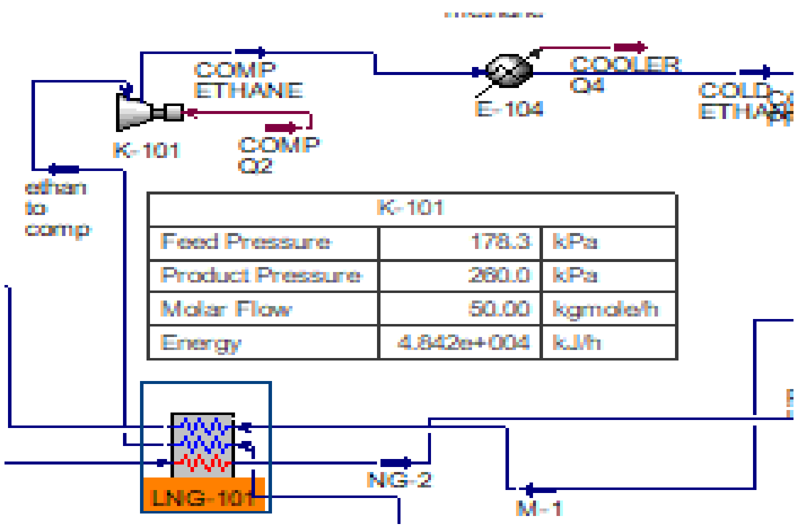
4.2.1: LNG Exchanger Design



LNG-101		
Number of Sides	3	
LMTD	43.66	C
UA (Calculated)	8.837e+005	kJ/C-h
Hot Pinch Temperature	-37.00	C
Cold Pinch Temperature	-42.00	C

Figure 28: LNG Exchanger Design Simulation LNG

4.2.2: Compressor Design



K-101		
Feed Pressure	178.3	kPa
Product Pressure	280.0	kPa
Molar Flow	50.00	kgmole/h
Energy	4.842e+004	kJ/h

Figure 29: Compressor Design Simulation LNG

4.2.3: Cooler Design

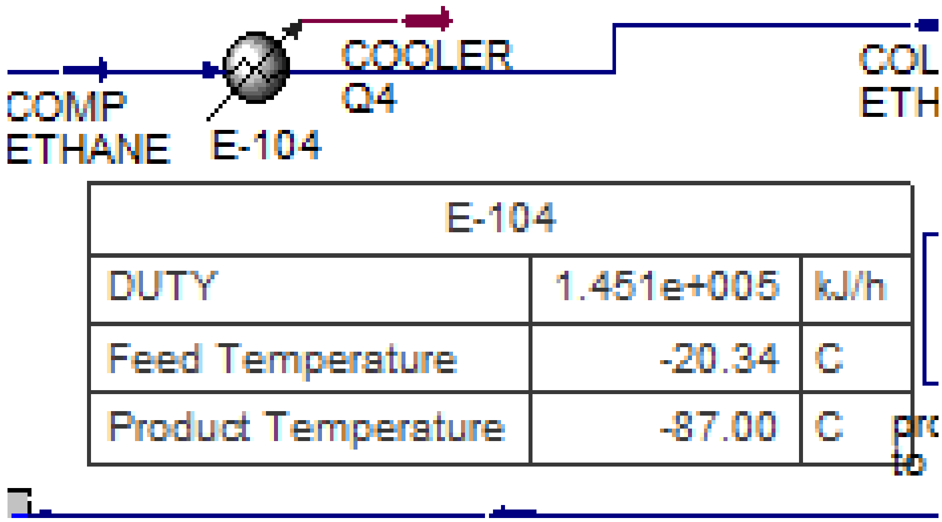


Figure 30: Cooler Design Simulation LNG

CHAPTER 5: STORAGE & TRANSPORATION

5.1: Introduction

LNG is transported via double-hulled tankers which are specially designed and insulated to prevent leakage or rupture in an accident. These vessels contain primary and secondary cargo containment systems that prevent leaks as well as sophisticated equipment to enhance safe navigation.

On land, LNG is stored at atmospheric pressure in specially engineered and constructed double-walled storage tanks. Most of these tanks have exterior walls and an inner tank that is constructed from a steel-nickel metal alloy specifically designed to accommodate the cold LNG. Should a leak develop in the inner wall, all the LNG would be contained by the outer walls.

Figure 31: LNG Liquefaction Export Facility in Kenai, Alaska

5.2: Storage Tank

LNG is stored at atmospheric pressure in double-walled insulated tank that are designed for storing the liquids at cryogenic temperature. The insulation is designed to minimize heat gain and reduce product losses due to boil-off. The boil-off rate from a typical tank is about 0.05 volume% per day. The tank capacity is typically 160,000m^3, matching the size of an average LNG carrier. Large tank capacity with 200,000m^3 or higher capacity is being built and may become the norm for new terminals in order to match todays large LNG carriers.

There are two main types of LNG storage tanks: in-ground storage tanks and above ground storage tanks.

Figure 33: A Satellite Storage Facility (left) and LNG Truck (right)

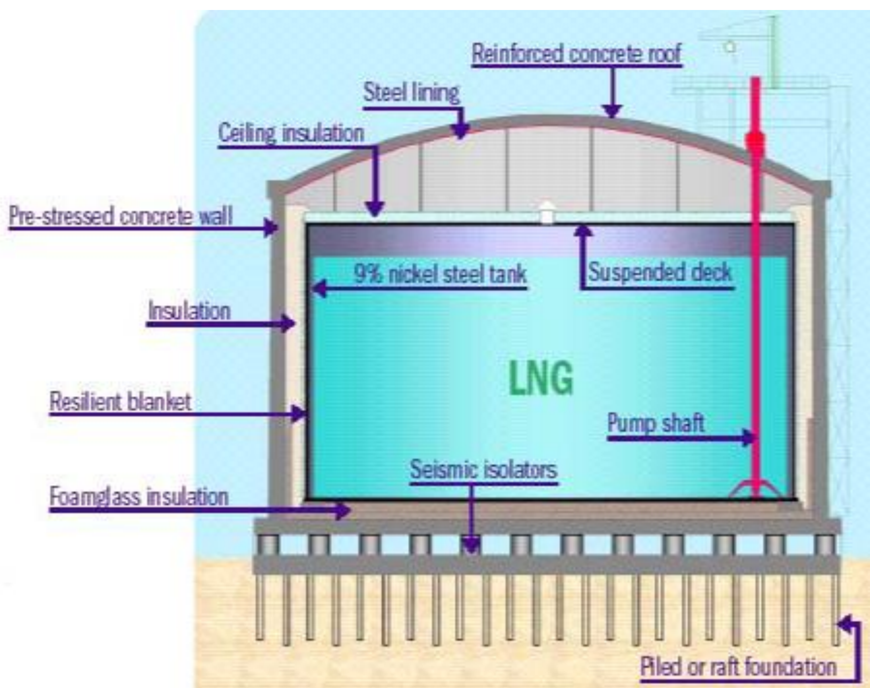


Figure 32: Conceptual Design of Storage Tanks

5.2.1: Single Containment Tank

A single containment tank is composed of a self-supporting inner cylindrical container made of 9% nickel steel. This inner tank is surrounded by an outer tank made of carbon steel, which holds an insulation material (perlite) in the annular space. The carbon steel outer tank is not capable of containing cryogenic materials; thus, the inner tank provides the only containment for the cryogenic liquid. However, single containment tanks are surrounded by a bund wall (constructed of prestressed concrete) or dyke external to the tank, which provides the secondary containment in the event of inner tank failure, although vapor would not be contained. In case of failure, vapor dispersion and flame radiation, if ignited, could result in serious damage to surrounding equipment and structures. The land requirements are greater than for other tanks because of the separation distance between the tank and the bund wall. This type of tank is the lowest cost option, which has been successfully used in the past. However, because it is more prone to external hazards than other types, insurance premiums are typically higher than the full containment, which penalizes the cost advantages

Figure 35: Single Containment Tanks

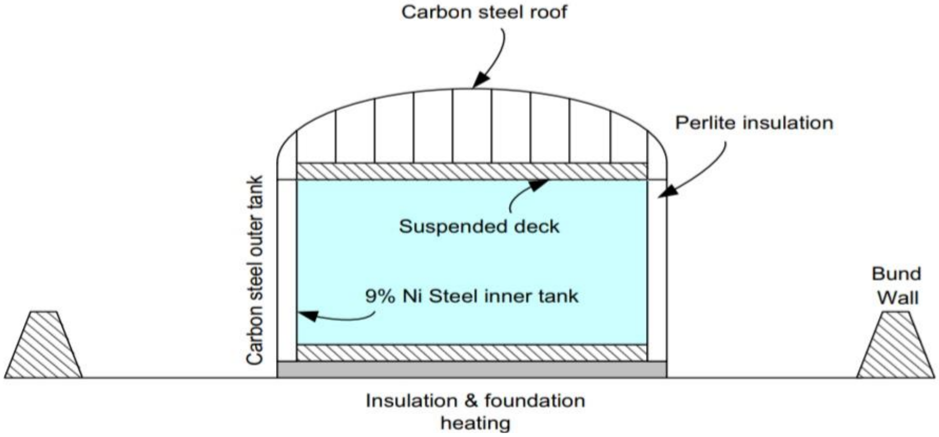


Figure 34: Typical Single Containment Tanks

5.2.2: Double Containment Tank

The double containment tank is similar to a single containment tank, with the addition of constructed walls as the secondary containment instead of a containment Therefore, if the inner tank fails, the secondary container is designed to contain the cryogenic liquid. The outer wall also limits dispersion of the LNG vapor. The outer concrete wall increases the cost of the tank, but less space is required because the containment dike is no longer necessary.

Figure 36: Double Containment Tanks

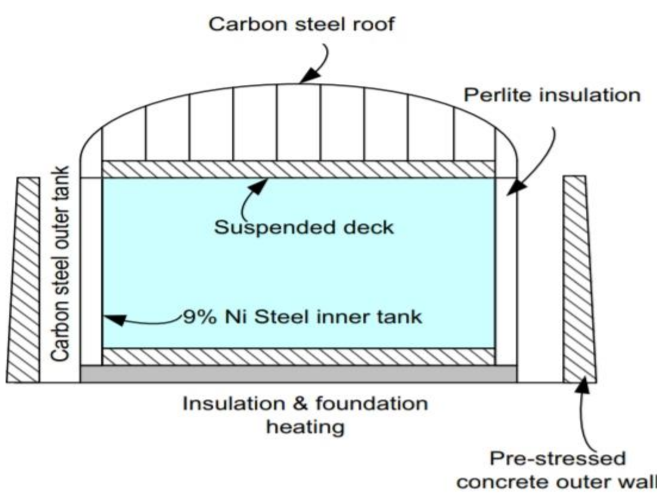


Figure 37: Double Containment Tanks

5.2.3: Full Containment Tank

A full containment tank is a double containment tank in which the annular gap between the outer and inner tanks is sealed. The majority of LNG storage tanks built in the last 10 years worldwide have been designed as full containment tanks. In this tank, the secondary container is liquid and vapor tight. In case of inner tank failure, the secondary container remains LNG tight. The secondary container wall is generally made of post-stressed concrete and the roof is usually reinforced concrete. The full containment tank has provisions for top connections only. There are no connections for pipelines or instruments penetrating the sides or bottom of the tank. All connections, such as the top fill line, pump wells, pump discharge, and vapor recovery, are permitted only through the inner tank. Full containment tanks cost from 10 to 20% more than single containment tanks. However, this type of storage has the advantage of an additional layer of safety against external elements such as fire, blasts, and atmospheric impacts.

Figure 38: Full Containment Tanks

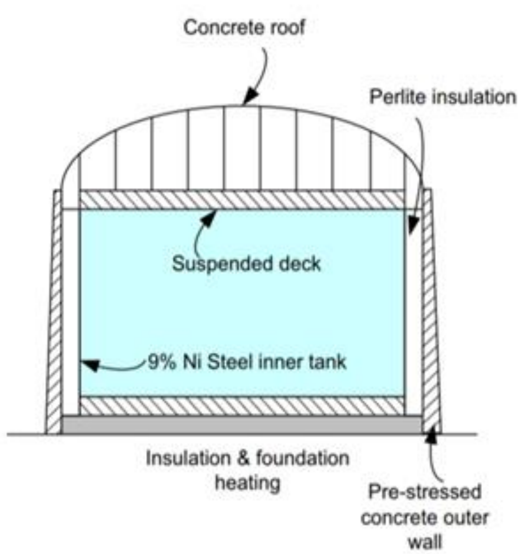


Figure 39: Typical Full Containment Tank

5.2.4: In Ground Tank

An in-ground tank consists of a stainless-steel membrane, supported by rigid polyurethane foam insulation. This in turn is supported within a reinforced concrete caisson. The roof consists of a dome-shaped carbon steel structure supporting a suspended deck with glass wool insulation. There is no risk of spillage with this high-integrity storage design. It is also more earthquake-proof as the seismic motion is not amplified in the underground tanks compared to the aboveground counterpart. With the earth berm, the tanks can be located close to one another, which is an advantage where land and space are limited. The record for the largest LNG tank in the world was first set by an in-ground tank (200,000 m^3), although several aboveground tanks have recently been built with a similar capacity.

Figure 40: In Pit LNG Storage Tank

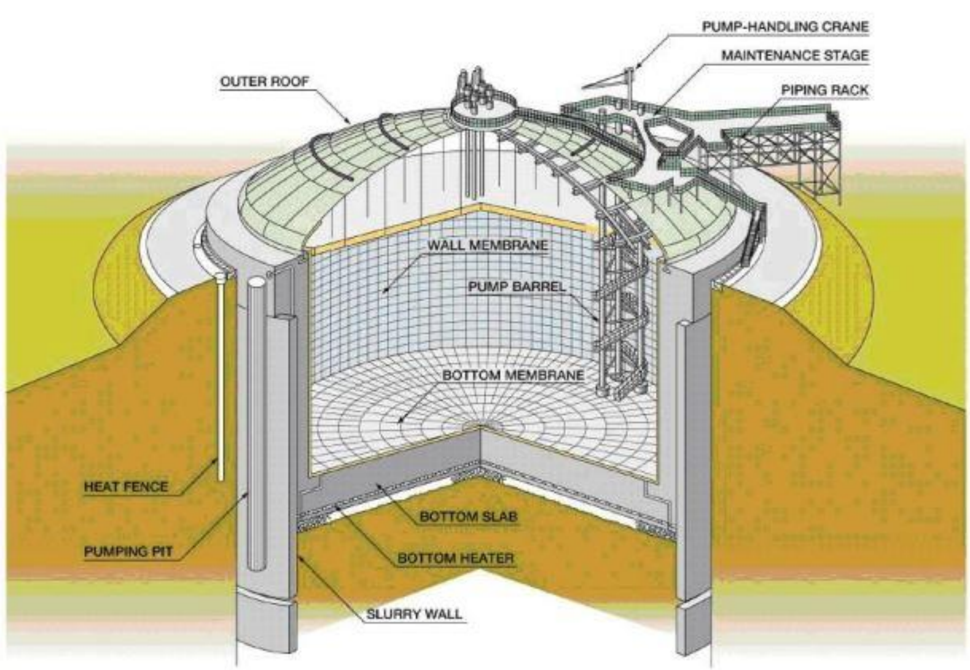


Figure 41: Typical in Ground Tanks

5.3: Transportation

LNG (liquefied natural gas) is typically transported by sea in specialized tankers. These tankers are specifically designed to carry LNG at very low temperatures and are highly insulated to keep the LNG in a liquid state. The LNG is loaded onto the tanker at a liquefaction plant, where it has been cooled to its liquid state. The tanker then transports the LNG to its destination, which could be a receiving terminal, where the LNG is re-gasified and sent to the natural gas pipeline network or stored for later use. During transportation, the temperature of the LNG is maintained at around -160 degrees Celsius (-260 degrees Fahrenheit) by a series of refrigeration systems. These systems are powered by the boil-off gas that is produced as the LNG warms up slightly during transportation. LNG tankers are typically quite large and can carry up to around 170,000 cubic meters of LNG. The tankers are also double-hulled to reduce the risk of leakage or spillage in the event of an accident.

Overall, the transportation of LNG is a highly specialized and complex process, but one that has become increasingly important as the demand for natural gas continues to grow around the world.

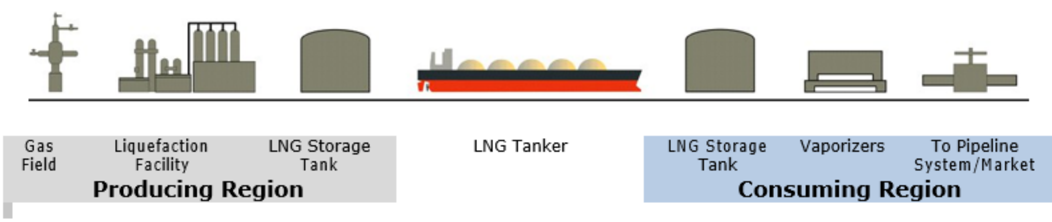


Figure 36: LNG Value Chain

5.3.1: Pipeline

Selecting the appropriate pipeline and sizing it correctly for the transportation of LNG requires careful consideration of a number of factors.

Firstly, the pipeline must be constructed of materials that are suitable for the extreme low temperature of the LNG. Typically, pipelines used for transporting LNG are made of specially designed cryogenic materials, such as stainless steel or aluminum.

Secondly, the pipeline must be sized correctly to ensure that it can transport the required volume of LNG at the desired flow rate. The pipeline size will depend on a number of factors, including the distance the LNG needs to travel, the pressure at which the LNG needs to be transported, and the flow rate required to meet the demand.

Thirdly, the pipeline must be designed to handle any fluctuations in pressure or temperature that may occur during transportation. This may require the use of pressure relief valves, temperature sensors, and other safety features to prevent accidents or damage to the pipeline.

Finally, the pipeline must be carefully monitored and maintained to ensure that it remains in good condition and operates safely over the long term. This may require regular inspection and testing to detect any signs of corrosion or other issues that could compromise the integrity of the pipeline.

In summary, selecting and sizing the appropriate pipeline for transporting LNG is a complex process that requires careful consideration of several factors, including material selection, pipeline sizing, safety features, and ongoing maintenance and monitoring. Proper planning and execution of these steps are critical to ensuring the safe and efficient transportation of LNG., for example glass foam and a vacuum layer. This complex insulation system makes LNG pipelines significantly more difficult and expensive to manufacture than standard natural gas pipelines.

5.3.2: Gas Feed Transportation

Gas feed transportation for LNG typically involves the use of pipelines or tankers . Pipelines are a common mode of transportation for natural gas and are used to transport gas from production fields to liquefaction plants, and then from liquefaction plants to regasification terminals. These pipelines are typically made of steel and are designed to operate at high pressures to allow for the efficient transport of large volumes of gas.

Tankers are also used for the transportation of LNG over long distances, particularly between countries or regions where pipelines are not feasible. These tankers are specially designed to carry LNG at very low temperatures and are highly insulated to keep the LNG in a liquid state. They can carry up to around 170,000 cubic meters of LNG and are double-hulled to reduce the risk of leakage or spillage in the event of an accident. In addition to pipelines and tankers, natural gas can also be transported via truck or rail, particularly for shorter distances or in areas where pipelines or tankers are not available. Overall, the transportation of natural gas feed for LNG involves the use of a variety of transportation modes and methods, each with its own unique benefits and challenges. Careful planning and execution are required to ensure the safe and efficient transport of gas feed to and from LNG facilities.

5.3.3: Marine Transport

Figure 37: Marine

Marine transport of LNG (liquefied natural gas) involves the transportation of LNG by sea using specialized LNG carriers, also known as LNG tankers. These tankers are specifically designed to keep the LNG in a liquid state during transportation .LNG tankers can vary in size, ranging from small-scale tankers that carry up to around 20,000 cubic meters of LNG, to large-scale tankers that can carry up to around 266,000 cubic meters of LNG. The size of the tanker will depend on a number of factors, including the volume of LNG that needs to be transported and the distance that needs to be covered . The LNG is loaded onto the tanker at the liquefaction terminal, typically by cooling it to a temperature of around -160 degrees Celsius (-260 degrees Fahrenheit) and transferring it into specialized insulated tanks on the tanker. Once loaded, the LNG tanker will set off on its journey, which can take anywhere from a few days to several weeks depending on the distance to the destination .During transportation, the LNG is kept at a very low temperature using specialized insulation systems and is typically carried at atmospheric pressure. The tankers are also equipped with a range of safety features, including emergency shutdown systems, fire detection and suppression systems, and gas detection systems. Once the LNG arrives at the receiving terminal, it is typically offloaded using specialized equipment and stored in large tanks until it is needed. The LNG is then re-gasified by passing it through a heat exchanger, which raises the temperature of the LNG and converts it back into a gaseous state. The re-gasified gas is then transported through pipelines to end-users, such as power plants, industrial facilities, or residential homes . Marine transport of LNG requires specialized infrastructure and equipment to ensure that the LNG is transported safely and efficiently, and to comply with relevant regulations and safety standards. It also requires careful planning and execution, as LNG can be potentially hazardous if not handled correctly.

Engineering design for safety also applies to LNG ships. An onboard containment system stores the LNG, where it is kept at atmospheric pressure (to keep air from entering the tank) and at -256°F (-160°C). Existing LNG ship cargo containment systems reflect one of three designs. As of October 2011:

Spherical (Moss) design accounts for 30 percent of the existing ships, Membrane design account for about 68 percent, and Self-supporting structural prismatic design account for about 2 percent.

Figure 38: Spherical Tank

Many ships currently under construction, however, are membrane type ships. The membrane and prismatic ships look more like oil tankers with a less visible containment tank structure above the main deck. The cargo containment systems of membrane-type LNG ships (see Figure 45) are made up of a primary container, a secondary containment, and further insulation.

Figure 39: LNG Lagos - Membrane Type LNG Carrier

CHAPTER 6: SAFETY AND ENVIRONMENT CONSIDERATION

6.1: Safety and Environment Considerations:

-Safety Considerations:

Fire and Explosion Risk: LNG is a flammable substance and can ignite in the presence of an ignition source. In case of a leak, it can quickly vaporize and form an explosive mixture with air. To mitigate these risks, safety measures such as fire protection systems, gas detectors, and emergency shutdown systems are installed at LNG facilities.

Cryogenic Hazard: LNG is stored and transported at extremely low temperatures. Direct contact with LNG can cause rapid freezing of tissues and severe frostbite. Thus, personnel handling LNG must wear personal protective equipment such as gloves and eye protection.

Transportation Risk: LNG transportation carries inherent risks such as collisions, grounding, and hull damage. Accidents involving LNG carriers can have serious consequences and may result in environmental damage and loss of life.

-Environmental Considerations:

Methane Emissions: Methane is a potent greenhouse gas that contributes to climate change. Although LNG has lower carbon emissions than other fossil fuels, uncontrolled releases of methane can significantly offset these benefits. Therefore, proper handling, transportation, and storage of LNG are crucial to minimize emissions.

Marine Pollution: Accidental spills or leaks during transportation of LNG can result in marine pollution, affecting marine ecosystems and marine life. To prevent this, appropriate safety measures such as double-hull tankers, collision avoidance systems, and emergency response plans are employed.

Land Use and Water Consumption: LNG infrastructure development can require significant land use, leading to habitat loss and environmental disturbance. Additionally, the production and processing of LNG require substantial amounts of water, leading to water depletion and ecological impacts.

LNG offers several benefits, but its safety and environmental considerations must be carefully managed to ensure safe operations and minimize the impact on the environment. Effective risk management, emergency response planning, and proper handling and storage are critical in ensuring the safe use of LNG.

6.2: Safety of LNG

LNG, or liquefied natural gas, is a safe and widely used fuel. However, as with any form of energy, there are some risks associated with its production, transportation, and storage.

The main risk associated with LNG is the potential for fire or explosion. This can occur if the LNG is accidentally released and contacted with a source of ignition, such as a spark or open flame. However, the risk of such incidents is low, as LNG is stored and transported under very specific conditions that minimize the risk of leaks or spills.

LNG is also non-toxic and non-corrosive and does not pose a threat to the environment or human health in the event of a spill or release. This is because LNG is lighter than air and quickly dissipates into the atmosphere, rather than pooling on the ground.

Overall, when handled and transported properly, LNG is a safe and reliable source of energy. However, it is important that all safety protocols and regulations are followed to ensure that the risks associated with LNG are minimized.

6.2.1: Compare Between the LNG Fire and other Fuel

The behavior of a fire caused by LNG (liquefied natural gas) can be different from fires caused by other fuels due to the unique characteristics of LNG. Here are some key differences between LNG fires and fires caused by other fuels:

Flame color: The flame from an LNG fire is usually invisible, while the flames from fires caused by other fuels can be visible and have distinct colors.

Heat intensity: The heat intensity of an LNG fire is generally lower than that of other fuels, such as gasoline or diesel. This is because LNG has a lower heat content per unit of volume compared to other fuels.

Flame propagation: LNG fires tend to have a lower flame propagation rate than other fuels, which means they are less likely to spread quickly.

Vapor cloud: One of the unique characteristics of LNG is that it can create a vapor cloud if it is released into the atmosphere. If the vapor cloud ignites, it can cause a fire or explosion. This is not typically a risk with other fuels.

Firefighting approach: The approach to fighting an LNG fire is different from other fuel fires. Because the flames from an LNG fire are typically invisible, firefighters use infrared cameras to detect and monitor the fire. In addition, water can be used to cool the surrounding area and prevent the fire from spreading, but direct water streams should not be used on the LNG fire itself as it can cause the LNG to spread.

In summary, while there are similarities between fires caused by different fuels, there are also important differences that need to be considered when dealing with an LNG fire.

Proper training, equipment, and protocols are necessary to respond to a fire caused by any fuel, including LNG, in a safe and effective manner.

Table 13: Comparison of Properties of Liquid Fuels

Properties	LNG	Liquefied Petroleum Gas (LPG)	Gasoline	Fuel Oil
Toxic	No	No	Yes	Yes
Carcinogenic	No	No	Yes	Yes
Flammable Vapor	Yes	Yes	Yes	Yes
Forms Vapor Clouds	Yes	Yes	Yes	No
Asphyxiant	Yes, but in a vapor Cloud	Same as LNG	Yes	Yes
Extreme Cold Temperature	Yes	Yes, if refrigerated	No	No
Other Health Hazards	None	None	Eye irritant, narcosis, nausea, others	Same as gasoline
Flash point (°F)	-306	-156	-50	140
Boiling point(°F)	-256	-44	90	400
Flammability Range in Air, %	5-15	2.1-9.5	1.3-6	N/A
Stored Pressure	Atmospheric	Pressurized (atmospheric if refrigerated)	Atmospheric	Atmospheric
Behavior if spilled	Evaporates, forming visible "clouds". Portions of cloud could be flammable or explosive under certain conditions.	Evaporates, forming vapor clouds which could be flammable or explosive under certain conditions.	Evaporates, forms flammable pool; environmental cleanup required.	Same as gasoline

Table 14: Autoignition Temperature of Liquid Fuels

Fuel	Autoignition Temperature, ºF
LNG (primarily methane)	1004
LPG	850-950
Ethanol	793
Methanol	867
Gasoline	495
Diesel Fuel	Approx. 600

6.2.2: Burn of LNG

LNG (Liquefied Natural Gas) is a highly flammable substance, and if ignited, it can result in a fire or explosion. When LNG is exposed to a source of heat or ignition, it will vaporize and create a flammable gas cloud that can ignite, causing a fire.

The heat of the fire will cause the LNG to boil off and release methane gas, which can further fuel the fire. The duration and severity of the fire will depend on various factors, such as the amount of LNG involved, the rate of release, and the effectiveness of the fire suppression systems.

LNG fires can be difficult to extinguish, as the fuel itself is difficult to access and the flames may not be visible. Water should not be used to extinguish an LNG fire, as it can cause the LNG to spread and create additional fires. Instead, specialized firefighting foam or dry chemical agents may be used to control the fire and prevent it from spreading.

In addition to the immediate risks of an LNG fire, there may be long-term effects on the environment, such as air pollution and water contamination. Therefore, it is important to handle and transport LNG safely, and to have effective emergency response plans in place to minimize the risk of fires and other incidents.

6.2.3: Explosion of LNG

An explosion can occur if a large amount of LNG (Liquefied Natural Gas) is rapidly vaporized and ignites in an enclosed space or if there is a failure in the storage or transportation systems. The main risk of an explosion associated with LNG is in the event of a rapid release of a large amount of gas, either through equipment failure or during an accident.

If a significant amount of LNG is released, it can vaporize quickly, creating a flammable gas cloud. If the gas cloud comes into contact with an ignition source, such as a spark or open flame, it can ignite and cause an explosion. The explosion can cause damage to equipment, buildings, and other infrastructure in the vicinity.

LNG storage facilities are designed to minimize the risk of explosions by incorporating safety features such as pressure relief valves, fire and gas detection systems, and emergency shutdown systems. Additionally, the transportation of LNG is done in specially designed containers that are made to withstand high pressure and impact.

While the risk of an LNG explosion is relatively low, it is important to have effective emergency response plans in place to deal with any incidents that may occur. This includes proper training of personnel and the use of specialized equipment and procedures to control the situation and minimize damage.

Is an LNG Spill Detectable?

Yes, an LNG (Liquefied Natural Gas) spill is detectable using various methods.

One of the primary methods for detecting an LNG spill is using gas detectors, which can be installed in the vicinity of the storage or transportation equipment. These detectors can detect the presence of LNG in the air and trigger an alarm or emergency shutdown system to prevent any further release.

In addition, visual inspection can also be used to detect an LNG spill, as it can be identified by the formation of a white cloud or fog that hovers above the ground. This is due to the cooling effect of the vaporizing LNG, which causes the water vapor in the air to condense and create the cloud.

Remote sensing technologies such as infrared cameras and satellite imagery can also be used to detect and monitor LNG spills. Infrared cameras can detect the heat signature of the vaporized LNG, while satellite imagery can provide an overview of the affected area and help to track the spread of the spill.

Overall, there are several methods for detecting an LNG spill, and it is important to have effective monitoring and detection systems in place to quickly identify and respond to any incidents that may occur.

6.2.4: LNG Environmentally Friendly

Compared to other fossil fuels, such as coal or oil, LNG (Liquefied Natural Gas) is generally considered to be more environmentally friendly. Here are a few reasons why:

Lower greenhouse gas emissions: The combustion of natural gas, of which LNG is a form, produces fewer greenhouse gas emissions than coal or oil. This means that burning LNG can help to reduce carbon dioxide emissions, which contribute to climate change.

Reduced air pollution: LNG produces lower levels of nitrogen oxides, sulfur dioxide, and particulate matter compared to coal or oil. This can help to reduce air pollution and improve air quality.

Safer transportation: LNG is transported by tankers, which are considered safer than oil tankers due to the lower risk of spills and explosions.

Potential for renewable energy: Natural gas reserves are abundant and can be found in many parts of the world. Additionally, there is a growing interest in using renewable natural gas, which is produced by capturing and processing methane emissions from landfills, livestock operations, and other sources.

However, it is important to note that LNG is still a fossil fuel, and its production, transportation, and use can have negative environmental impacts, such as methane leaks during production or transportation and disturbance to wildlife habitats. Therefore, while LNG may be considered more environmentally friendly compared to other fossil fuels, it is not a perfect solution and should be used in conjunction with efforts to increase the use of renewable energy sources and reduce overall energy consumption.

CHAPTER 7: Economic Viability

7.1: Natural Gas Reserves and Supply

According to the most recent BP estimates Yemen's gas reserves stood at 16.9 TCF in 2011 with the majority of the reserves being located in the Block 18-Marib field, however due to previously poor incentives to search for additional natural gas reserves there may be undiscovered natural gas volumes. In particular, there may be new offshore reserves that may bolster the present reserve estimations of Yemen.

7.2: Natural Gas Market Estimate

various demands for sectors including the:

- Power sector
- Cement industry
- Refining industry
- Fertilizer industry
- Desalinization
- Transportation
- Household and commercial

7.3: Pipeline Optimization Study

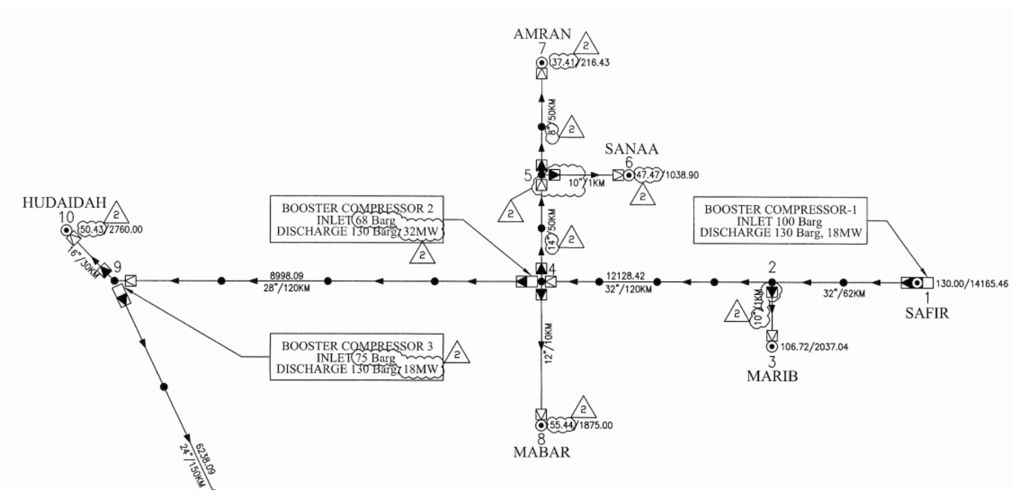


Figure 40: Pipeline Optimization Study

7.4: Gas Pricing and Economic Viability

Gas pricing in Yemen can be developed using several methodologies, but the deciding factor is whether there is free capacity connecting the uncommitted reserves in the Marib field with world market prices. Limited capacity implies that the relevant pricing regime changes from being dependent on international market prices to being dependent on the internal production and exploration costs.

The sector analysis resulted in an estimate of 12 BCM. The latter was based on a detailed information data base prepared by the Consultant and has formed the basis for both the conceptual design of pipelines and the economic analysis.

The following sectors were included in the sector analysis:

- Energy Sector, representing the power industry and refineries
- Industrial sector, representing cement industry and mining
- Agricultural sector, representing fertilizer industry
- Environmental sector, representing desalination plants

In the gas market report available information is presented for each sector as regards present activities, future development plans and an estimate of the corresponding market estimate. The total market estimate amounts to about 0.42 TCF or 12 BCM. Nearly half of this consumption is within the power sector followed by the transportation sector and cement industry. The accumulated gas consumption amounts to 5.0 TCF for 20 years.

Technical Concept and Pipeline System:

Most of earlier studies have investigated pipeline routing in the central mountainous regions between Sana'a and Hudaydah. This area in characterized by many obstacles (mountains, valleys, water crossings) and considered as most costly compared to pipeline routing along the coastal regions west and south of the mountainous central region. In addition, the central mountainous region is the region in Yemen with most earthquakes with an epicenter located in Dhamar region between Sana'a and Taiz.

Location and scale of the potential gas market has changed significantly since 2002. Firstly, a new Master Plan for the power sector has been developed with a proposed new power capacity of 3000 MW. Besides location in Marib and Mabar the new plants will in accordance with the Master Plan be developed in coastal areas of Hudaydah .

From these developments the Consultant has proposed a new routing of the pipeline with the purpose to avoid the costly mountainous region in central and move the pipeline closer to the planned consumption centers.

The gas pipeline is proposed to be established in 2 stages. The first stage of the gas pipeline goes from the Marib Block 18 at the Central Processing Unit following the Hunt Oil pipeline to the cross-section point on the highway between Sana'a and Ma- bar (close to Khadar). This stage also includes spur lines towards north to Sana'a and the cement plant in Amran and south to the planned power plants at Mabar. From here the pipeline further goes in parallel with the oil pipeline until Bajil and finally to Hudaydah. Stage 1 pipelines and installations are proposed to be established in parallel .

The pipe system consists of 362 km pipeline of 32", 65 km of 16" and 100 km of 14". This secures a minimum pressure of 25(bar G) for the entire system .

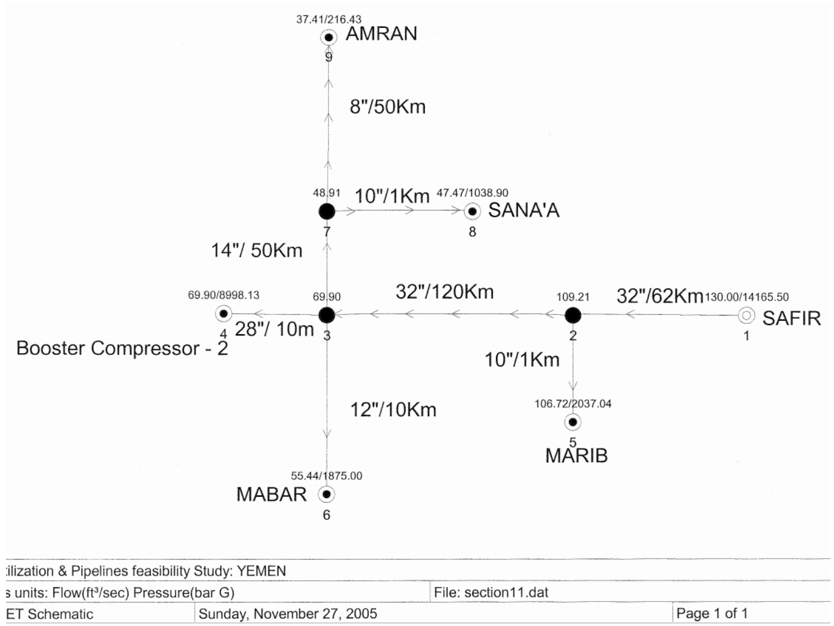


Figure 41: Gas Utilization Pipelines Feasibility Study in Yemen

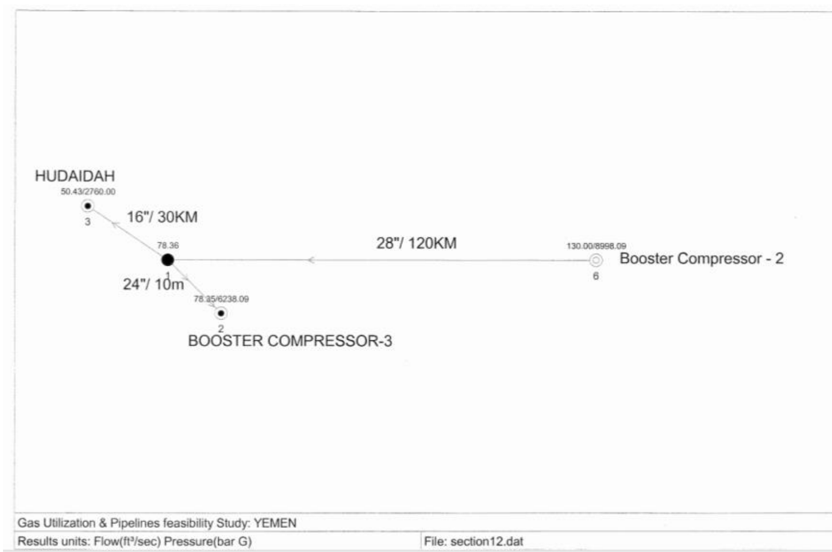


Figure 42: Gas Utilization Pipelines Feasibility Study in Yemen

APPENDIXS

A: physical Properties of Natural Gas Components

B: Tables and Figures in Chapter required

C: Results of Hysys Simulation

CONCLUSION

In conclusion, in this project, we have explored the potential of liquefied natural gas (LNG) production in Yemen, particularly in the Tihama basins near Rass Issa. We have outlined the objectives of this study, which include applying principles of chemical engineering to LNG production, simulating the Belhaf project, utilizing local natural gas resources for energy needs, encouraging natural gas utilization in local industries, and exploring economic opportunities through LNG exports.

Throughout the project, we have covered various aspects of LNG production, including its definition, components, properties, and the liquefaction process. We have also examined the materials and energy balances required for LNG production and discussed the design of the facility, emphasizing the core liquefaction process. The handling, storage, transportation, and export of LNG were addressed, ensuring a comprehensive overview of the entire LNG production cycle.

Moreover, we have addressed the critical aspects of safety and environmental considerations, highlighting the importance of adhering to best practices and precautions in LNG production to protect both workers and the environment. Finally, we have assessed the economic feasibility of the project and its potential to tap into global markets for natural gas, which could significantly benefit the Yemeni economy.

Recommendation:

Based on the findings and analysis presented in this project, it is recommended that Yemen seriously consider the establishment of an LNG facility in Rass Issa to capitalize on its abundant natural gas resources. This endeavor has the potential to achieve multiple objectives:

1. **Utilization of Local Resources**: Developing an LNG facility in Tihama basins can effectively harness Yemen's natural gas resources, ensuring a reliable local energy source and reducing dependence on foreign energy imports.
2. **Economic Growth**: LNG production can significantly boost Yemen's economy by capitalizing on the global demand for natural gas. By exporting LNG to European and African markets, Yemen can create a new revenue stream and enhance its economic stability.
3. **Industrial Integration**: Encouraging local petrochemical industries and factories to utilize natural gas for energy and feedstock can drive industrial growth, increase efficiency, and create job opportunities.
4. **Energy Security**: A domestic LNG facility will enhance energy security by diversifying the energy mix and reducing reliance on a single energy source.
5. **Environmental Benefits**: By adopting best practices for safety and environmental protection in LNG production, Yemen can minimize the impact on its environment and demonstrate a commitment to sustainable development.
6. **Education and Skill Development**: The development of an LNG industry in Yemen will require skilled professionals in various disciplines, offering opportunities for education and skill development within the country.

However, it's important to emphasize that the success of such a project will depend on careful planning, sound management, compliance with international standards, and a commitment to safety and environmental stewardship. Collaborations with international partners and experienced companies in the LNG industry can provide valuable expertise and support.

In conclusion, the establishment of an LNG facility in Rass Issa holds great promise for Yemen's economic and energy future. It can serve as a model for responsible resource management, contribute to economic growth, and enhance energy security in the country. Properly executed, this project has the potential to unlock significant benefits for Yemen and its people.

REFERANCES:

1. Benefits of integrating NGL extraction and LNG liquefaction, technology, Elliot, D., et al., AIChE Journal, 2005: p. 1943-1958.

2. Center of Liquefied Natural Gas (2007) About LNG. CLNG.

3. Elementary Principles of Chemical Processes, Richard M.Felder & Ronald W.Rousseau., 3rd ed. 2005.

4. Elements of Chemical Reaction Engineering, H.Scott Fogler., 4th ed.

5. Energy analysis of multistage cascade refrigeration cycle used for natural gas liquefaction. International Journal of Energy Research, Kanoglu, M., 2002.

6. Energy Conversion and Management Castillo,on the conceptual design of precooling stage of LNG plants using propane or an ethane/propane mixture, L., & Dorao, C. A., 2012.

7. Energy Information Administration, Natural Gas Annual 2007, December 2008. And Energy Information Administration, Annual Energy Review 2007, June 2008.

8. Engineering Data Book; 12th ed.

9. Environmental Impact Assessment, Fundy Engineering, Canaport Pond & Contiguous Alder Wetland Removal 2005a.

10. Gas Processors Suppliers Association (1994) Engineering Data Book. Tulsa Qatar gas (2002) Feed comp.

11. Handbook of Petroleum Processing, Steven A.Treese, Peter R.Pujado & David S.J.Jones 2nd ed.

12. HYSYS: An Introduction to Chemical Engineering Simulation, Abd Hamid, 2007.

13. Liquefied Natural Gas as a Motor Fuel, and a Refrigerant: Methodology of Evaluation of Ecological Suitability of Truck-Mounted Refrigerating Systems. Chemical and Petroleum Engineering, Kirillov, N., 2002.

14. LNG: An eco-friendly cryogenic fuel for sustainable development. Applied Energy, Kumar, S., et al., 2011.

15. LNG plant equipment (Statoil), in Seminar with Supplier Association, Murmanshelf, Pettersen, J., 2012: Murmansk, Russia.

16. Markets for natural gas. Encyclopedia of Energy, Correljé, A.F., 2004.

17. Marshall and swift equipment cost index, Chemical Engineering Journal (2007).

18. Performance enhancement of propane pre-cooled mixed Refrigerant LNG plant, Applied Energy, Mortazavi, A., et al 2012.

19. Propane Precooling Cycles for Increased LNG Train Capacity, in 14th International Conference and Exhibitions on Liquefied Natural Gas, Paradowski, H., M. Bamba, and C. Bladanet, 2004: Doha, Qatar 21-24 March.

20. Perry's Chemical Engineers Handbook, Don W.Green & Marylee Z.Southard 9th ed.

21. Yemen LNG Upstream Facilities Project. Yemen LNG Company Ltd. Process Design Basis Manual.