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***Experimental Study and Optimization of turbo expander
operating parameters of the "GPL2 CIS-DP-HMD" unit***

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I hope that all who have contributed directly or indirectly to the development of this work will find expression of our sincere gratitude.

DEDICATION

We are pleased to dedicate this work:

To our dear mothers who always give us hope in life and who never stop praying for us. And to our dear parents for their encouragement and support, especially for their love and sacrifices, so that nothing would hinder the progress of our studies. To our brothers and sisters, to all our family members, and to our best friends, each with his own name. And to all our teachers who contributed to us reaching this stage.

Abstract

In our investigation, we examined the performance of the Turbo-expander through a comprehensive thermodynamic analysis. To achieve this goal, we employed a combination of manual calculations and digital simulations using HYSYS software. The findings from our analysis revealed a yield of 65%, notably lower than the anticipated design yield of 82%. This discrepancy underscores the necessity of investigating the impact of varying parameters such as temperature, pressure, and flow rate on the yield of the Turbo-expander and consequently on the recovery rate of LPG. The outcomes of our study were meticulously presented and interpreted. They suggest that optimal hydrocarbon recovery is achieved at lower temperatures, higher pressures, and flow rates closely aligned with the design specifications. These findings underscore the importance of further exploration to optimize the performance of the Turbo-expander system.

Keywords: Turbo-expander. Pressure. Temperature GPL. Condensate. Hysys.

ملخص

في بحثنا هذا قمنا بدراسة الموسع التوربيني (Turbo-expander) من خلال تحليل حراري شامل. لتحقيق هذا الهدف، اعتمدنا على مزيج من الحسابات اليدوية والمحاكاة الرقمية باستخدام برنامج HYSYS. أظهرت نتائج تحليلنا نسبة عائد بلغت 65%، وهو أقل بكثير من نسبة العائد المتوقعة بلغت 82%. هذا التباين يؤكد على ضرورة استكشاف تأثير تغير المعاملات مثل درجة الحرارة والضغط ومعدل التدفق على نسبة العائد للجهاز الممتص الحراري وبالتالي على معدل استرجاع الغاز البترولي المسال. تم تقديم وتفسير نتائج دراستنا بعناية فائقة. تشير هذه النتائج إلى أن استرجاع الهيدروكربونات يتحقق بشكل أفضل عند درجات حرارة منخفضة، وضغوط عالية، ومعدلات تدفق تقترب من المواصفات التصميمية. وتؤكد هذه النتائج على أهمية المزيد من الاستكشاف لتحسين أداء نظام الموسع التوربيني.

الكلمات الرئيسية: توربو الموسع. ضغط. درجة الحرارة جي بي إل. المكثفات. هيسيس.

Résumé

Dans notre enquête, nous avons examiné les performances du Turbo-expandeur grâce à une analyse thermodynamique complète. Pour atteindre cet objectif, nous avons utilisé une combinaison de calculs manuels et de simulations numériques à l'aide du logiciel HYSYS. Les résultats de notre analyse ont révélé un rendement de 65 %, nettement inférieur au rendement de conception prévu de 82 %. Cet écart souligne la nécessité d'étudier l'impact de différents paramètres tels que la température, la pression et le débit sur le rendement du turbo-détendeur et par conséquent sur le taux de récupération du GPL. Les résultats de notre étude ont été méticuleusement présentés et interprétés. Ils suggèrent que la récupération optimale des hydrocarbures est obtenue à des températures plus basses, à des pressions plus élevées et à des débits étroitement alignés sur les spécifications de conception. Ces résultats soulignent l'importance d'une exploration plus approfondie pour optimiser les performances du système Turbo-expandeur.

Mots-clés : Turbo-expandeur. Pression. Température GPL. Condensat. Hysys.

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Symbols

Symbols	Designations	Unit
P	Pressure	(bar)
Q	Amount of heat	KJ
QG_{PL R}	Quantity of LPG in residual gas	(T/J)
QR_{GPL}	Quantity of LPG recovered	(T/J)
S	Entropy	(kj/kg.)
T	Temperature	(°C)
U	Internal energy	KJ
V	Volume	m ³
W	Mechanical work	KJ/h
η	The yield	(%)
C₆	Hexane (C ₆ H ₁₄)	
C₇	Heptane (C ₇ H ₁₆)	
CO₂	Carbon dioxide	
C₂⁻	C ₂ and C ₁	
C₄⁺	C ₄ and C ₅	
C₅[±]	C ₅ and C ₆	
H, h	Enthalpy	(kj/kg)
H₂	Hydrogen	
H₂O	water	
He	Helium	
IC₄	I- butane (I-C ₄ H ₁₀)	
IC₅	I- pentane (I-C ₅ H ₁₂)	
O₂	oxygen	
KW	Kilo watt.	
M	Molecular weight	kg/kmole
n	Polytropic coefficient	
N₂	Nitrogen	
NC₄	N-butane (N-C ₄ H ₁₀)	
NC₅	N-pentane (N-C ₅ H ₁₂)	

GENERAL INTRODUCTION

GENERAL INTRODUCTION

The HASSI Messaoud oil field is considered one of the most important in Algeria and globally. Given the importance of hydrocarbons in the economic development of our country and thanks to the advanced oil and gas technology on a global scale, it is essential to improve the rational exploitation of this deposit, which is one of the characteristics of SONATRACH's energy policy. The export of natural gas, crude oil and condensate is one of the main sources of income for the country, after natural gas, crude oil.

Due to its economic and ecological benefits, it is the most sought-after fuel both locally and internationally.

In 1997, the CIS (southern industrial center) commissioned the GPL2 unit which aims to recover LPG and associated gas condensate from the separation of crude oil. Using the LR1 pipe, the LPG is sent to HEH (HAOUD EL HAMRA) and then to the Arzew complex through the pumping stations.

LPG losses in the residual gas and condensate of the GPL2/CIS-HMD unit where we carried out our practical training are estimated at 380 tonnes per day, which represents a significant financial loss. Most of these losses are located in the cryogenic section and mainly depend on the efficiency of the liquefaction operation, which is mainly influenced by the temperature upstream of the cryogenic section. As the temperature upstream of the section decreases, the liquefaction rate increases, resulting in a maximum LPG recovery rate.

The turbo expander plays a crucial role in every sector of the gas or oil industry as it plays a crucial role in the liquefaction of LPG. To achieve low downstream temperature and pressure, it is essential to ensure proper expansion operation. With this in mind and due to its impact on production, it was suggested to us to analyze "the impact of turbo-expansion efficiency on LPG production".

To do this, our memory is divided into two parts:

The theoretical part is made up of four chapters:

chapter I: Natural Gas Operation

chapter II: presentation of the HMD and Liquefied petroleum gas (LPG) processing

chapter III: Presentation Turbo Expander

chapter IV: MAINTENANCE OF TURBOEXPANDERS

The practical part consists of one chapter

Chapter V: CALCULATION AND APPLICATION PART

It describes the calculation method used to evaluate the efficiency of the turboexpander and simulates the latter using HYSYS software to verify our calculations. Furthermore, the effect of thermodynamic parameters (T_e , P_e and Q_m) on the turboexpander efficiency as well as on the LPG recovery rate was studied. Finally, an economic calculation was performed showing the financial gains achieved due to the increase in the LPG recovery rate.

CHAPTER I: NATURAL GAS OPERATION

I.1. Introduction

Natural gas, a fossil fuel primarily composed of methane, results from the decomposition of organic matter dating back millions of years. It is found in rocky underground reservoirs and is extracted by drilling. Used for various applications such as heating, cooking and power generation, it also serves as a raw material for the manufacture of chemicals and plastics.

Being a non-renewable primary energy source, widespread and increasingly exploited on a global scale, natural gas has several advantages: its relative abundance, its versatility, its ecological qualities and its economic competitiveness. Its effective use requires technical expertise throughout the supply chain, from production to transportation.

Natural gas undergoes a treatment process to meet market requirements, guaranteeing its quality and facilitating its transportation and distribution. Specifications such as calorific value, C5+ compound and water content are essential to obtain a gas that complies with standards. Thus, the raw gas extracted from the wells is subjected to sequential treatment to remove water, recover heavy hydrocarbon fractions (condensate) and LPG (liquefied petroleum gas)[1].

I.2. Definition of natural gas

Natural gas, similar to oil and coal, is a fossil energy source found naturally in porous rock formations in gaseous form. It is mainly composed of methane (CH_4), representing between 70% and 95% of its composition, accompanied by a notable quantity of CO_2 and H_2O , as well as traces of metallic elements. As a result, it is mainly made up of hydrogen and carbon, giving it its name as a hydrocarbon[1].

I.3. Source of natural gas

Organic matter buried underground for millions of years is the main source of natural gas. This organic matter comes from plants, animals and other organisms that lived in ancient seas and swamps. As these organisms died, they were covered in sediment and exposed to high pressures and temperatures. Time passed and the organic matter decomposed into natural gas. In addition to the decomposition of organic matter, it is possible to produce natural gas through thermal cracking of oil. This happens when oil is heated to high temperatures with a catalyst[4].

I.4. Natural gas exploitation process

I.4.1. Natural gas exploitation goes through five stages

Production: extraction on sites then transport to France



Figure I-1: natural gas production[5]

Transport: transport of natural gas from import entry points to the different regions of France



Figure I-2 :GAS TRANSPORT[6]

Storage: storage of gas in saline cavities, in aquifers or in old deposits



Figure I-3: Storage[7]

Distribution: transport of gas to suppliers



Figure I-4: Distribution[8]

Gas supply: resale of gas to consumers



Figure I-5: Gas supply[9]

I.4.2. Extractions and processing

It is common for natural gas and crude oil to be linked and extracted at the same time from the same deposits or production areas. On average, 80% of liquid hydrocarbons come from crude oil; the remaining 20%, among the lightest fractions, propane and butane, are generally liquefied to facilitate their transport. Natural gas extraction and exploration (searching for deposits) are much the same techniques as those in the oil industry. Moreover, a large part of the world's known gas deposits was discovered during exploration campaigns aimed at exploring oil.

When extracting a gas under pressure, its cooling and expansion at the wellhead causes the hydrocarbons (C5 to C8 that it may contain) and water to condense³⁴. The recovered light liquid hydrocarbons, called “natural gas condensates” or “natural gas well liquid” correspond to an extremely light, very high value oil (yielding gasoline and naphtha). Everything else (C1 to C4 hydrocarbons, carbon dioxide, hydrogen sulfide, and helium) is gaseous at room temperature and delivered by pipeline to a gas processing plant. In this factory (which may be close to the deposits, or close to the places of consumption).

Condensates and LPG have such a market value that certain deposits are exploited solely for them, the “poor gas” (methane) being reinjected gradually, for lack of local outlets. Even when most of the lean gas is sold, part of it is often reinjected into the field, to slow the drop-in pressure, and ultimately recover a greater part of the condensates and LPG.

The other part (the largest) is transported by gas pipeline or LNG tanker to the places of consumption. The gas then undergoes dehydration by dew point, then the different components are separated. Hydrocarbons C2 to C4 are marketed under the name of liquefied petroleum gas (LPG and not LNG). Carbon dioxide is most often simply released into the atmosphere unless there is a nearby user. Sometimes, it is reinjected into an underground formation (CO2 sequestration) to reduce greenhouse gas emissions. If helium is available in adequate quantities, it is separated and marketed - in some cases it constitutes a significant part of the revenue generated by the deposit[10].

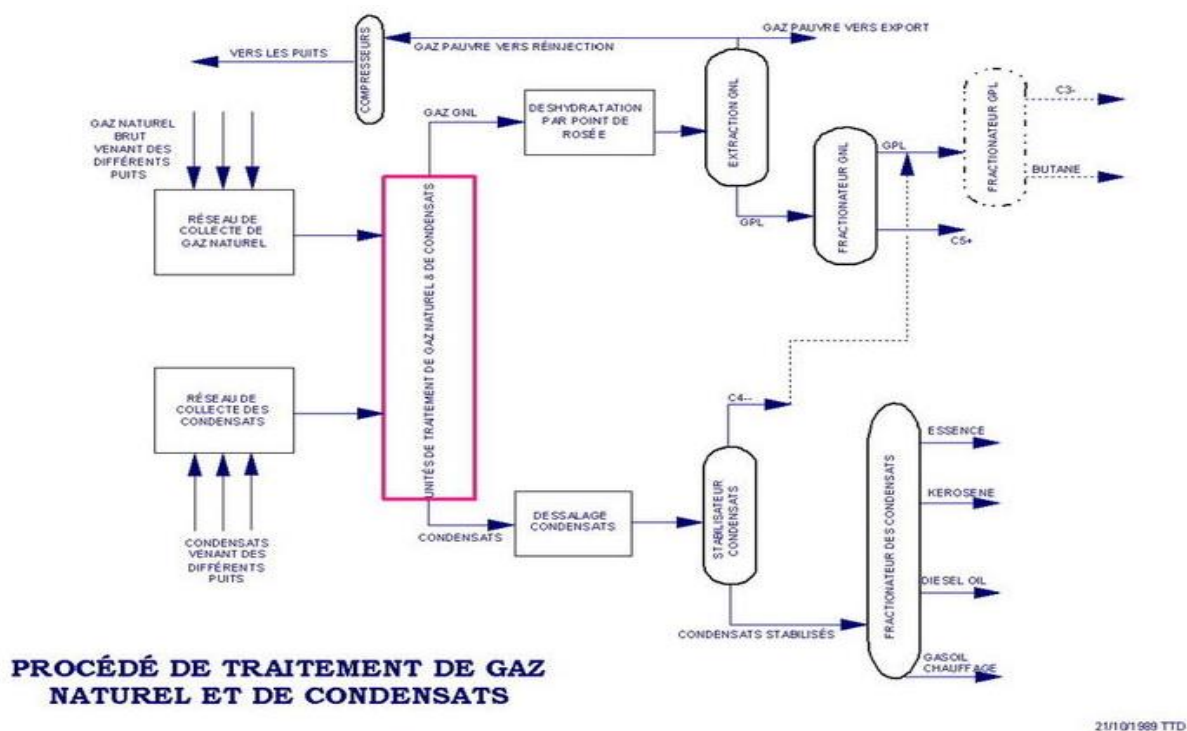


Figure I-6: GAS TREATMENT PROCESS NATURAL AND CONDENSATE[11]

I.5. Transition of natural gas

The goal of the energy transition is to change the way energy is used, reduce the amount of energy consumed and make it more environmentally friendly. In order to achieve the transition, it is necessary to adopt fewer polluting energies, reduce energy consumption and avoid imbalances by using more efficient methods.

I.6. Properties of natural gas

I.6.1. Chemical composition

Natural gas consists mainly of methane (CH_4), the simplest hydrocarbon. In addition to methane, natural gas also contains small amounts of other hydrocarbons, such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}).

Natural gas may also contain non-hydrocarbon impurities, such as carbon dioxide (CO₂), nitrogen (N₂), and hydrogen sulfide (H₂S).

The exact composition of natural gas varies depending on its geographic source. However, the typical composition of natural gas is as follows:[2]

- * Methane (CH₄): 80-95%
- * Ethane (C₂H₆): 2-10%
- * Propane (C₃H₈): 0-5%
- * Butane (C₄H₁₀): 0-2%
- * Carbon dioxide (CO₂): 0-15%
- * Nitrogen (N₂): 0-10%
- * Hydrogen sulfide (H₂S): 0-5%

I.7. Types of natural gas

I.7.1. Types of natural gas according to their composition:

The composition of dry natural gas is mainly methane (CH₄), with residues of ethane and propane.

Wet natural gas: contains larger amounts of liquid hydrocarbons, such as ethane, propane and butane.

Acidic natural gas contains significant quantities of hydrogen sulfide (H₂S), a toxic gas with an unpleasant odor.

Mild Natural Gas: Has little or no amount of hydrogen sulfide gas.[13]

I.7.2. Types of natural gas according to source:

Underground natural gas deposits are rich in conventional natural gas.

Oil shale gas is found in oil shales, which are sedimentary rocks that contain large quantities of organic substances.

Coal gas is obtained by transforming coal into gas.[13]

I.7.2.1. Different types of natural gas depending on their use:

Gas is used as fuel to generate heat and electricity.

Transportation gas is used to power vehicles.

It serves as a raw material in the petrochemical industry as a feed gas.

I.8. Environmental impacts of natural gas

I.8.1. Greenhouse gas emissions

Methane is a powerful greenhouse gas, with a potency of 25 times greater than that of carbon dioxide. From extraction, distribution and use, methane escapes, which leads to greenhouse gas emissions. Research and exploitation of natural gas can generate emissions carbon dioxide and methane.

I.8.2. Air pollution

Emissions of nitrogen oxides, carbon monoxide and particulate matter can be associated with the combustion of natural gas. These emissions have the capacity to promote the creation of smog and cause respiratory problems.

I.8.3. Water pollution

The process of extracting natural gas through hydraulic fracturing can result in contamination of groundwater using chemicals. Natural gas leaks may also contaminate groundwater and surface waters.

I.9. Physical properties of natural gas:

Colorless and odorless: In its natural state, natural gas is colorless and odorless.

Lighter than air: The density of natural gas is lower than that of air, which causes it to rise into the atmosphere[14].

Flammable: Natural gas is a highly flammable fossil fuel.

Non-toxic: Natural gas is non-toxic in its natural concentrations.

Non-polluting: When burned efficiently, natural gas produces small amounts of pollutants compared to other fossil fuels.

Low boiling point: The boiling point of natural gas is very low (-161.5°C), which makes it easy to liquefy.

High flash point: Natural gas has a high flash point (650°C), which makes it less flammable than other fossil fuels.

I.10. The challenges of natural gas

I.10.1. Price volatility:

Many elements influence the price of natural gas, such as demand seasonality, global supply and political variations. Constantly changing prices can cause uncertainty for consumers and businesses.

I.10.2. Dependence on imports:

Several countries rely on natural gas imports to meet their requirements. Imports can pose a risk to energy security and dependence on foreign suppliers.

I.10.3. Limited infrastructure:

The infrastructure required for the transportation and distribution of natural gas includes pipelines and storage terminals. The construction and operation of these infrastructures can represent significant expenses, which can hinder the development of the natural gas industry.

I.10.4. Limited storage:

Unlike oil, natural gas is not easy to store in quantity important. This can cause problems in meeting growing demand or supply shortages.

I.11. The economic importance of natural gas

Natural gas is an important natural resource that has a significant impact on the global economy:

I.11.1. energy source:

The second largest source of global energy after oil is natural gas, which provides approximately 23% of total energy consumption. Natural gas is used to generate electricity and heat homes and industrial infrastructure.

I.11.2. Clean fuel:

Natural gas is an environmentally friendly fuel that burns more efficiently and emits fewer emissions compared to other fossil fuels. This makes it an attractive alternative for reducing greenhouse gas emissions, greenhouse and fight climate change.

I.11.3. Transport fuel:

Commercial vehicles like trucks and buses are increasingly using plus, natural gas as a transportation fuel. Natural gas generates fewer emissions than conventional diesel, making it a more ecological alternative.

I.11.4. economic development:

Natural gas can play a major role in economic growth, particularly in developing countries. Natural gas has the capacity to provide reliable and affordable energy, thus promoting industrial and commercial development.

I.12. Disadvantages of natural gas:**I.12.1.1.a. Environmental negatives**

Greenhouse gas emissions:

- The leaks
- Air pollution

I.12.1.1.b. Economic negative points:

- Price volatility
- Dependence on imports
- Infrastructure costs
- Noise and visual pollution
- Health and safety issues

I.13. Conclusion:

Natural gas is expected to continue to play an essential role in the coming years. However, it is essential to consider environmental concerns and continue to develop technologies for ecological extraction and reduction of climate change. We are also studying the use of natural gas in the energy transition.

CHAPTER II :
PRESENTATION OF THE
HMD AND LIQUEFIED
PETROLEUM GAS
(LPG) PROCESSING

II.1. presentation of the HMD

II.1.1. Geographical location:

The Hassi Messaoud oil field is located 850 km south/southeast of Algiers and 350 km from the Tunisian border, with an area of 2500 km². It is divided geographically into two zones: the north field (HMD/N) and the south field (HMD/S) [15].



Figure II.1: Geographical location[16]

II.1.2. Presentation of the equipment:

A well is produced using a three-phase mixture that includes liquid hydrocarbons and gases, water and impurities.

Before being shipped, this production is processed in the CIS and CINA industrial complexes. The treatment of effluents from producing wells is the task of the four complexes CIS, UTBS, CINA and ZCINA, which consist of a chain of more or less complex processes. The methods used are designed to respond to:

- ✚ Crude oil processing: oil-water-gas separation, desalting and stabilization in order to produce crude oil that meets commercial standards (TVR, Salinity, Density, etc.)
- ✚ The treatment of gases produced during the crude oil treatment process for the production of LPG and condensates.

Part of the crude is refined for the production of fuels, which helps supply the local market. In addition, residual gases are reinjected and water is injected to maintain reservoir pressure[15].

II.1.3. Description of GPL2 item:

In 1997, the southern industrial center of HASSI-MESSAOUD inaugurated the LPG liquefied petroleum gas processing unit, after a partnership agreement between the national company SONATRACH and the Japanese company JGC. JGC was responsible for the technical part of the project, while the construction works were carried out by Algerian construction companies and companies distributed as follows.



Figure II.2:Description of LPG2 item[17]

80% of the work is carried out by the Grand Travaux Patrollers company (GTP), 16% by the Civil Engineering and Concrete company (GCB), 3% by the National Construction and Carpentry company (ENCC), and 1 % by the company Steel Engineering Metallic/Company Boiler making Metallic (SIDEM/ECM).

❖ The total hours of work carried out amounted to 34,560 hours.

Mixed Algerian-Japanese personnel officially started production on January 5, 1997

The objective of the GPL2 unit is to obtain the LPG (liquefied propane/butane mixture) present in the gases which supply the unit.

❖ The LPG product is sent to Arzew through pumping stations (LR1 pipe).

❖ The condensate generated in the unit is transferred to UVC, while the residual gas, mainly composed of methane and ethane, part of which is used for fuel gas needs, is sent to the compression stations for its reinjection in commercial markets, for local needs. NAFTAL sends these two products using the storage of the GPL1 unit[18].

II.1.4. Operating diagram of the LPG2 unit

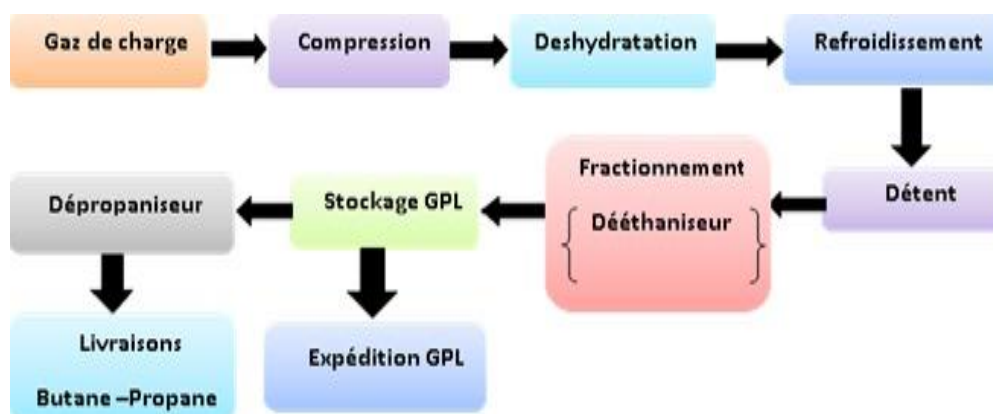


Figure II.3: Operating diagram of the LPG2 unit

II.1.5. Unit capacity:

	Treatment capacity (1000 Nm ³ / day)		
	Design	Current	Lean gas
Feed gas	24 000	25 000	24 000

Table II-1: Unit processing capacity [18]

	Production (tons/day)		
	Design	Current	Lean gas
LPG	4890	3000	2650
Condensate	1050	800	600
Propane	240	240	240
Butane	160	160	160

Table II-2: Production capacity of the unit [18]

II.1.6. Characteristics of the LPG2 unit:

Three identical trains form the GPL-2 unit which includes the following sections 40 MNm³/J distribution system supplies CIS's two LPG distribution systems A Boosting part (section 10) consists of four turbochargers with a unit power of 30,000 HP.

Each train is made up of three identical trains (section 11-12-13):

Three dehydrators (molecular sieve) a turbo-Expander (cooling and expansion). a fractionation composed of dethanizer and debutanizer columns. a hot oil loop (regeneration). exchangers and air coolers. a Depropanizer (section 14) for the production of commercial propane and butane. Four LPG storage stations: (section 15) of 500 m³ each, as well as a shipping “pump house”. Characteristics (section 16):

- a service air and instrument air system;
- a nitrogen unit for the manufacture of nitrogen gas;
- a methanol injection device aims to eliminate the formation of hydrates;
- a water tank for the fire network (security) with a “pump room”
- a unit of gaseous fuel.
- a condensate recovery unit (UVC) [18].

II.2. Liquefied petroleum gas (LPG) processing

II.2.1. Definition of liquefied petroleum gas

Liquefied petroleum gas is a mixture of gases, which includes light fractions of paraffin hydrocarbons, mainly composed of Butane and Propane. At room temperature and atmospheric pressure, it may remain liquid under the following conditions.

The pressure level is measured at room temperature, while atmosphere and low temperatures are considered moderate.

Thanks to this characteristic, it can be kept in a limited volume (250 liters of gaseous LPG equivalent to one liter of liquid LPG), which facilitates its transport compared to non-condensable gases (methane, ethane) which require very high pressures, and it is easy to market, in steel bottles. The gas is added during use.

GPL has a chemical composition that varies depending on standards and uses in various countries.

GPL is also used as an efficient fuel for vehicles, and in various sectors because it offers advantages over diesel by contributing to lower costs.

Nitrogen oxide emissions represent 50%; carbon monoxide emissions represent 60%; hydrocarbons and particles represent 90%.[19]

II.2.2. Types of LPG

The main types of LPG used for treatment are

(Propane (C₃H₈))

Butane (C₄H₁₀)

Butane-propane (a mixture of the two)[19].

II.2.3. The physical nature of LPG

LPG is mainly composed of propane and butane in different proportions depending on their origin (natural gas, associated gas) and the deposit[19].

The components	Molar Mass (kg/kmol)	Liquid Viscosity at 100°F (mm ² /s)	Critical Temperature (°K)	Critical Pressure (bar)
Propane (C ₃ H ₈)	44,094	0,1858	369,85	42,48
I-butane (i – C ₄ H ₁₀)	58,124	0,2586	407,85	36,41
N-butane (n – C ₄ H ₁₀)	58,124	0,2773	425,16	37,97

Table II-3: Physical properties of LPG.

II.2.4. Origin of LPG:

LPGs come from different sources, such as crude oil after refining as a by-product; recovery of gas fields; recovery of associated gases (oil fields); and the production of by-products from natural gas liquefaction (LNG) units[19].

II.2.5. The multiple applications of LPG

The applications of propane and butane are many and varied.

Domestic uses (cooking, heating); Petrochemical uses (olefin production); Uses of LPG in the field of refrigeration and air conditioning; Uses of LPG as a fuel for vehicles Uses of LPG as a heating source in industrial furnaces Power plant uses: fuel for electricity generation[20].

II.2.6. The danger of LPG

The presence of LPG may represent a risk if the following measures have not been taken into account

LPG can cause a fire hazard if there is a leak or the gas escapes into the atmosphere.

It is best to never fill tanks with more than 85% LPG.

Due to their vapor being heavier than air, it accumulates in the lowest points, which requires avoiding cavities, aerating and ventilating contaminated areas It has a low viscosity, which leads to many leaks, so it is important to avoid unwelded assemblies as much as possible.

It is important to clean the liquid pipes after unloading to avoid the risk of tank rupture in the event of overfilling[19].

II.2.7. The importance of liquefied petroleum gas (LPG)

Liquefied petroleum gas (LPG) is an important and versatile energy source that has various applications in the residential, commercial and industrial sectors. Its main importance is:

II.2.7.1. Providing clean energy:

It is a rather ecological fossil fuel compared to coal or oil. Its burning is extremely efficient, resulting in reduced carbon dioxide and carbon monoxide emissions compared to other energy sources.

II.2.7.2. Comfort

It is easily transportable and storable, making it suitable for regions that do not have major gas pipelines. It is suitable for many applications, such as heating, cooking and water heating.

II.2.7.3. Diversity

LPG can be used in different areas such as homes, businesses and industries. It is used in different uses such as cooking, heating, electricity generation and fuel transportation.

II.2.7.4. Applicable option:

LPG constitutes a feasible alternative in regions where natural gas or electricity is absent. It can serve as a substitute for conventional fuels, such as gasoline or diesel, in the field of Transportation.

II.2.7.5. Sustainability:

LPG is a fossil fuel; however, it has a less detrimental impact on the environment than other fossil fuels. This emits less greenhouse gases, which makes it more ecological.

II.2.8. LPG station components

II.2.8.1. Tank and storage components:

II.2.8.1.a. LPG storage tank: usually a cylindrical or spherical tank above or below ground.

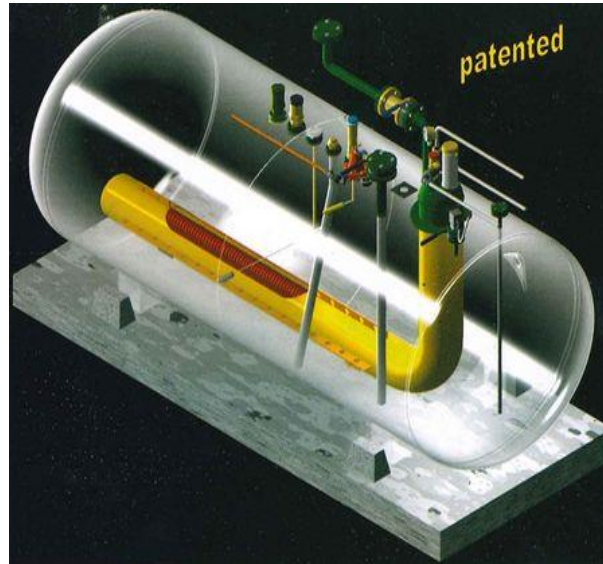


Figure II.4: LPG storage tank[21]

II.2.8.1.b. Pressure relief valve: regulates the gas pressure inside the tank.



Figure II.5: Pressure relief valve[21]

II.2.8.1.c. Liquid Level Gauge: Measures the LPG level in the tank.

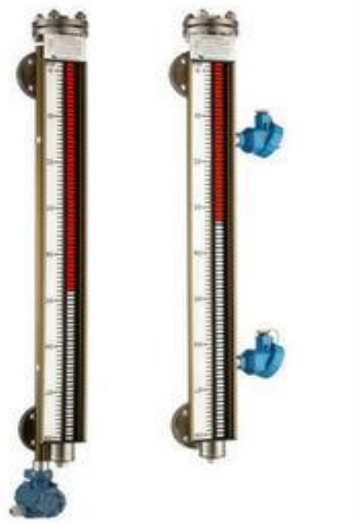


Figure II.6: Liquid Level Gauge[21]

II.2.8.1.d. Main isolation valve: shuts off gas flow to the station.



Figure II.7: Main isolation valve[21]

II.2.8.1.e. Float valve: Prevents overfilling of the tank.



Figure II.8: Float valve[21]

II.2.8.2. Evaporation system components:

Evaporator: converts liquid LPG into gas.

Pressure regulator: regulates the pressure of the LPG leaving the evaporator.

Gas Vapor Line: Carries vaporized LPG to appliances

II.2.8.3. Distribution system components:

II.2.8.3.a. Gas pipelines: transport liquefied petroleum gas to devices.



Figure II.9: Gas pipelines[22]

II.2.8.3.b. Individual pressure regulators: regulate the LPG pressure of each device.



Figure II.10: Individual pressure regulators[23]

II.2.8.3.c. Isolation valves: Allow gas to be shut off to individual appliances for maintenance or repair purposes.



Figure II.11 : Isolation valves[24]

II.2.8.3.d. Leak Detectors: Monitor for gas leaks.



Figure II.12: Leak Detectors[25]

II.2.8.4. Security components:

Fire detection and suppression system: detects fires and extinguishes them in the station.

Ventilation system: eliminates LPG vapors from the storage area.

Security Fence: Prevents unauthorized entry into the station.

Warning labels: warn of the dangers of LPG.

II.2.8.5. Additional components:

Unit of measurement: Measures the quantity of LPG consumed.

Control system: monitors and controls the operation of the plant.

Communication system: allows communication between the terminal, customers and LPG suppliers.

II.2.9. Liquefied petroleum gas (LPG) processing

Liquefied petroleum gas (LPG) is treated to remove impurities and improve its quality before use. The treatment process includes the following steps:[26]

Stripping: Light hydrocarbon gases, such as methane and ethane, are removed from LPG.[26]

Desulfurization: sulfur compounds are removed from LPG to prevent corrosion of equipment and devices[26].

Drying: Water vapor is removed from LPG to prevent the formation of ice in pipes and user equipment[26].

Storage:

Treated LPG is stored in special pressure tanks before being transported to points of use[26].

II.2.10. Sources of LPG

Liquefied petroleum gas (LPG) is mainly produced:

In crude oil refineries, during the distillation of petroleum, or during the thermal cracking or catalytic reforming of products for the production of essences.

In natural gas (NG) treatment and separation units intended to separate and collect condensates (propane, butane, light gasoline, etc.) By direct recovery of gases separated from crude.

CHAPTER III :
PRESENTATION TURBO
EXPANDER

III.1. Introduction

This chapter aims to provide an overall analysis of turbo-expanders and their classifications, focusing on definitions, constituent elements and especially the operating principle. They are employed in various sectors such as power generation, industrial uses, and many more.

In the field of cryogenic natural gas processing, expansion turbines, also called turbo-expanders, have gained popularity as energy recovery turbines. In addition, certain types of installations are now designed because of their high efficiency and operational reliability.

III.2. The concept of détente

In the field of thermodynamics, the expansion or expansion of a gas corresponds to the opposite of compression, that is to say the decrease in temperature and pressure, which allows cold to be generated. in a facility.

Expansion in the GPL2 unit can be done in two different ways:

- By a machine (Turbo-Expander)
- By a valve (also known as Joule-Thomson).

III.3. General about Turbo expander

III.3.1. Definition of turbomachines

Turbomachines are a broad category of devices that transform energy using a fluid. Generally, a turbomachine is a device that provides or removes energy from a fluid through the dynamic action of a rotor. Turbo is the prefix of the Latin word “turbines” which means “which turns” [27].

III.3.2. Classification of turbomachines

Different methods can be used to classify them, the first of which concerns the direction of energy transfer. Turbomachines are then classified into two main categories.

- Turbines are machines that provide energy to the fluid, such as compressors, fans, pumps...
- turbines are machines that extract energy from fluid for use as mechanical work.

Another category of turbomachines is based on the main direction of flow relative to the axis of rotation of the machine. Based on this criterion, we can distinguish:

- The direction of flow of axial turbomachines is parallel to the axis of rotation of the machine.
- In radial or centrifugal turbomachines, a large part of the flow at the inlet or outlet is positioned in the direction normal to the axis of rotation[27].

III.3.3. History

It appears that the first turbo-expanders were developed around 1934 or 1935 by Guido Zerkowitz, an Italian engineer employed by the German company Linde AG. In 1939, the design of centrifugal turbo-expanders was refined by Russian physicist Piotr Kapitsa. The first version of his prototype was made of Monel metal, with an outer diameter of 8 cm, driving 40,000 revolutions per minute and capable of expanding 1,000 cubic meters of air. A water pump was used as a brake and obtained an efficiency of between 79% and 83%. Since then, the majority of these machines for industrial use have been based on Kapitsa's design. Thanks to the LD process, the production of liquid oxygen has seen a revolution in steelmaking.

Piotr Kapitsa was named Nobel Prize winner in physics in 1978 for his overall research in low temperature physics. In 1983, San Diego Gas & Electric was one of the first gas distributors to install an expansion turbine in a natural gas pressure regulating station, which allowed it to recover part of the injected energy to compression[28].

III.3.4. Definition of turbo expander

A turbo-expander is an extremely efficient turbine, offering multiple benefits. This machine is today the most commonly used and the most reliable for low flow rates and very low temperatures (and often for quite high pressures).

An expansion turbine, also called a Turbo-Expander, is a machine that transforms the energy of a gas or water vapor into mechanical work as it expands in the turbine. Due to this rapid expansion, the amount of heat given up or received by the system decreases considerably, which agrees with the first law of thermodynamics.

When the work is done, the internal energy of the gas decreases, which causes a significant reduction in temperature. This therefore allows the turbo-Expander to operate either as a cold generator (in the refrigeration circuit) or as a generator of mechanical work in power circuits. This is why turbo-Expanders are widely used in the field of cryogenics for the production of cold.



Figure III.1: *The Atlas Copco MAFI-TRENCH turbo-expander/compressor assembly[29]*

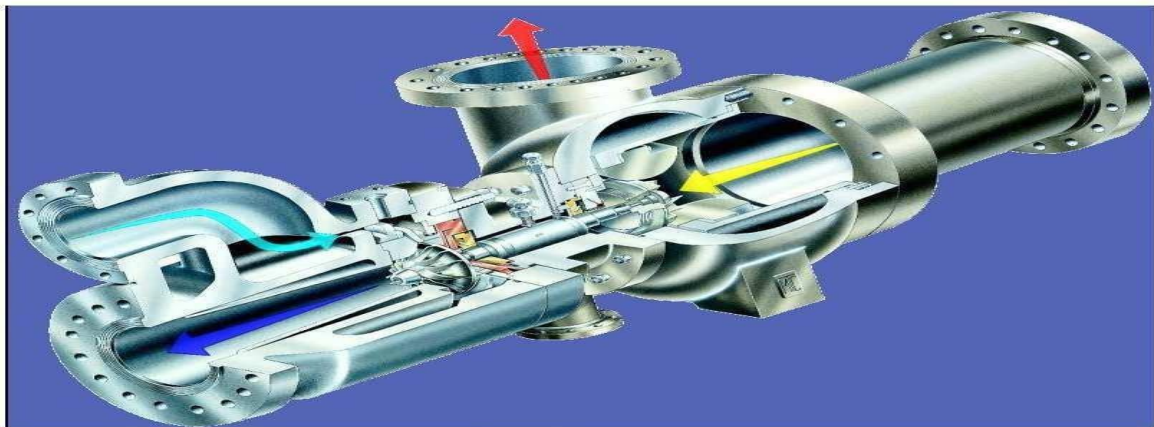


Figure III.2: *View of a turbo-expander[29]*

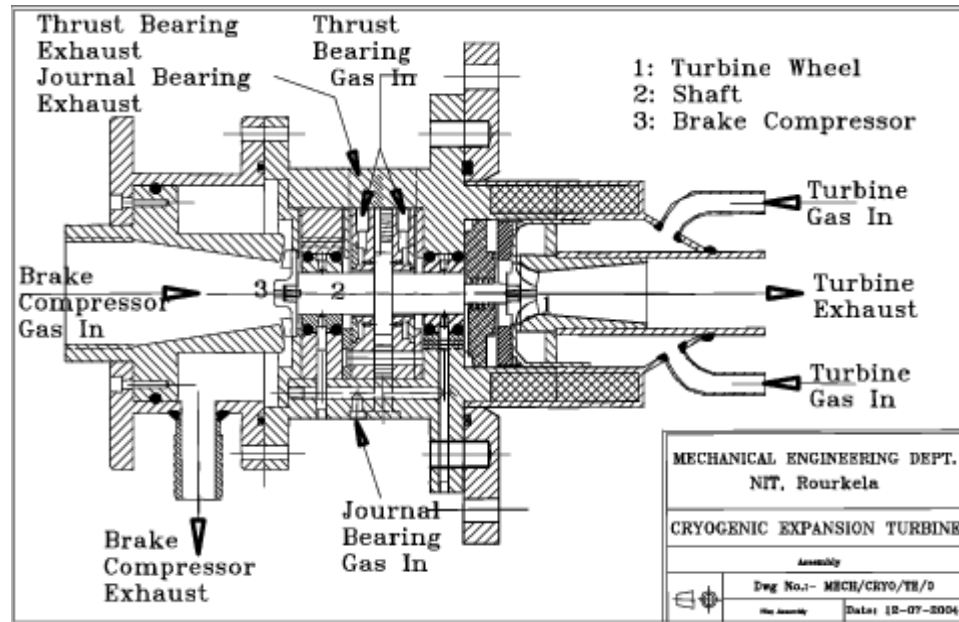


Figure III.3: Descriptive diagram of the turbo-expander components[30]

III.3.4.1. Descriptions of the components and main functions of the machine:

MAFI-TRENCH corporation has developed the turbo-expander, which is mounted on a chassis and equipped with its own lubrication and sealing gas system. It mainly consists of three main parts.

The rotating part of the expander (turbine), the compressor housing. The expander and compressor housings contain the gas to be treated, which is then directed to the expander and compressor wheels respectively thanks to the geometry of the articles.

The rotating part, considered the heart of the machine, is the most delicate part of the expander-compressor assembly, as it includes the two impellers, the two shaft sleeves and the shaft itself.

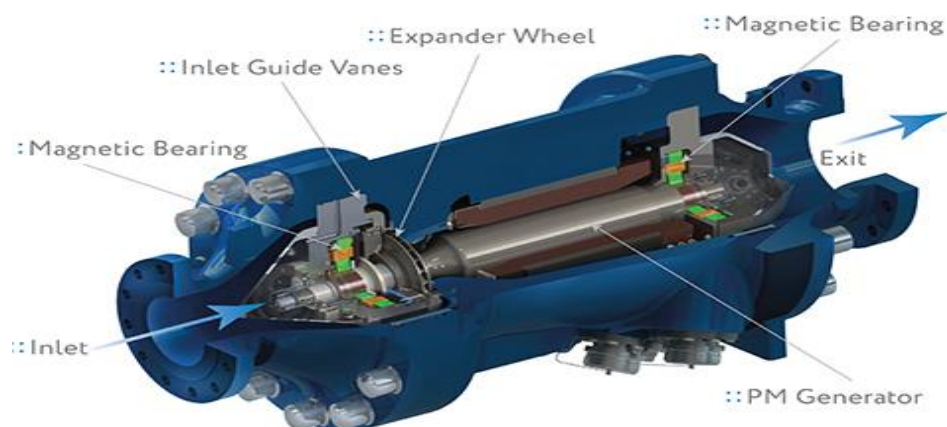


Figure III.4: Constituents of a turbo expander[31]

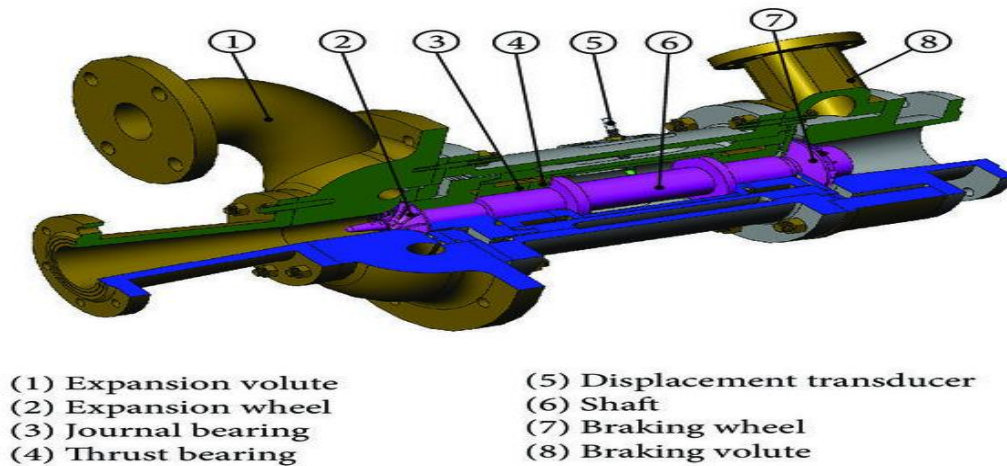


Figure III.5: Descriptive diagram of the turbo expander[32]

III.3.4.1.a. Expansion wheel (Expander)

This is a rapid expansion wheel (operating speed of 10000rpm) which has the function of relaxing the gas pressure energy, resulting in a drop-in supply pressure from 95 to 21 bar, which results in a decrease in temperature from 12 to -47°C [33].

III.3.4.1.b. The compressor wheels

The expansion wheel captures kinetic energy and converts it into mechanical energy in order to compress the light residual gas (C1, C2) from 20 to 31 bars, then transport it to the compression stations to be reinjected into the reservoir.

The turbine and compressor wheels are manufactured using plates, bars and parts made of strong and compact materials.

Tests for resistance to vibration and resonant frequencies of the blade and disc were carried out on each wheel. The turbo-expander can be used from zero to start speed, without having to worry about having harmful resonance on the wheels.

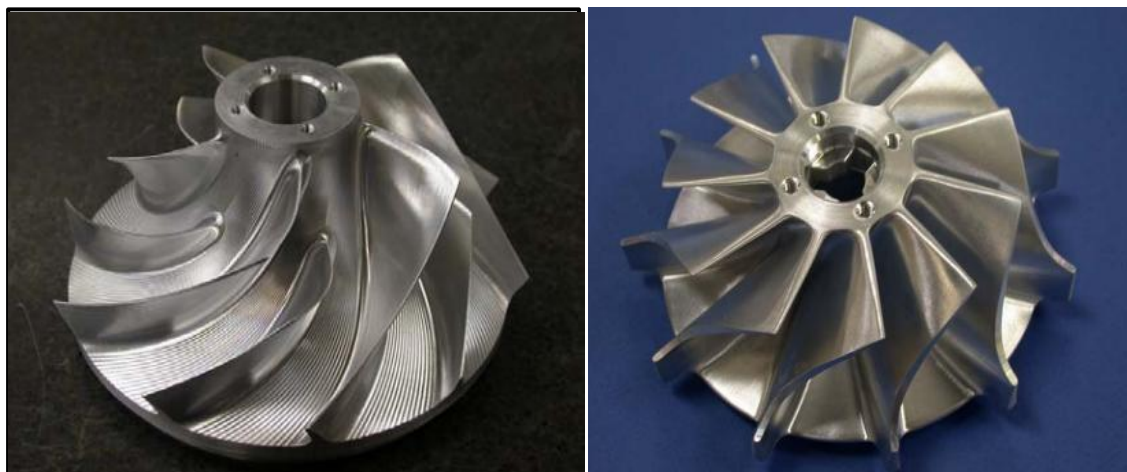


Figure III.6: The compressor wheels And Expansion wheel (Expander)[29]

III.3.4.1.c. The turboexpander shaft

The expander-compressor shaft design aims to operate below the critical bending and torsional resonance speed. The shaft is placed on a hot-plated aluminum strip in the area monitored by the vibration detection probes. This process is extremely strict on certain MAFI-TRENCH turbines.

Raising the wheels on the shaft creates the rotor which must be rotated and axially oriented on a specific tapped profile with cylindrical keys and grooves.

This design avoids stress concentrations associated with tabs and classic keyways. this assembly guarantees stable wheel fixation, even in conditions of speeds and extreme temperatures the adjustable feed rate guide vanes are the only moving parts remaining in the machine.

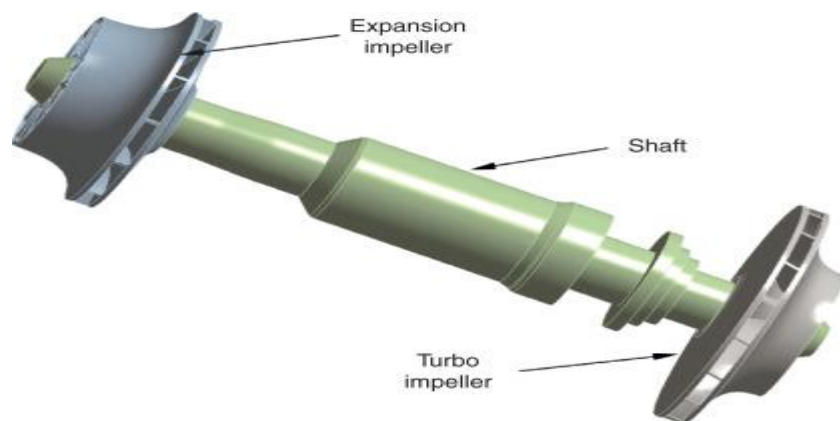


Figure III.7 :the turboexpander shaft[29]

III.3.4.1.d. Lauber directors (Distributor)

This is a valve that varies from vane. The design of this machine aims to adjust the flow rate of the feed gas by directing it towards the expansion wheel. The design of this wheel aims to guarantee positive control and high efficiency over a wide operating range, thanks to the IGV adjustment cylinder.

The device was developed to maintain maximum inlet pressure during expansion and can be adjusted to change the flow in a range from 0% to approximately 125% of the intended mass flow [29].

III.3.4.1.e. The bearings

In this machine, the radial bearings are fixed pad type. The bearings are equipped with a temperature detector which transmits temperature variations and signals dangerous situations.

It is essential to install axial bearings in order to maintain the axial position of the turbine within tolerances. MAFI-TRENCH machines use a profiled axial bearing, with each plain bearing fully machined. The design of these machines aims to support the same force in each axial direction.

A pressure probe port is placed on the front of each bearing to regulate the axial thrust. They are transmitted to the axial force limiter (ATE) which controls the axial thrust pressure signals.



Figure III.8 : *The bearings[29]*

III.3.5. Concept on the Turbo expander:

Turbo-expanders are commonly used in gas separation and liquefaction installations, as well as in natural gas and oil expansion stations. The expansion results from an isentropic transformation which results in work recovery at the level of the rotation shaft. This expansion is used in many industrial processes where a pressurized gas must be reduced to a lower pressure. Turbo expanders or turbo holders are commonly used as a means of refrigeration in industrial installations such as ethane extraction and liquid liquefaction.

Expansion or turbo-expansion turbines have seen an increase in interest as energy recovery turbines in cryogenic processing. Their use is widespread in the field of gas treatment, separation and liquefaction, mainly due to their high efficiency and high operational reliability.



Figure III.9: *The turbo expansion of the LPG2 unit[34].*

III.3.6. Auxiliary systems

III.3.6.1. Sealing gas system

Gas flow to the labyrinth seals inside the turbo-expander is regulated by the seal gas system. During normal operation of the machine, the sealing gas comes from two points in the process: the discharge of the turbochargers and the dehydration system 24. The system also includes a differential pressure regulator, filter and all required measuring tools. The liquid and solid particles entrained by the gas are collected by a separator filter which passes through the gas. If a pressure drop occurs (for example, if the filter becomes blocked), a solenoid valve that regulates the gas pressure opens to meet the required seal gas pressure.

This system fulfills three essential roles[34]:

- ❖ It is essential to ensure that it has adequate sealing gases in order to dissipate the heat generated by the magnetic bearings and rotor turbulence.
- ❖ Prevent cold, dirty process gas from entering the bearings below.
- ❖ It is important to maintain positive pressure in the bearing housing to avoid any air entry.

III.3.6.2. Lubricating System

The turbo-expander is equipped with a lubrication system which provides lubricating oil, cooled, filtered and under pressure to the bearings of its machines. Two screw pumps (one in standby and one in operation) draw in and discharge lubricating oil from an oil reservoir through a three-way valve. Accumulators allow filtered oil to pass through the filters to maintain a flow of oil during a possible lack of electrical power. They also continue the supply of oil to the bearings during a period of downtime due to low oil pressure. Before reaching the machine bearings, the oil passes through the filters a second time. After lubricating the machine components, the quantity of oil is directed directly to the oil tank[34].

III.3.6.3. Thrust equalization system ATE (Automatic Thrust Equalizer)

The patented thrust balancing method of Atlas Copco Mafi-Trench can be summarized as follows:

- The employment of active and automatic thrust balancing techniques to maintain the normal differential loads of the adjacent thrust bearings.
- The thrust bearing will be equipped with all necessary capacity for disturbances and transitions.
- This is done in the following way:
 - The magnetic thrust bearing system receives current signals which are transmitted to the PLC thrust controller.
 - The PLC thrust controller detects the more loaded thrust bearing among the two.
 - The thrust controller uses an output signal to regulate the position of a thrust control valve.
 - The thrust bearing will be equipped with all necessary capacity for disturbances and transitions.

This is done in the following way:

- The magnetic thrust bearing system receives current signals which are transmitted to the PLC thrust controller.
- The PLC thrust controller detects the more loaded thrust bearing among the two.
- The thrust controller uses an output signal to regulate the position of a thrust control valve.
- The thrust control valve regulates the pressure behind the compressor wheel to maintain a balanced axial load[33].

III.3.7. Advantages and disadvantages of the turbo-expander its use is in gas treatment, separation and liquefaction techniques[35].

- It allows the condensable fractions of natural gas to be recovered more efficiently
- It offers high performance compared to other relaxation systems
- It offers significant production capacity (for large installations).

Among its disadvantages: [35]

- It faces the problem of mechanical wear and tear, just like all moving machines.
- Installation costs are extremely high due to the material used and the manufacturing of these items.
- Cooling problem due to extremely low temperature (ranging from -60°C to -107°C).
- Creation of droplets likely to cause damage to the expansion fins.

III.3.8. Causes of stoppage

Sometimes the shutdown is caused by other process machinery, while other times it may be due to a specific cause. The most common cases can be observed:

- The overspeed problem (13500 to 14000 rpm) occurs when the inlet gas is rich in C3 (heavy), which requires an increase in the speed of expansion for the liquefied.
- Due to the associated compressor, since they share the same shaft, stopping the compressor will hinder expansion. Reasons for stopping the compressor include: Pumping vibrations (variable or very low inlet flow), suction overpressure, low pressure.
- Suction tank: very high/low level (98% /1.7%), or high/low pressure (100 barg /0 barg).

III.3.9. The Joule-Thomson valve

The Joule-Thomson valve (abbreviated JT) is used to reduce pressure by significantly increasing the temperature. It is positioned on the turbo-expander by-pass line, which makes it easier to expand the gas while it is out of service or starting up.

Its structure consists of a valve body where the fluid circulates, a control device, a servomotor that regulates the flow and other accessories adapted to each specific application. The seat, gaskets and gaskets guarantee water tightness. The liquid passes from the outside to the inside of the stack and flows towards the outlet port.



Figure III.10: Joule Thomson valve used in SH-FCP[36]

III.3.9.1. Principle of operation

Stacking provides the ability to fluctuate the flow rate while restricting the speed of flow through the object. The stack consists of several disks where the labyrinths have been dug in order to achieve a specific flow rate. A series of right-angle bends develop passage independence, with each passage having a specific number of elbows to restrict speed to the intended value. As each disk has a specific capacity, it is easy to precisely manage and control the total flow through the element. The flow rate is determined by the position of the piston in the stack, which reveals more or fewer passages in the discs. Since each disk has a maximum flow speed, the control element can operate at a fixed, set speed, primarily within the range of rated capacity, to minimize speed variations that usually cause noise, vaporization, cavitation, vibration and erosion[36].

III.3.9.2. The advantages and disadvantages of the JT valve

Profits:

- Light method.
- Indifferent to variations in the flow of treated gas.
- Gas pressure decreases significantly.

At the same time dehydrates the gas.

The disadvantages:

- Reduction in the quantity of liquid recovered (small production capacity)
- Responsive to pressure fluctuations of the gas in question.
- High upstream pressure is required.
- It is necessary to administer an inhibitor to prevent the formation of hydrates.

III.3.9.3. Comparison between JT valve and turbo-expander

Two methods can be used to reduce the gas temperature (and pressure): the JT valve or turbo-expansion.

The JT valve generates isenthalpic expansion, which keeps the enthalpy (H) constant and does not allow any work. $W = 0$, therefore $\Delta H = 0$. On the contrary, the energy of the gas flow is transformed into refrigeration thanks to isentropic expansion, then into mechanical work transmitted by a common shaft to the centrifugal compressor. For an optimal system, it is possible to recover approximately 86% of the energy present in the flow, which implies the recovery of thousands of horsepower of power.

Furthermore, according to the figure below, we can draw the conclusion that for the same inlet pressure and temperature ratio (Delivery envelope in blue), the outlet temperature of the turboexpander (in yellow) is lower than that of the JT valve (in purple), which leads to a decrease in dewpoint³. The turbo-expander has all of these advantages over the JT valve, making it more expensive and more effective in recovering heavy hydrocarbons (C3 and above).

III.3.10. Conclusion

We conclude in this chapter that the study of any industrial machine requires perfect mastery of the way in which it first takes into account all the constraints linked to the operation and the role of this machine in the process.

The volume of LPG generated by the expander is more than twice that generated by the valve (JT). It is essential to maintain the expansion while respecting the maintenance rules in order to avoid a decrease in its efficiency and, consequently, in the production of LPG.

CHAPTER IV : CALCULATION AND APPLICATION PART

IV.1. Introduction and Issues:

The southern CIS/HMD industrial complex has developed an LPG2 unit which aims to exploit 90% of the LPG potential present in the feedstock. Right now, the recovery rate is around 71%. Since LPG losses are in production train expansions. Effectively, as the outlet pressure of the K201 expander increases (expansion pressure), the temperature after expansion increases, resulting in a decrease in the expander efficiency (liquefaction rate), as well as the recovery rate. LPG.

Since the first years of its commissioning, the expansion pressure of the unit has increased, mainly due to the K201 expanders, which has resulted in a decrease in the LPG recovery rate. The practical internship in the “GPL2/CIS/HMD” unit. We were able to assess the reasons which disrupt the proper functioning of the expansion of train 1 and which lead to a drop in its efficiency, which leads to a reduction in the quantity of LPG produced there.

Among these reasons are:

The presence of strong vibrations at the expander or compressor bearings can cause a significant difference in equilibrium pressure (axial thrust) between the two compartments, which can lead to hole clogging caused by the formation of 'hydrates.

In addition, it is possible that the automatic balancing valve between the expander and the compressor (ATE) is broken or defective.

➤ We observe the presence of small cracks at the level of the bearings (expander or compressor);

The formation of hydrates results in significant blockage of the expander, resulting in an end of the molecular sieve cycle at the dehydrator.

Additionally, there is also a lack of spare parts and a drop-in pressure at the expander inlet.

With this in mind, the objective of this study is to evaluate the impact of the turbo-expansion efficiency on the LPG recovery rate during the cold section.

In this chapter, we suggest measuring the growth efficiency of a production train under unfavorable conditions (train 1), as well as studying its impact on LPG production.

This analysis is carried out using thermodynamic analysis. First, we will calculate the efficiency in the design case, then in the real case. Once we have performed our calculations manually for the two cases mentioned, we will carry out a simulation using the HYSYS software to validate and confirm our results.

Then, we modify the thermodynamic parameters (T, P, Qm) in order to analyze their impact on the yield and the recovery rate of the LPG in order to bring it as close as possible to the scenario. The gas used is enriched gas. The P-H pressure-enthalpy charts were used to calculate the enthalpies and entropies, as indicated in the Appendix.

IV.2. Simulation process:

Simulation is an instrument used in various sectors of engineering and research in general, which makes it possible to study the functioning of a system before implementing it and to improve its efficiency by testing various solutions and operating conditions. . The simulation is based on the creation of a model of the system, that is to say it makes it possible to represent the various phenomena:

Thermodynamic models allow the transfer of matter and heat during the various unit operations. These models consist of a series of equations developed with the aim of describing the behavior of an evolving system, such as phase separation, component splitting,

compression, expansion, heat exchange, etc. These equations are conservation equations of mass, energy and momentum, and can be algebraic or differential [20].

Several simulators can be used to simulate industrial processes (especially those in oil and gas): Aspen Plus, Chem CAD, HYSIM, HYSYS, Pro-II. The various functions that a process simulator should perform are as follows [33].

- Analysis of material and energy data
- Process improvement
- Equipment design
- Economic analysis of the process
- The selection of the thermodynamic model.

Several thermodynamic models are available in simulation software to predict liquid-vapor equilibrium, enthalpy and entropy, and transport properties.

These models use a variety of tools such as [33].

- The equations of state of Peng-Robinson (PR), Chao-Seader (CS), Soave-Redlick-Kwong (SRK)
- The empirical and semi-empirical correlations of Chao-Seader (CS) and Braun-Grayon (BG)
- The laws of the corresponding states.

Among this software we find HYSYS, what is HYSYS?

IV.3. Description of the HYSYS software:

The company Hygrotech (Canada) has developed HYSYS, process simulation software for process engineering, chemical engineering and energy. It is considered one of the most powerful simulation software. When designing an industrial process, the HYSYS simulator can be used to establish material and energy balances, as well as to size the equipment for this process. It can also be used to monitor already installed processes and readjust operating parameters in the event of a change in power composition or operating conditions of certain equipment, in order to determine equipment performance [33].

Leading oil and gas producers, refineries and engineering use Aspen HYSYS as their process simulation software in the energy industry.

HYSYS simulators are used in the following way:

The user must provide information on the components of the gas, liquid or mixture, select a thermodynamic model, establish the process flow diagram (PFD), as well as the parameters required for the calculation of each operation. Then, the simulator solves the process diagram and can also size certain equipment.

The simulator has the capacity to carry out technical-economic analyzes of the methods.

Through the use of HYSYS, we were able to simulate the relaxation part of the expansion in this study.

IV.4. Method for calculating the isentropic efficiency of a turbine:

Calculating the efficiency of a turbine is very interesting for comparing the real development of a gas.

Ultimately, the performance of an adiabatic machine is the ratio of actual work to isentropic work.

$$\eta_{is} = Wa/Wis.100 = \Delta Ha/\Delta His \dots\dots\dots (IV. 1)$$

The total enthalpy is calculated by:

$$Hx = \sum n Yi * Hi \dots\dots\dots (IV.2)$$

$$i = 1, 2, 3 \dots\dots n$$

IV.4.1. Calculation of the efficiency of the turbo-expander in the design case:

The operational design parameters of the turbo-expander were collected from the PFD of the LPG2 unit. The table below groups these parameters.

Table IV-1 :Turbo-expander operating parameters in the Design case[18]

Component	Installation points					
	18	19	36	38	21	32
H ₂ O	0,00	0,00	0,00	0,00	0,00	0,00
N ₂	3	3	3,05	3.05	0,19	3.65
CO ₂	1.56	1.56	1,75	1,75	1,33	1.61
C ₁	67.22	67.22	71.74	71.74	18.98	78.30
C ₂	17.30	17.30	20.43	20.43	32.68	13.77
C ₃	7.76	7.76	2.87	2.87	30.91	2.44
i-C ₄	0.64	0.64	0.06	0.06	3.08	0.08
n-C ₄	1.75	1.75	0.10	0.00	8.81	0.13
I-C ₅	0.25	0.25	0.00	0.00	1.29	0.01
n-C ₅	0.33	0.33	0.00	0.00	1.73	0.01
C ₆	0.15	0.15	0.00	0.00	0.78	0.00
C ₇	0.04	0.04	0.00	0.00	0.22	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00
PM (kg/kmole)	22.91	22,91	20.64	20.64		19.64
Flow rate (kg/h)	258779	258779	254549	254549	78340	180439
Pressure (bar)	95	21.3	19.7	30.6	21,3	21.3
Temperature (°C)	12	-43.2	42.3	81.4	-42.1	-42.1

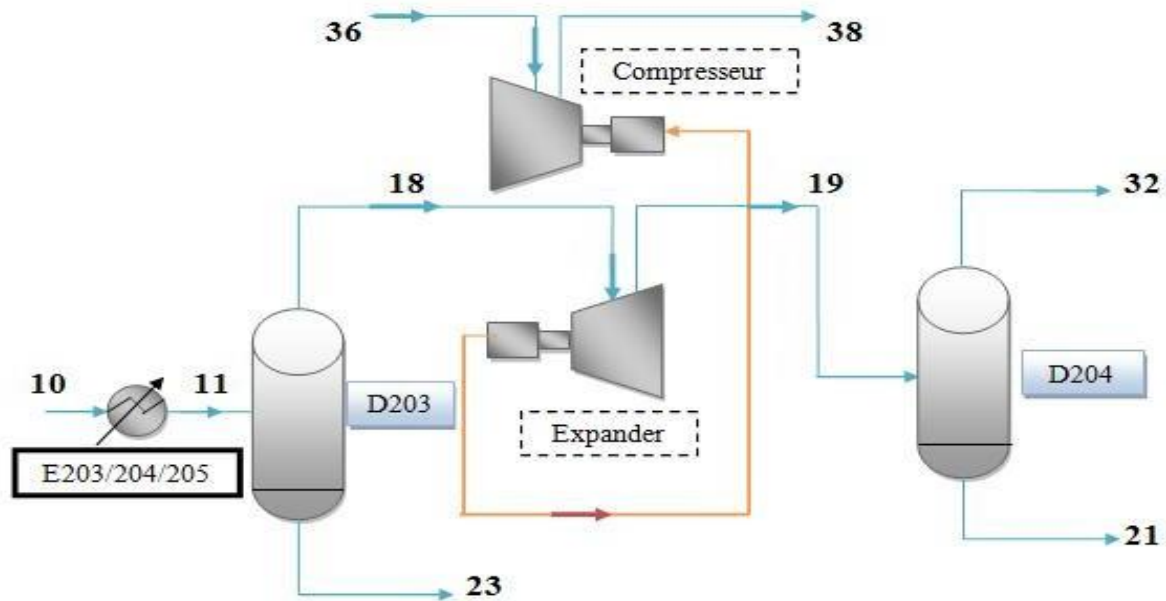


Figure IV.1: Design diagram of the cryogenic battery

IV.4.1.1. Design simulation using HYSYS software:

Table IV-2: Turbo-expander operating design parameters obtained by HYSYS.

Component	Installation points					
	18	19	36	38	21	32
H ₂ O	0	0	0	0	0	0
N ₂	2,93	02,93	3,05	3,05	0,20	3,57
CO ₂	1,56	01,56	1,75	1,75	1,29	1,63
C ₁	66,52	66,52	71,74	71,74	18,62	77,78
C ₂	17,53	17,53	20,43	20,43	32,08	14,11
C ₃	8,05	8,05	2,87	2,87	31,02	2,65
i-C ₄	0,67	0,67	0,06	0,06	3,17	0,09
n-C ₄	1,88	1,88	0,10	0,10	9,18	0,16
I-C ₅	0,28	0,28	0	0	1,41	0,008
n-C ₅	0,36	0,36	0	0	1,87	0,007
C ₆	0,17	0,17	0	0	0,89	0
C ₇	0,05	0,05	0	0	0,26	0
Total	100	100	100	100	100	100
PM (kg/kmole)	23.13	23.13	20.63	20,63	37,51	19,75
Flow rate (kg/h)	258760	258760	254550	254550	80017	178740
Pressure (bar)	95	21.3	19.71	30.61	21.3	21.3
Temperature (°C)	12	-42,1	42,3	79.79	-42,1	-42,1

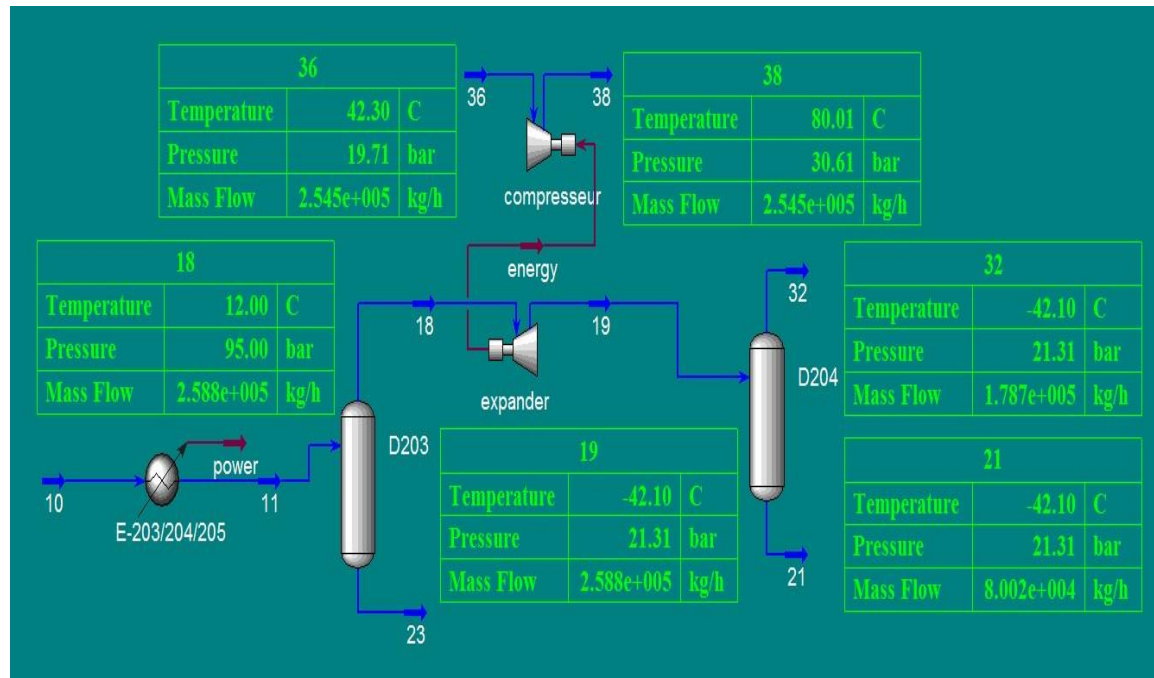
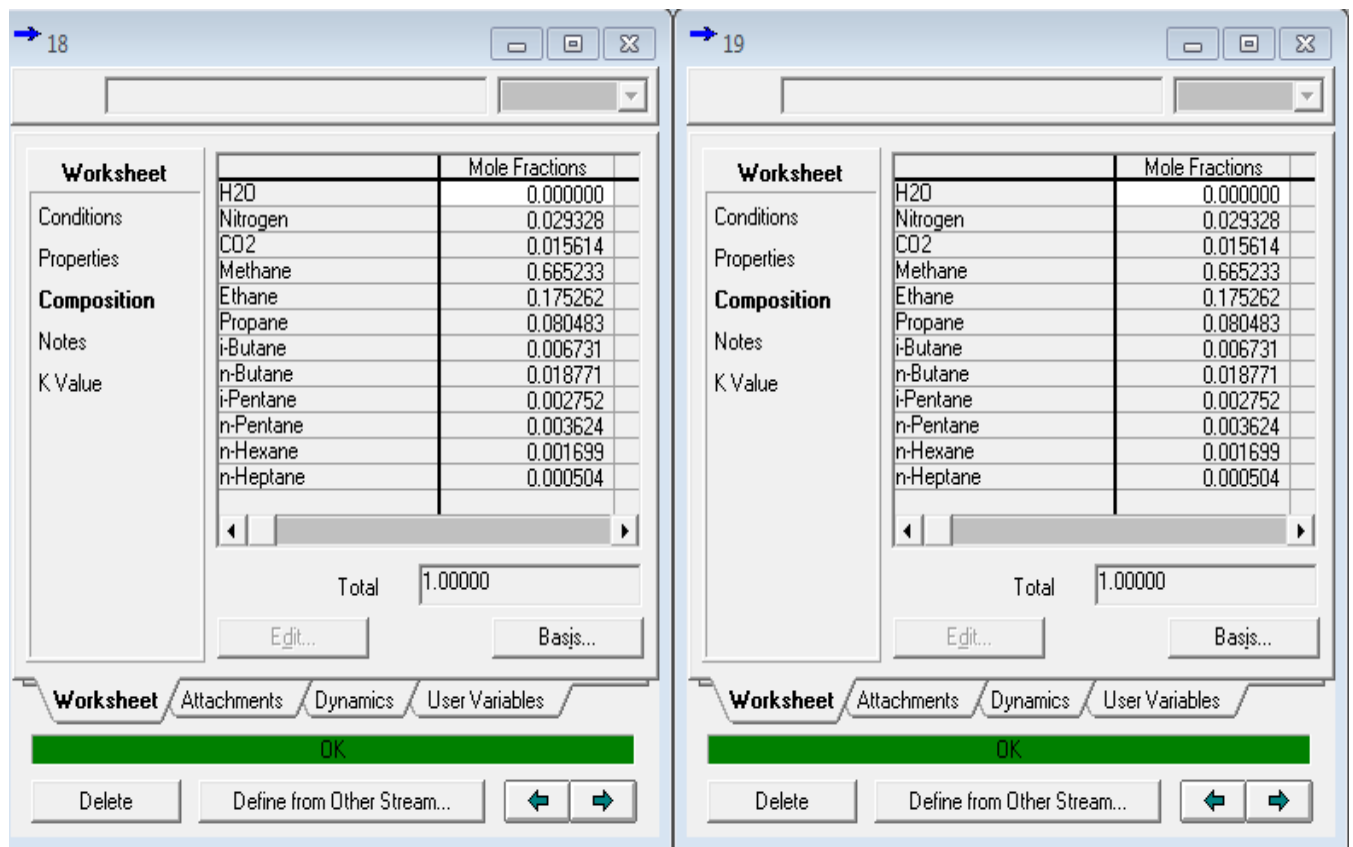


Figure IV.2 :Simulation results in the Design case.

❖ Verification of the composition of the points obtained by the HYSYS simulator:



36

Worksheet	Mole Fractions	
Conditions	H2O	0.000000
Properties	Nitrogen	0.030499
Composition	CO2	0.017499
	Methane	0.717377
	Ethane	0.204294
	Propane	0.028699
	i-Butane	0.000600
	n-Butane	0.001031
	i-Pentane	0.000000
	n-Pentane	0.000000
	n-Hexane	0.000000
	n-Heptane	0.000000
Notes		
K Value		
Total		1.00000

Edit... Basis...

Worksheet Attachments Dynamics User Variables

OK

Delete Define from Other Stream... ← →

38

Worksheet	Mole Fractions	
Conditions	H2O	0.000000
Properties	Nitrogen	0.030499
Composition	CO2	0.017499
	Methane	0.717377
	Ethane	0.204294
	Propane	0.028699
	i-Butane	0.000600
	n-Butane	0.001031
	i-Pentane	0.000000
	n-Pentane	0.000000
	n-Hexane	0.000000
	n-Heptane	0.000000
Notes		
K Value		
Total		1.00000

Edit... Basis...

Worksheet Attachments Dynamics User Variables

OK

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32

Worksheet	Mole Fractions	
Conditions	H2O	0.000000
Properties	Nitrogen	0.035764
Composition	CO2	0.016257
	Methane	0.778131
	Ethane	0.140930
	Propane	0.026350
	i-Butane	0.000857
	n-Butane	0.001557
	i-Pentane	0.000078
	n-Pentane	0.000068
	n-Hexane	0.000007
	n-Heptane	0.000001
Notes		
K Value		
Total		1.00000

Edit... Basis...

Worksheet Attachments Dynamics User Variables

OK

Delete Define from Other Stream... ← →

21

Worksheet	Mole Fractions	Vap
Conditions	H2O	0.000000
Properties	Nitrogen	0.002027
Composition	CO2	0.012889
	Methane	0.186345
	Ethane	0.320890
	Propane	0.310102
	i-Butane	0.031643
	n-Butane	0.091790
	i-Pentane	0.014095
	n-Pentane	0.018704
	n-Hexane	0.008876
	n-Heptane	0.002637
Notes		
K Value		
Total		1.00000

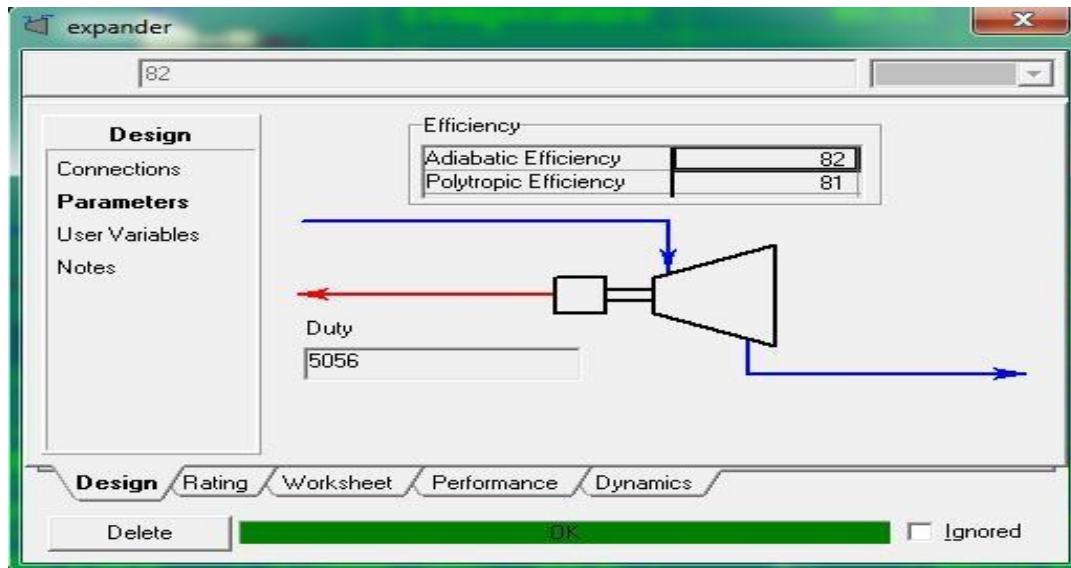
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Worksheet Attachments Dynamics User Variables

OK

Delete Define from Other Stream... ← →

The efficiency in the design case obtained by the HYSYS simulator is: 82%.



IV.4.1.2. Calculation of yield manually from enthalpy charts (Annex):

❖ Calculation of the compressor inlet and outlet enthalpies (36) and (38):

Table IV-3: Enthalpy calculation results (Design) points (36) and (38)

Component	Y_i	h_{i36}	$h_{i36} * Y_i$	h_{i38}	$h_{i38} * Y_i$
N ₂	0,0305	323,68	9,87224	363,82	11,09651
CO ₂	0,0175	504,24	8,8242	535,08	9,3639
C ₁	0,7173	932,29	668,7316	1018,9	730,95886
C ₂	0,2043	662,7	135,3896	727,77	148,68341
C ₃	0,0287	313,50	8,9971	640,21	18,374027
i-C ₄	0,0006	302,63	0,1815	407,12	0,244272
n-C ₄	0,001	303,49	0,3034	407,64	0,40764
I-C ₅	0	35,07	0	132,06	0
n-C ₅	0	16,30	0	114,25	0
C ₆	0	-59,44	0	33,513	0
C ₇	0	-134,59	0	-40,44	0

$$H_{36} = \sum h_{i36} * Y_i$$



$$H_{36} = 832,29 \text{ kJ/kg}$$

$$H_{38} = \sum h_{i38} * Y_i$$



$$H_{38} = 919,128 \text{ kJ/kg}$$

❖ Calculation of the input and output enthalpies of the expander (18) and (19):

Table IV-4: Enthalpy calculation results (Design) /points (18) and (19is).

Component	Y_i	h_{i18}	$h_{i18} * Y_i$	S_{i18}	h_{19is}	$h_{19is} * Y_i$
N ₂	0,0293	274,96	8,0563	5,37	177,04	5,1873
CO ₂	0,0156	223,28	3,4832	1,05	212,64	3,3171
C ₁	0,6652	775,08	515,5832	3,95	626,97	417,0604
C ₂	0,1752	278,37	48,7704	1,11	259,6	45,4819
C ₃	0,0804	235,15	18,9061	1,06	221,12	17,7780
i-C ₄	0,0067	235,03	1,5747	1,07	222,27	1,4892
n-C ₄	0,0187	235,91	4,4115	1,07	223,57	4,1808
I-C ₅	0,0027	- 27,026	- 0,0730	- 0,14	-38,61	-0,10426
n-C ₅	0,0036	- 46,95	- 0,1690	- 0,20	-58,46	-0,2104
C ₆	0,0017	-122,81	- 0,2088	- 0,44	-133,76	-0,2274
C ₇	0,0005	-316,27	- 0,0977	- 0,64	-205,97	-0,1030

$$H_{19is} = \sum h_{i19is} * Y_i$$

$$H_{18} = \sum h_{i18} * Y_i$$



$$H_{18} = 600,236 \text{ kJ/kg}$$



$$H_{19is} = 493,849 \text{ kJ/kg}$$

❖ The calculation of H_{19} :

The charts do not allow us to read the value of the enthalpy H_{19} , unlike the previous enthalpies, because at the outlet of the expander, we obtain a mixture (liquid + vapor). In this situation, the principle of energy conservation is used between the compressor and the expander.

$$W_{comp} = Q_{m(comp)} (H_{38} - H_{36}) \dots\dots\dots (IV.3)$$

$$W_{comp} = 22104612,9 \text{ kJ/h}$$

The expansion compressor is a turbine engine which converts the energy available in the active fluid into mechanical energy. This energy is collected at the end of the shaft to drive the compressor. This means that pressure losses are reduced, which means that the work of the expansion is practically equivalent to the work of the compressor.

$$W_{comp} = W_e \dots\dots\dots (IV.4)$$

$$Q_{m(comp)} (H_{38} - H_{36}) \dots\dots\dots (IV.5)$$

$$Q_{m(exp)} (H_{18} - H_{19}) \dots\dots\dots (IV.6)$$

We know that:

$$Qm(exp) = Qm(18) = 258760 \text{ kg/h} \dots\dots\dots (IV.7)$$

$$Qm(comp) = Qm(36) = 254550 \text{ kg/h} \dots\dots\dots (IV.18)$$

$$h_{19} = h_{18} - \frac{Qm(36)(h_{38} - h_{36})}{Qm(18)} \dots\dots\dots IV.19)$$

$$\text{Yield} = \frac{h_{18} - h_{18}}{h_{18} - h_{18is}} \text{ IV. 20)}$$

from where:

By comparing the results (compositions, conditions and performances) obtained thanks to the simulation of the design case with HYSYS to those provided by the manufacturer (rich design), it is obvious that the difference does not exceed 2%. Thus, HYSYS allows to simulate the real case.

IV.4.2. Calculation of the turbo expander efficiency in the real case:

In the control room (DCS) of the LPG2 unit, we collected the actual operating parameters of the turbo-expander. The expander power components were obtained using the HYSYS simulator.

❖ Actual parameters:

Expander	Compressor:
T18 = 8,7 °C P18 = 94,1 bar	T36 = 42,3 °C P36 = 19,41 bar
T19 = -46,5 °C P19 = 19,97 bar	T38 = 74,6 °C P38 = 29,36
Qv 18 = 254,6 knm ³ /h = 254600 nm ³ /h	Qv 36 = 288,6 knm ³ /h = 288600 nm ³ /h

$$Qm \text{ (Kg/h)} = (1/22,4) * M * Qv \text{ (Nm}^3\text{/h)} \dots\dots\dots (IV.21)$$

The results of the chromatographic analyzes (carried out in the GPL unit 2 laboratory) of the LPG samples.

Table IV-5 :Actual compositions of points 18 and 36

Component	18	36
N ₂	2,51	2,64
CO ₂	2,10	2,29
C ₁	67,61	72,32
C ₂	19,13	20,71
C ₃	6,13	1,73
i-C ₄	0,48	0,06
n-C ₄	1,38	0,17
I-C ₅	0,12	0,08
n-C ₅	0,54	0
C ₆	0	0
C ₇	0	0
PM (kg/kmole)	22,287	20,531

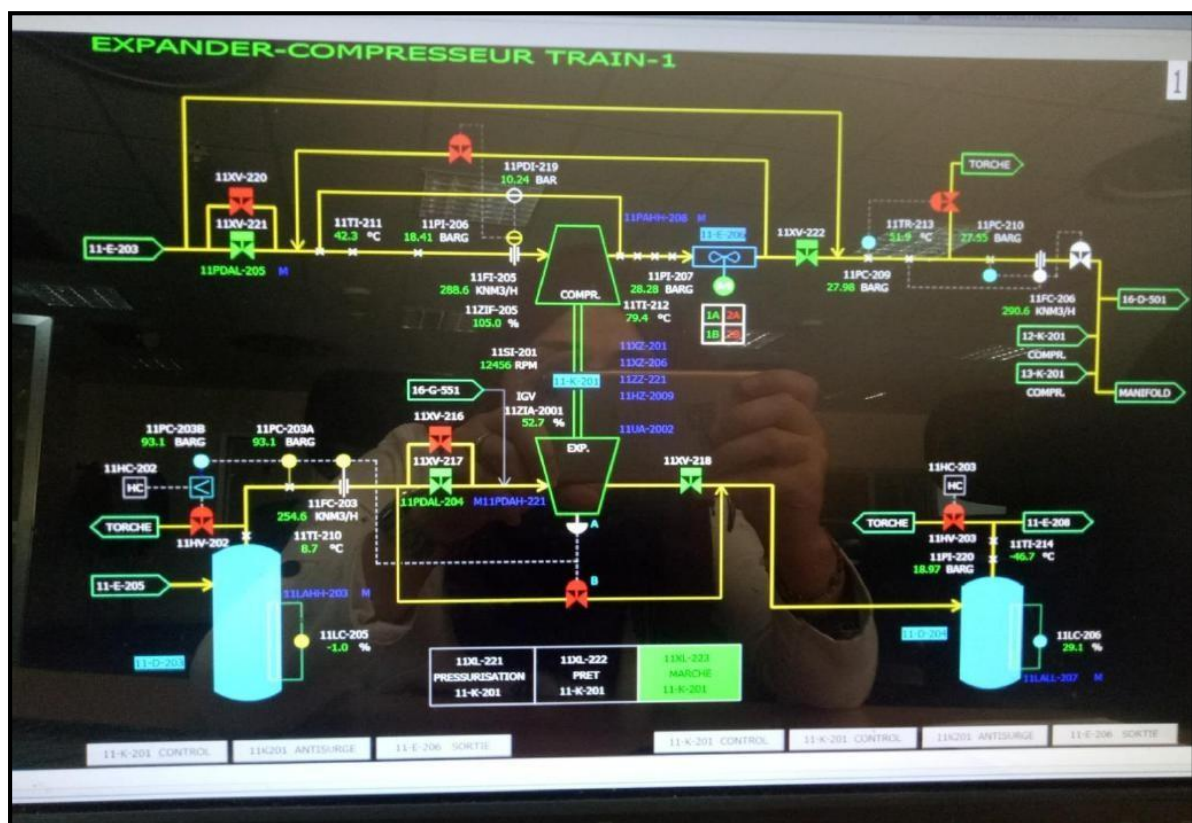


Figure IV.3 :Actual operating parameters of the expander and compressor recorded

Table IV-6 :Actual operating parameters of the turbo-expander obtained by HYSYS.

Component	Installation points					
	18	19	36	38	21	32
N ₂	2,51	2,51	2,64	2,64	0,16	2,97
CO ₂	2,10	2,10	2,29	2,29	1,81	2,15
C ₁	67,61	67,61	72,32	72,32	18,67	77,26
C ₂	19,13	19,13	20,71	20,71	37,99	15,41
C ₃	6,13	6,13	1,73	1,73	26,99	2,01
i-C ₄	0,48	0,48	0,06	0,06	2,60	0,059
n-C ₄	1,38	1,38	0,17	0,17	7,80	0,11
I-C ₅	0,12	0,12	0,08	0,08	0,71	0,003
n-C ₅	0,54	0,54	0	0	3,22	0,009
C ₆	0	0	0	0	0	0
C ₇	0	0	0	0	0	0
Total	100.00	100.00	100.00	100.00	100.00	100.00
Pressure (bar)	94,1	19,97	19,41	29,36	19,97	19,97
Temperature (°C)	8,7	-46,5	42,3	73,61	-46,5	-46,5
Flow rate (kg/h)	253236,07	253236,07	264520	264520	66896	186340

❖ Calculation of the compressor inlet and outlet enthalpies (36) and (38):

Table IV-7: Results of calculation of the enthalpies of points 36 and 38 (Real).

Component	Y _i	h _{i36}	h _{i36} *Y _i	h _{i38}	h _{i38} *Y _i
N ₂	0,0264	321,17	8,4788	356,09	9,4007
CO ₂	0,0229	502,14	11,4990	528,37	12,0996
C ₁	0,7232	926,88	670,3197	1001,5	724,28
C ₂	0,2071	658,33	136,340	713,13	147,6892
C ₃	0,0173	306,55	5,3033	415,47	7,1876
i-C ₄	0,0006	296,57	0,1779	390,66	0,2343
n-C ₄	0,0017	297,43	0,5056	387,3	0,6584
I-C ₅	0,0008	29,407	0,0235	113,23	0,09058
n-C ₅	0	10,559	0	95,297	0
C ₆	0	-67,112	0	15,182	0
C ₇	0	-55,016	0	-58,556	0

$$H_{36} = \sum h_{i36} * Y_i$$

$$H_{38} = \sum h_{i38} * Y_i$$



$$H_{36}=832,65 \text{ kJ/kg}$$



$$H_{38}=901,645 \text{ kJ/kg}$$

❖ Calculation of the entry (18) and exit (19) points of the expander:

Table IV-8: Enthalpy calculation results (18 and 19 is, Real case).

Component	Y_i	h_{i18}	$h_{i18} * Y_i$	S_{i18}	h_{19is}	$h_{19is} * Y_i$
N ₂	0,0251	270,53	6,7633	5,36	171,51	4,2877
CO ₂	0,021	214,34	4,4797	1,03	204,15	4,26673
C ₁	0,6761	764,25	515,7923	3,91	615,43	415,3537
C ₂	0,1913	266,56	51,3661	1,07	248,08	47,8050
C ₃	0,0613	225,77	13,8171	1,03	211,78	12,9821
i-C ₄	0,0048	226,29	1,0862	1,04	213,55	1,02290
n-C ₄	0,0138	227,04	3,1559	1,04	214,7	2,9843
I-C ₅	0,0012	- 35,36	- 0,0424	- 0,17	-46,95	-0,0563
n-C ₅	0,0054	- 55,49	- 0,2997	- 0,24	-67,00	-0,3618
C ₆	0	-131,16	0	- 0,47	-142,12	0
C ₇	0	-203,73	0	- 0,67	-214,34	0

from equations (9) and (10) we find:

$$H_{19}=524.29 \text{ kJ/kg}$$

$$\eta = 66, 66 \%$$

❖ Verification using simulation by HYSYS software:

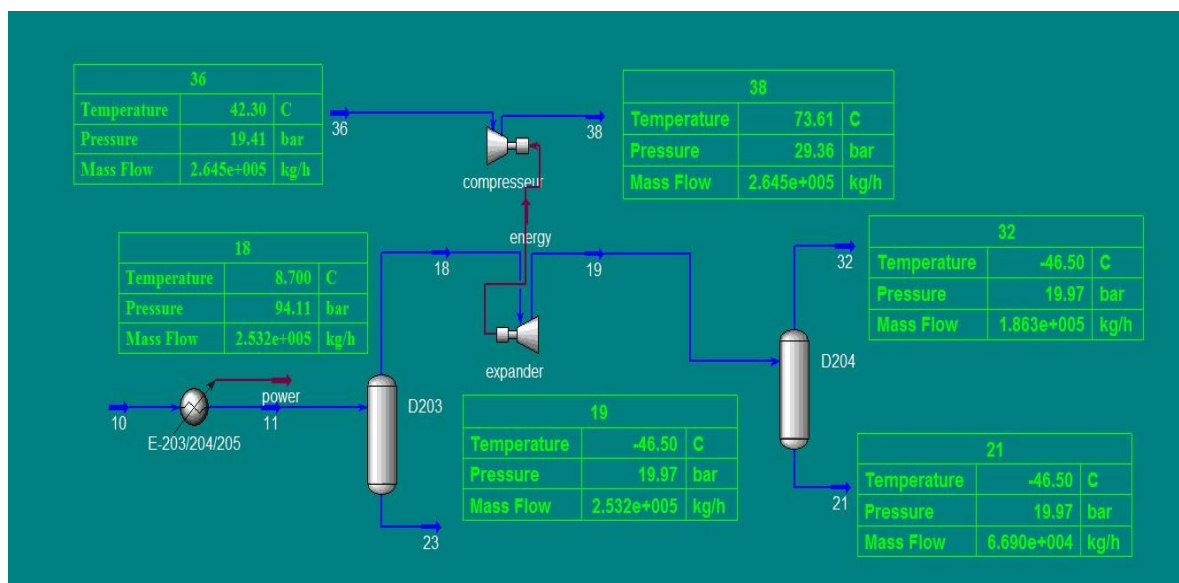
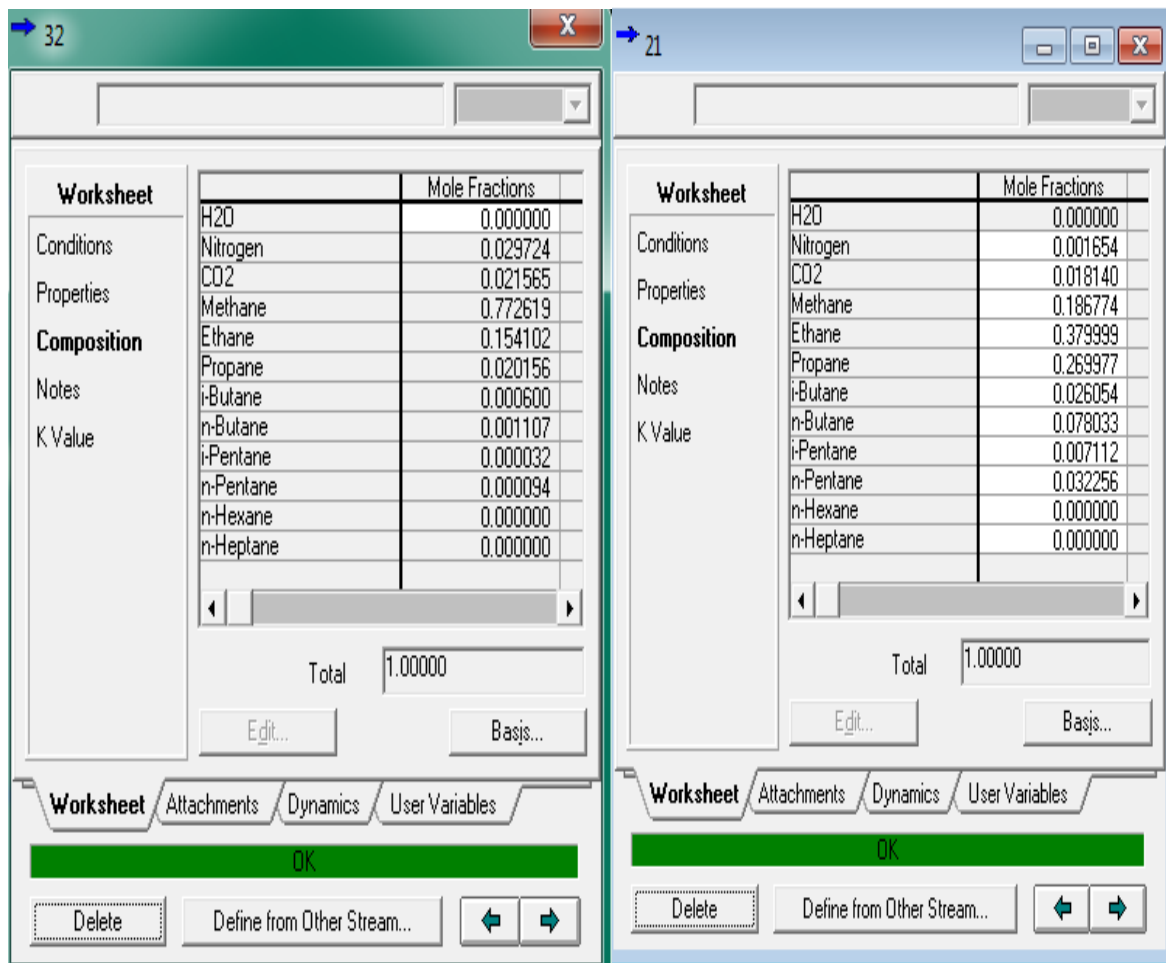


Figure IV.4 Simulation results in the real case.



Worksheet 32

Component	Mole Fractions
H2O	0.000000
Nitrogen	0.029724
CO2	0.021565
Methane	0.772619
Ethane	0.154102
Propane	0.020156
i-Butane	0.000600
n-Butane	0.001107
i-Pentane	0.000032
n-Pentane	0.000094
n-Hexane	0.000000
n-Heptane	0.000000

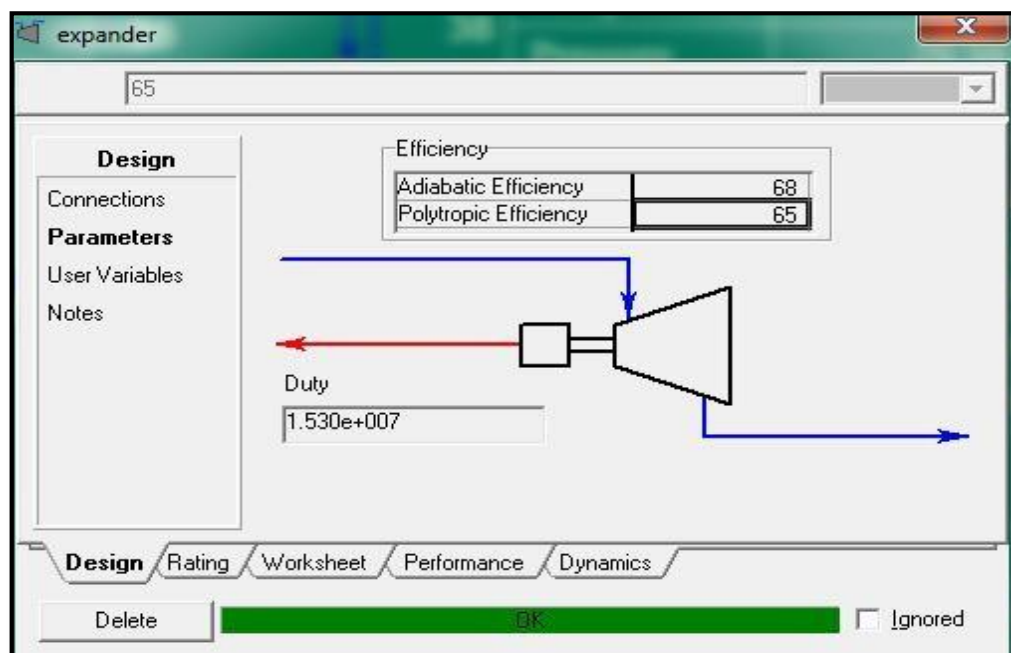
Total: 1.00000

Worksheet 21

Component	Mole Fractions
H2O	0.000000
Nitrogen	0.001654
CO2	0.018140
Methane	0.186774
Ethane	0.379999
Propane	0.269977
i-Butane	0.026054
n-Butane	0.078033
i-Pentane	0.007112
n-Pentane	0.032256
n-Hexane	0.000000
n-Heptane	0.000000

Total: 1.00000

The performance in the real case obtained by the HYSYS simulator is: $\eta = 65\%$



expander

65

Design

Connections

Parameters

User Variables

Notes

Efficiency

Adiabatic Efficiency	68
Polytronic Efficiency	65

Duty

1.530e+007

Design Rating Worksheet Performance Dynamics

Delete OK Ignored

❖ **Interpretation of results:**

It is obvious that the values obtained in the two design and real situations using the manual calculation method are similar (with a difference of 2%) to those obtained using the simulation with the HYSYS software, which confirms the latter. It is perfectly acceptable to have a deviation of 2%, taking into account measurement errors by charts.

The turbo-expander offers an actual efficiency of 65%, which is considerably lower than the design efficiency of 82%. This difference has a considerable impact on production.

IV.5. Material balance around the expander

To assess the losses linked to the failure of the expansion, a material balance will be carried out at this level. The calculation data is shown in the table below.

Table IV-9: Expander calculation data

Component	Feed gas (18)	Residual gas (32)
Propane (C₃)	0,0613	0,02006
I-butane (IC₄)	0,0048	0,00060
N-butane (C₄)	0,0138	0,00110
Flow rate (Nm³/J)	6110400	5059413,33

Under normal conditions of pressure and temperature (0°C =273.13°K) and (1 atm=1 kg/cm²) .one mole of gas occupies 22.4 liters.

The molecular weight of propane is equal to 44.10 kg/mole.

The molecular weight of butane is equal to 58.124 kg/mole.

❖ **The flow rate of propane (C₃) in the feed gas (18):**

$$Q_{m \text{ C}_3} (\text{GA}) = (Q_V \text{ GA} / 22.4) * Y_{\text{C}_3 \text{ GA}} * 44.10. 10^{-3} (\text{Ton} / \text{day})$$

$$Q_{m \text{ C}_3} (\text{GA}) = (6110400/22.4). 0.0613. 44.10. 10^{-3} = 737.43 (\text{Ton} / \text{day})$$

❖ **The flow rate of butane (C₄) in the feed gas (18)**

$$Q_{m \text{ C}_4} (\text{GA}) = (Q_V \text{ GA} / 22.4) * Y_{\text{C}_4 \text{ GA}} * 58.124 10^{-3} (\text{Ton} / \text{day})$$

$$Q_{m \text{ C}_4} (\text{GA}) = (6110400/22.4). (0.0048 + 0.0138). 58.124. 10^{-3} = 295 (\text{Ton} / \text{day})$$

❖ **The LPG flow rate in the feed gas (18):**

$$Q_{m \text{ LPG}} (\text{GA}) = Q_{m \text{ C}_3} (\text{GA}) + Q_{m \text{ C}_4} (\text{GA}) = 737.43 + 295 = 1032.43 (\text{Ton} / \text{day})$$

❖ **The flow of propane (C₃) in the residual gas:**

$$Q_{m \text{ C}_3} (\text{RES}) = (Q_V \text{ RES} / 22.4) * Y_{\text{C}_3 \text{ RES}} * 44.10 10^{-3} (\text{Ton} / \text{day})$$

$$Q_{m \text{ C}_3} (\text{RES}) = (5059413.33/22.4) 0.02006. 44.10. 10^{-3} = 199.81 (\text{Ton} / \text{day})$$

❖ **The flow rate of butane (C4) in the residual gas:**

$$Q_{m \text{ C4}} (\text{RES}) = (Q_{v \text{ RES}} / 22.4) * Y_{\text{C4 RES}} * 58.124 \cdot 10^{-3} (\text{Ton} / \text{day})$$

$$Q_{m \text{ C4}} (\text{RES}) = (5059413.33/22.4) \cdot (0.0006 + 0.0011) \cdot 58.124 \cdot 10^{-3} = 22.32 (\text{Ton} / \text{day})$$

❖ **The LPG flow rate in the residual gas (losses):**

$$Q_{m \text{ LPG}} (\text{RES}) = Q_{m \text{ C3}} (\text{RES}) + Q_{m \text{ C4}} (\text{RES}) = 199.81 + 22.32 = 222.13 (\text{Ton} / \text{day})$$

❖ **Quantity recovered of propane**

$$Q_{R \text{ C3}} = Q_{m \text{ C3}} (\text{GA}) - Q_{m \text{ C3}} (\text{RES}) = 737.43 - 199.81 = 537.62 (\text{Ton} / \text{day})$$

❖ **Quantity recovered of butane:**

$$Q_{R \text{ C4}} = Q_{m \text{ C4}} (\text{GA}) - Q_{m \text{ C4}} (\text{RES}) = 295 - 22.32 = 272.68 (\text{Ton} / \text{day})$$

❖ **Quantity recovered of LPG (production):**

$$Q_{R \text{ LPG}} = Q_{m \text{ LPG}} (\text{GA}) - Q_{m \text{ LPG}} (\text{RES}) = 1032.43 - 222.13 = 810.3 (\text{Ton} / \text{day})$$

Actual LPG recovery rate is the Quantity of LPG recovered (bottom 21) over Quantity of LPG in the feed gas (18).

$$Q_{R \text{ LPG}} / Q_{m \text{ LPG}} = 0.78 = 78\%$$

Table IV-10: Results of calculation of the material balance of the expander.

Quantity of propane in the feed gas (18) (Ton/J)	737,43
Quantity of butane in the feed gas (18) (Ton/J)	295
Quantity of LPG in the feed gas (18) (Ton/J)	1032,43
Quantity of propane in the residual gas (head 32) (Ton/J)	199,81
Quantity of butane in the residual gas (head 32) (Ton/J)	22,32
Quantity of LPG in the residual gas (head 32) (Ton/J)	222,13
Quantity of propane recovered (bottom 21) (Ton/D)	537,62
Quantity of butane recovered (bottom 21) (Ton/J)	272,68
Quantity of LPG recovered (bottom 21) (Ton/D)	810,3
Current LPG recovery rate (LPG yield) (%)	78,48%

❖ Interpretation of results:

Table IV.10 presents the material balance of the cryogenic section, which allowed us to notice the presence of LPG losses. These losses amount to approximately 222.13 tons each day.

The analysis of the impact of the variation of thermodynamic parameters on the turbo-expander efficiency and, consequently, on the LPG recovery rate was motivated by this production shortage. To maximize and improve the performance of the expansion, it is necessary to adjust its operating conditions.

IV.6. Study of influence of parameters (T, P and Qm) on the yield of expand it:

The operating parameters which determine the proper functioning of the turbo-expander are pressure, temperature and flow rate. The aim of this study is to seek the best operating parameters in order to maximize the recovery of hydrocarbons in the liquid state. The results obtained (the yield and molar composition of the liquid phase at the bottom of the separation flask point 21 and the quantity of LPG produced) are represented in the tables below.

The manufacturer of the turbo-expander has planned to work under entry and discharge conditions.

output, as follows:

The inlet temperature varies between $T_{\min} = -3^{\circ}\text{C}$ and $T_{\max} = 15^{\circ}\text{C}$.

The inlet pressure varies between $P_{\min} = 90 \text{ bar}$ and $P_{\max} = 97 \text{ bar}$.

The outlet temperature varies between $T_{\min} = -43^{\circ}\text{C}$ and $T_{\max} = -52^{\circ}\text{C}$.

The outlet pressure varies between $P_{\min} = 18 \text{ bar}$ and $P_{\max} = 23 \text{ bar}$.

1st case: variation of the inlet temperature:

In this situation, the inlet temperature (point 18) will be changed while maintaining the inlet and outlet pressures as well as the flow rate.

In order to analyze the impact of this variable, which is directly linked to the outlet temperature, on the expansion efficiency, we considered the gas as an ideal gas in order to determine the outlet temperature for injecting it into HYSYS software.

❖ For a polytropic transformation we have:

$$T_s/T_e = P_s/P_e^{(n-1)/n} \dots\dots\dots \text{(IV.22)}$$

$$\ln(T_s/T_e) = (n-1/n) * \ln(p_s/p_e) \dots\dots\dots \text{(IV.23)}$$

So, we find $n = 1 / (1 - \ln(T_s/T_e) / \ln(p_s/p_e)) \dots\dots \text{(IV.24)}$

To calculate the polytropic coefficient we have:

$$T_e = 8.7^\circ\text{C} + 273 = 281.7 \text{ K}$$

$$T_s = -46.5 + 273 = 226.5 \text{ K}$$

$$P_e = 94.11 \text{ bar and } P_s = 19.97 \text{ bar}$$

We find the polytropic coefficient $n=1.16371$

$$T_s/T_e = [P_s/P_e]^{(n-1)/n} \dots \dots \dots (IV.25)$$

Table IV-11: Results of calculations of the outlet temperature (T_s)

$n-1/n$	$T_e (^\circ\text{C})$	$T_e (\text{K})$	$P_e (\text{bar})$	P_s	$T_s (\text{K})$	$T_s (^\circ\text{C})$
0,1406	-2	271	94,11	19,97	217,93	-55,07
0,1406	0	273	94,11	19,97	219,54	-53,46
0,1406	4	277	94,11	19,97	222,75	-50,25
0,1406	6	279	94,11	19,97	224,36	-48,64
0,1406	8	281	94,11	19,97	225,97	-47,03
0,1406	10	283	94,11	19,97	227,58	-45,42
0,1406	8,7	281,7	94,11	19,97	226,53	-46,47

The calculation is repeated for each the in order to obtain T_s . This data is then integrated into the HYSYS software to evaluate performance.

The table below presents the results obtained (outlet temperature, performance, flow rate from the bottom of tank 21 and composition):

Table IV-12: Results of variation of inlet temperature.

$T_e (^\circ\text{C})$	-2	0	4	6	8	10
$T_s (^\circ\text{C})$	-55,07	-53,46	-50,25	-48,64	-47,03	-45,42
$\eta (\%)$	70	69	68	67	66	64
$Q_{m \ 21} (\text{T/J})$	2034,55	1952,74	1791,07	1710,91	1631,47	1552,85
N_2	0,0019	0,0018	0,0018	0,0017	0,0017	0,0016
CO_2	0,0218	0,0211	0,0197	0,0190	0,0184	0,0177
C_1	0,2220	0,2147	0,2011	0,1948	0,1887	0,1829
C_2	0,4102	0,4060	0,3954	0,3892	0,3824	0,3751
C_3	0,2335	0,2405	0,2545	0,2613	0,2679	0,2742
$i-C_4$	0,0206	0,0215	0,0235	0,0245	0,0257	0,0269
$n-C_4$	0,0603	0,0632	0,0695	0,0730	0,0768	0,0807
$I-C_5$	0,0054	0,0056	0,0063	0,0066	0,0070	0,0074
$n-C_5$	0,0242	0,0255	0,0283	0,0299	0,0317	0,0335
C_6	0	0	0	0	0	0
C_7	0	0	0	0	0	0
$Q_{m \ C_3} (\text{T/J})$	615,33648	601,97808	571,71528	554,65	536,3184	516,72312
$Q_{m \ IC_4} (\text{T/J})$	71,39088	70,82928	69,47616	68,66	67,74528	66,71376
$Q_{m \ NC_4} (\text{T/J})$	209,5836	208,53024	205,95	204,37	202,56792	200,51136

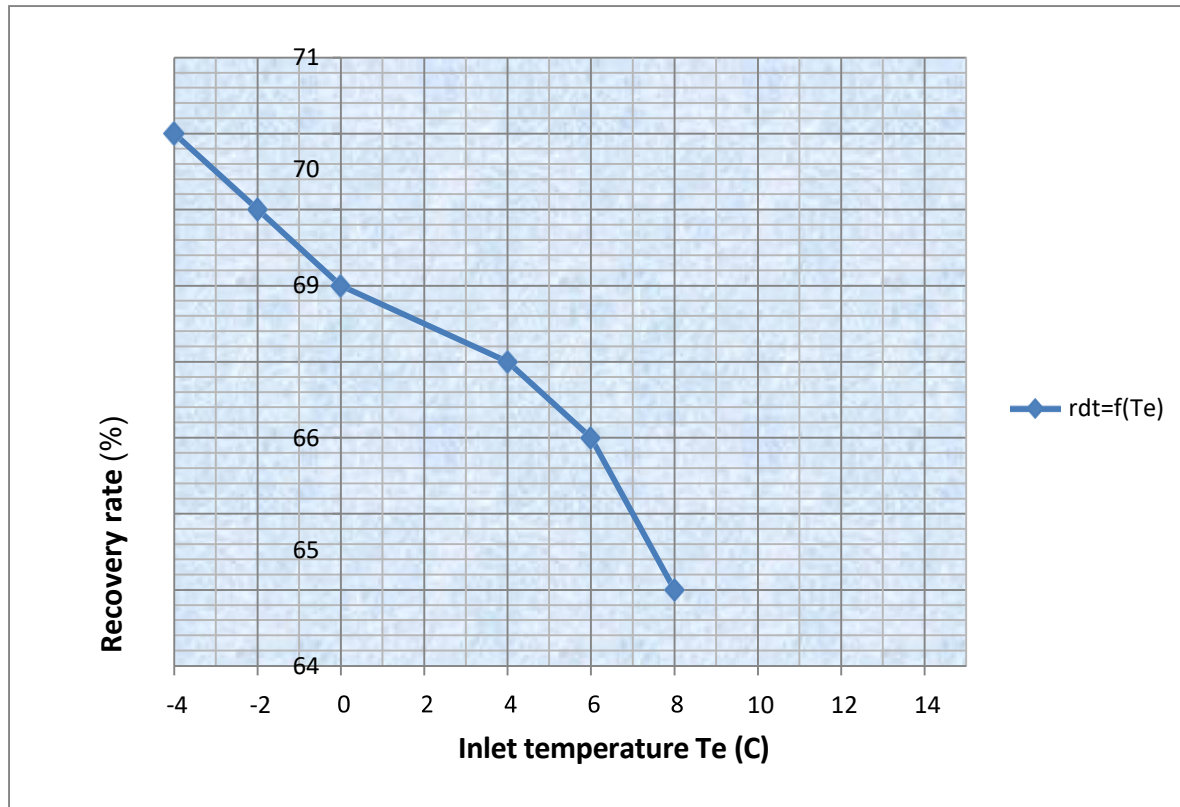


Figure IV.5: Variation in expander efficiency depending on the inlet temperature.

Table IV-13: Evaluation of losses in the event of variation in inlet temperature.

T_e (°C)	-2	0	4	6
$Q_{m\ 32}$ (T/J)	4043,04	4124,93	4 286,59	4 366,76
C_3	0,0124	0,0137	0,0164	0,0180
i- C_4	0,00032	0,0004	0,0005	0,0005
n- C_4	0,00056	0,0006	0,0008	0,0009
$Q_{m\ C_3}$ (T/J)	115,35	128,71	158,97	176,03
Q_{mIC_4} (T/J)	3,9	4,46	5,81	6,62
$Q_{m\ NC_4}$ (T/J)	6,87	7,92	10,50	12,07
$Q_{GPLR\ (32)}$ (T/J)	166,12	141,09	175,28	194,72
$QR_{GPL\ (21)}$ (T/J)	896,30	881,32	847,14	827,69
LPG recovery rate (%)	86,81%	85,54%	82,05%	80,16%

Quantity recovered of LPG Q_{RGPL} (21) (product):

$$\sum_{21} Q_m C_3 + Q_m I C_4 + Q_m N C_4$$

Quantity of LPG in the residual gas $Q_{\text{LPG R}}$ (32) (losses):

$$\sum_{32} Q_m C_3 + Q_m I C_4 + Q_m N C_4$$

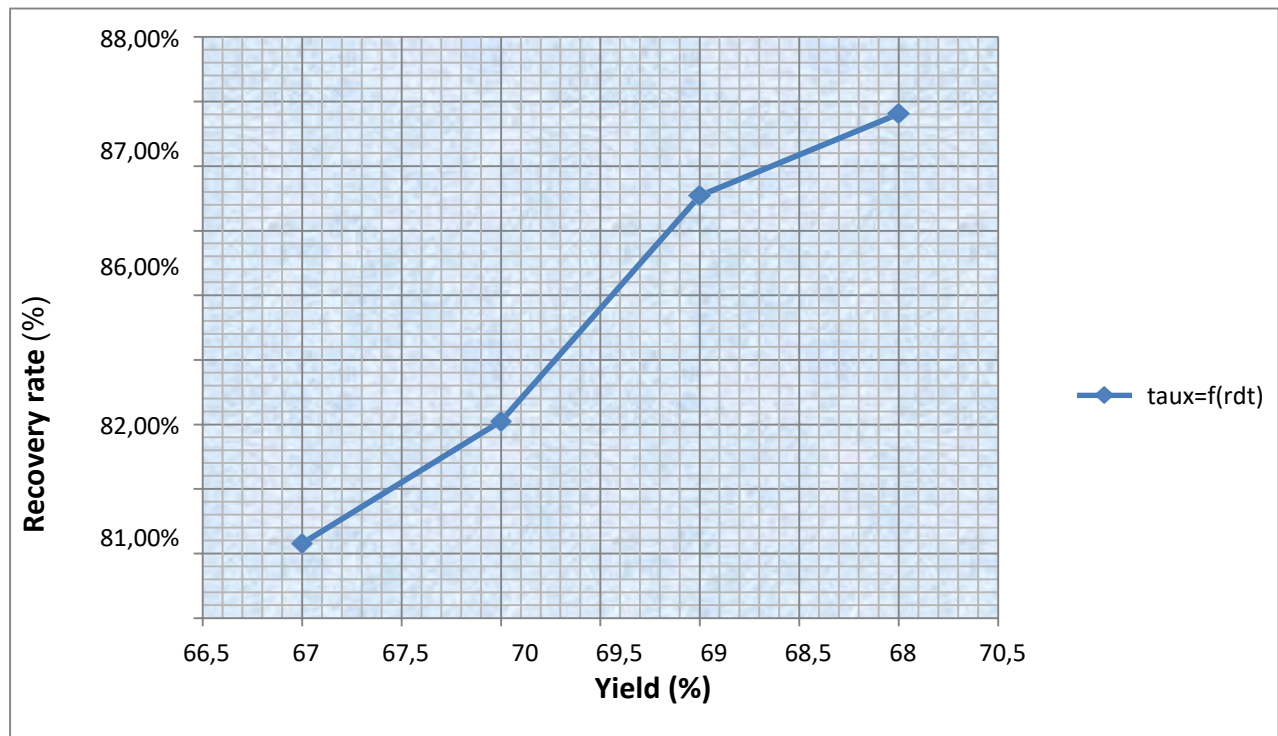


Figure IV.6: Recovery rate depending on the yield from the temperature variation.

❖ **Comment:**

The increase in yield is directly linked to the outlet temperature, so the lower this temperature is, the better the recovery of liquid hydrocarbons will be. In order to achieve a low T_s , the inlet temperature must be lowered.

2nd case: Variation of inlet pressure:

In this situation, we will adjust the inlet pressure while maintaining: inlet temperature, outlet pressure and flow rate. In order to calculate T_s as a function of P_e , we use the method mentioned above. The results obtained are grouped in the table below.

Table IV-14: Results of inlet pressure variation.

P_e (bar)	90	92	94	97
T_s(°C)	-45,04	-45,75	-46,43	-47,43
η(%)	67	66	65	64
Q_{m 21} (T/J)	1534,42	1568,89	1602,07	1651,13
N₂	0,0016	0,0016	0,0017	0,0017
CO₂	0,0176	0,0178	0,0181	0,0185
C₁	0,1816	0,1841	0,1865	0,1902
C₂	0,3733	0,3766	0,3797	0,3841
C₃	0,2756	0,2729	0,2703	0,2662
i-C₄	0,0271	0,0266	0,0261	0,0254
n-C₄	0,0817	0,0799	0,0782	0,0758
I-C₅	0,0075	0,0073	0,0071	0,0069
n-C₅	0,0340	0,0331	0,0323	0,0312
C₆	0	0	0	0
C₇	0	0	0	0
Q_{m C3} (T/J)	511,92	520,84	529,16	540,99
Q_{m IC4} (T/J)	66,45	66,93	67,37	67,98
Q_{m NC4} (T/J)	199,99	200,95	201,83	203,04

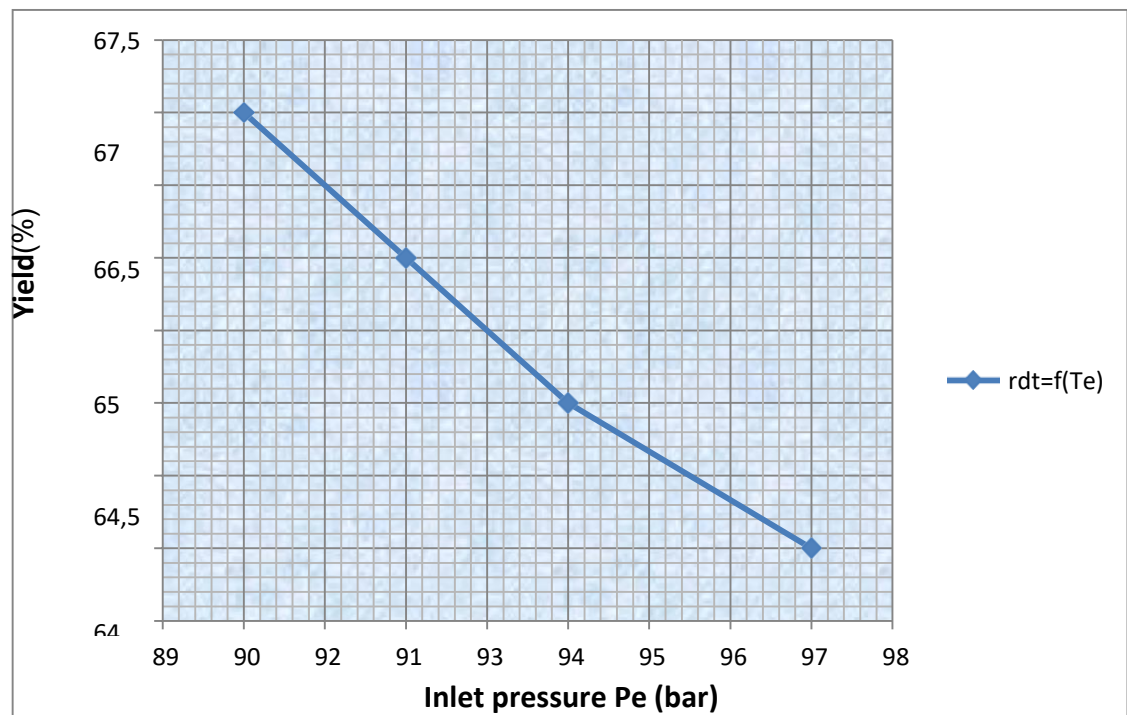


Figure IV.7 Variation of efficiency as a function of inlet pressure

Table IV-15 Evaluation of losses in the case of variation of inlet pressure

P_e (bar)	90	92	94	97
$Q_{m\ 32}$ (T/J)	4543,25	4508,77	4 475,59	4 426,53
C_3	0,0217	0,0210	0,0202	0,0192
i- C_4	0,00067	0,0006	0,0006	0,0006
n- C_4	0,00124	0,0012	0,0011	0,0010
$Q_m\ C_3$ (T/J)	218,77	209,85	201,52	189,69
$Q_m\ IC_4$ (T/J)	8,8	8,35	7,91	7,30
$Q_m NC_4$ (T/J)	16,46	15,5	14,62	13,41
$Q\ GPL_R$ (32) (T/J)	244,06	233,7	224,05	210,40
$Q\ R_{LPG}$ (21) (T/J)	778,36	788,72	798,36	812,01
LPG recovery rate (%)	75,39%	76,39%	77,32 %	78,65%

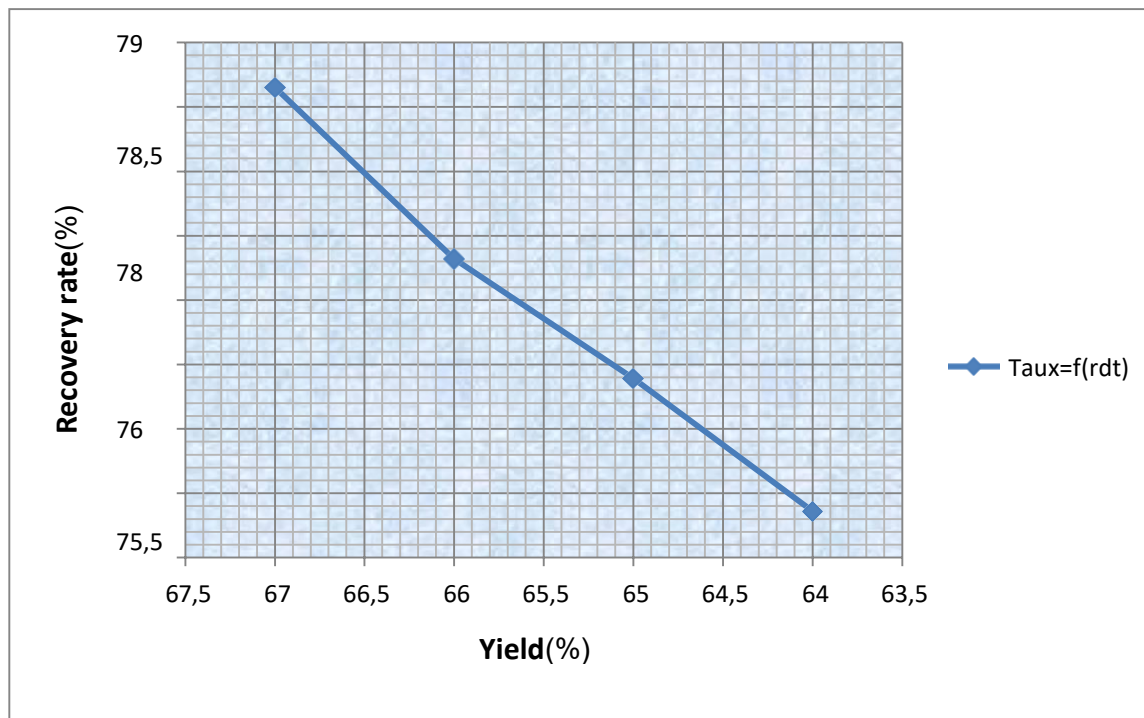


Figure IV.8 LPG recovery rate depending on the yield from the pressure variation

Comment

The efficiency of a turbo-expander corresponds to the ratio between the energy supplied by the wheel and that present in the gas $\Delta H_a/\Delta H_{is}$. By increasing the suction pressure, the efficiency decreases (Figure IV.7), which indicates a decrease in the transformed energy so that ΔH_a decreases. in favor of ΔH_{is} (Figure IV.9)

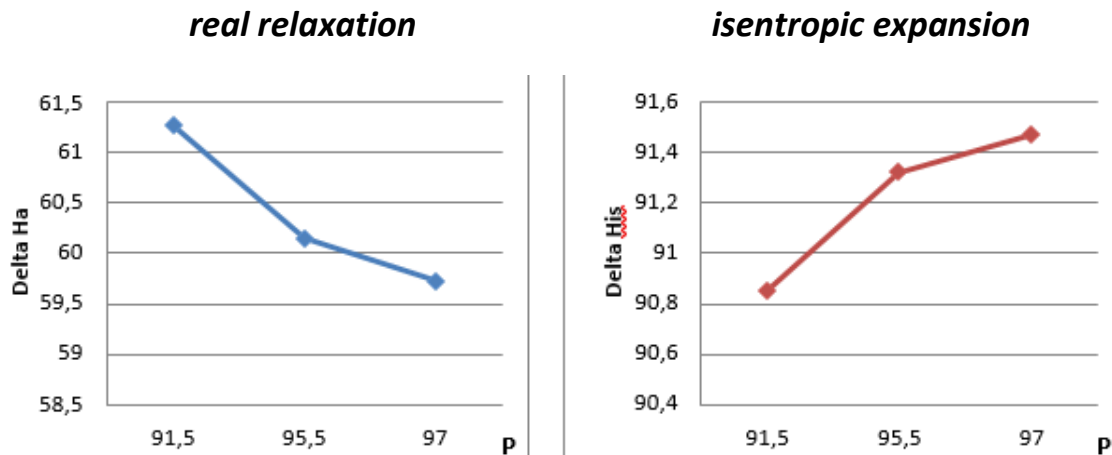


Figure IV.9 Real and isentropic expansions

On the other hand, by increasing the suction pressure, there will be a decrease in the pressure through the machine and the associated temperature, which will allow low cryogenic temperatures to be achieved (proportionality between temperature and pressure), which favors better recovery of the liquid under these conditions (Figure IV.8).

Thus, low efficiency expanders can be used to achieve low temperatures while increasing suction pressure.

3rd case: Variation in supply flow:

The characteristic curve provided by the manufacturer (Appendix) was used to study the impact of the variation in flow rate on the efficiency of the expander. We introduced the flow rate passing through the machine and the corresponding efficiency on HYSYS, while setting the operating parameters (T_e , P_e , P_s) and letting the latter calculate the outlet temperature.

- According to the characteristic curve $\eta / \eta_{\max} = f(V\%)$.
- ($V\%$) Percentage of maximum mass flow.
- The maximum efficiency guaranteed by the manufacturer is $\eta_{\max} = 87\% = 0.87$.
- For $\eta_{\max} = 0.87$ we will have $V/100=1$
- The maximum mass flow rate guaranteed by the manufacturer $Q_{\max} = 320148.34 \text{ kg/h}$
- To calculate the flow corresponding to each yield we have: $V/100 * Q_{\max}$

For example: $1 * 320148.34 = 320148.34 \text{ kg/h}$

$0.07361 * 320148.34 = 23566.12 \text{ kg/h}$

To calculate the efficiency corresponding to each flow rate we have: $\eta_{\max} * (\square / \eta_{\max})$ The results obtained are given in the table below:

Table IV-16 Results of the characteristic curve.

V%	$\eta / \eta_{\max}$	V/100	$\eta = \eta_{\max} * (\eta/\eta_{\max})$	Flow rate (kg/h)
7,36	0,78	0,07361	0,6832	23566,12
20,07	0,85	0,2007	0,7428	64253,77
31,45	0,90	0,3145	0,7865	100686,66
42,83	0,94	0,4283	0,8183	137119,54
54,87	0,96	0,5487	0,8382	175665,4
78,29	0,99	0,7829	0,8659	250644,14
100	1,0000	1	0,87	320148,34
122,5	0,98	1,225	0,8540	392181,72
132,5	0,96	1,325	0,8382	424196,56
141,2	0,94	1,412	0,8223	452049,46
150,6	0,92	1,506	0,8024	482143,41
160,6	0,88	1,606	0,7706	514158,24

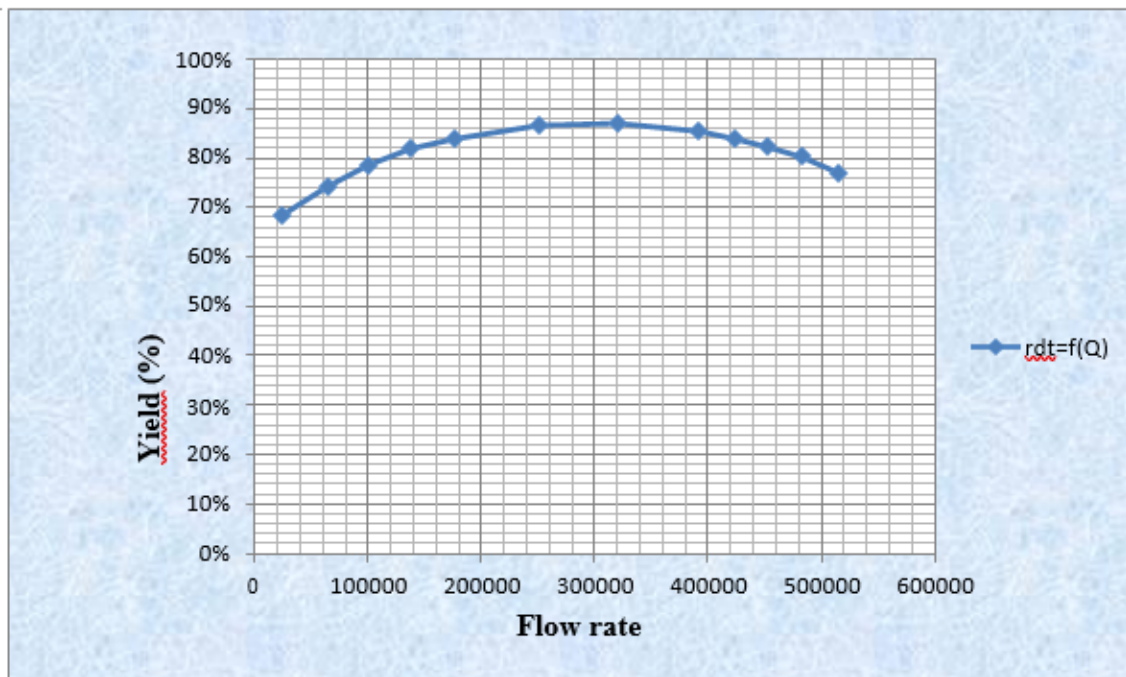


Figure IV.10 Variation of yield depending on flow rate

Table IV-17 Results of varying the expander feed rate

Q₁₈ (kg/h)	137119.54	175665.4	250644.14	320148,34	392181.723	424196.557
T_s(°C)	-49,23	-49,55	-50	-50,064	-49,81	-49,55
η(%)	81,83	83,82	86,60	87	85,41	83,82
Q_{m 21} (T/J)	942,38	1218,36	1760,38	2252,57	2739,84	2942,16
C₃	0,2588	0,2574	0,2555	0,2552	0,2563	0,2574
i-C₄	0,0241	0,0239	0,0236	0,0236	0,0237	0,0239
n-C₄	0,0717	0,0710	0,0700	0,0699	0,0705	0,0710
PM (kg/kmole)	35,39	35,31	35,21	35,19	35,25	35,31
Q_{m C₃} (T/J)	303,816	391,584	563,328	720,36	878,376	945,6
Q_{m IC₄} (T/J)	37,346	47,959	68,647	87,72	107,266	115,812
Q_{m NC₄} (T/J)	110,990	142,408	203,613	260,16	318,312	343,896

Table IV-18 Loss assessment results in the case of flow variation.

Q₁₈ (kg/h)	137119.54	175665.4	250644.14	320148,34	392181.72	424196.557
Q_{m 32} (T/J)	2348,496	2997,6	4254,96	5430,96	6672,72	7238,64
C₃	0,0174	0,0170	0,01661	0,0166	0,0168	0,0170
i-C₄	0,0005	0,0005	0,00046	0,0005	0,0005	0,0005
n-C₄	0,0009	0,0009	0,00084	0,0008	0,0009	0,0009
Q_{m C₃} (GA) (T/J)	395.64	506,85	723,21	923,76	1131,6	1223,98
Q_{m C₃} (RES) (T/J)	91,82	115,27	159,88	203,39	253,22	278,38
Q_{m IC₄} (GA) (T/J)	40,77	52,22	74,51	95,17	116,59	126,11
Q_{m IC₄} (RES) (T/J)	3,42	4,26	5,87	7,5	9,32	10,30
Q_{m NC₄} (GA) (T/J)	117 ,20	150,14	214,23	273,65	335,21	362,57
Q_{m NC₄} (RES) (T/J)	6,21	7,73	10,62	13,49	16,89	18,69
Q_{m GPL} (GA) (T/J)	553,61	709,21	1011,95	1292,58	1583,34	1712,66
QGPL_R (T/J)	101,45	127,26	176,37	224,38	279,43	307,37
QR_{GPL} (T/J)	452,15	581,95	835.58	1068,2	1303,95	1405,30
taux de récupération GPL (%)	81,67%	82,20%	82,57	82,64%	82,35%	82,05%

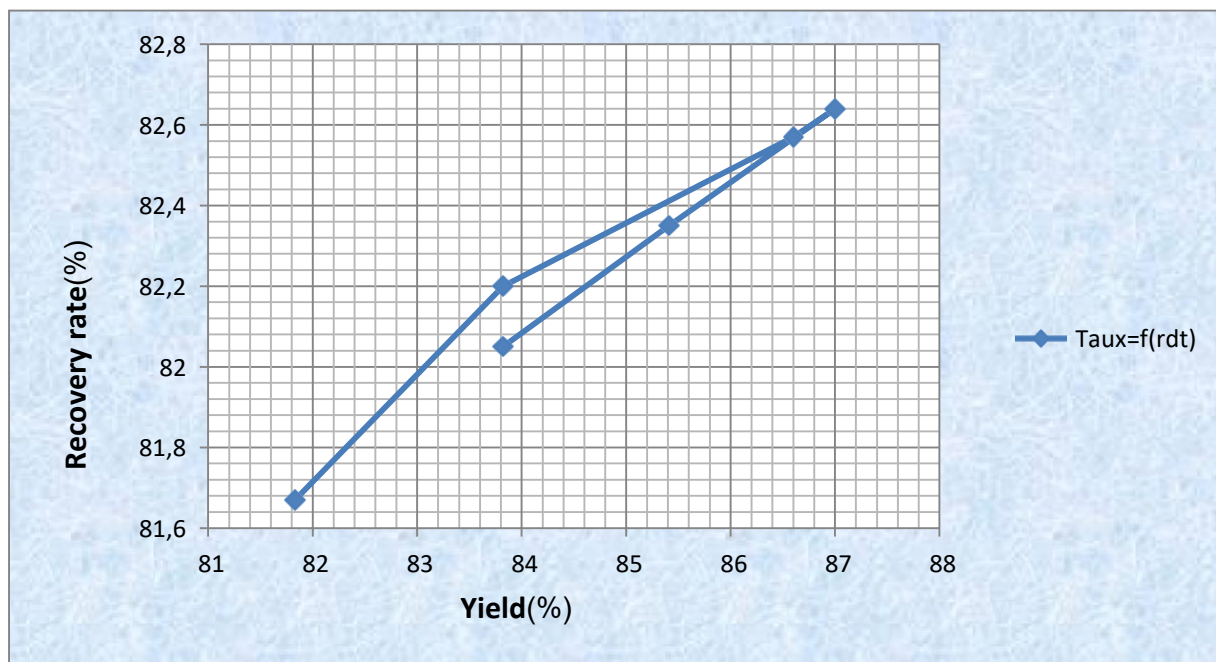


Figure IV11. Recovery rate depending on the yield from the flow variation

Comment:

The increased efficiency in the first part (Figure IV.10) is associated with a progressive increase in the opening of the IGVs, which leads to an increase in the rate of recovery of the kinetic energy contained in the gas and a decrease in the pressure. This favors obtaining very low temperatures, which favors a higher recovery rate of the liquid phase (Figure IV.11).

The drop-in efficiency in the second part (Figure IV.10) by increasing the flow rate (boosting phenomenon) is associated with a drop-in rotation speed due to the overload of the turbo-expander. This causes a decrease in pressure and results in a decrease in machine efficiency, which results in a decrease in enthalpy and a low recovery rate (Figure IV.11).

Thus, flow rate fluctuations have an impact on the dynamic behavior of the machine and, consequently, on its efficiency.

IV.7. Economic study

After each technical study, it is crucial to carry out an economic study of the feasibility of an investment, because it provides specific information to identify.

Difficulties and challenges. The main goal of this study is to measure expenses, as well as the efficiency of the resources used, with emphasis on the financial and economic profitability of these different options.

LPG losses from the GPL2 unit are estimated at around 380 Ton/J, particularly in the cryogenic section with a value of 222.13 Ton/J. According to estimates, the annual losses in dollars for an LPG price of \$700/Ton (price for the year 2018) are respectively \$9,7090,000/year and \$5,6754,215/year.

❖ Valorization of the variation of parameters at the input of the expander:

In the LPG2 unit, it is possible to regulate the supply pressure and flow rate of each train by modifying the energy (or power) supplied to the Boosters. They consist of a suction tank, a six-level centrifugal compressor driven by an MS5002C gas turbine, a battery of air coolers to improve the temperature of the gas discharged by the compressor to 50°C and a repression balloon. Thus, each booster consumes the same amount of energy as the compressor and the air cooler.

The total energy consumption corresponds to the energy consumption of the compressor and the dry coolers.

On the other hand, the HYSYS software, by simulating the compression process as illustrated in Figure IV.12, allows us to evaluate the energy consumption of each booster in terms of electrical energy in KWH, each time that the compressor discharge pressure or suction flow rate is changed. Since the price of one kilowatt hour KWH in our country is 11.56 da, which is equivalent to 0.057 dollars, it is possible to take into account the energy supplied for each booster.

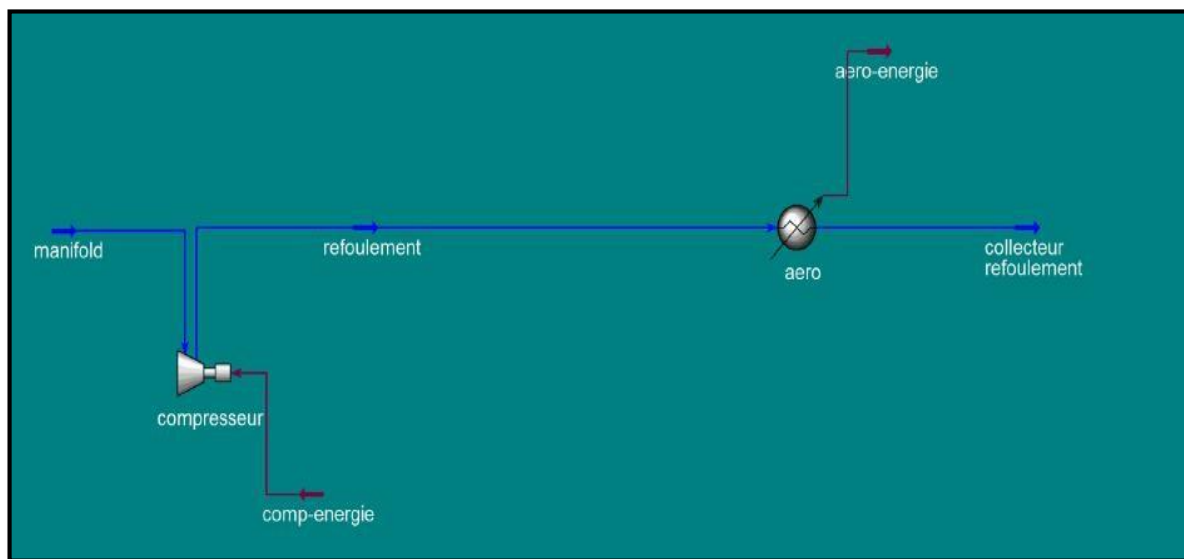


Figure IV.12: Simulation diagram of the compression process.

IV.7.1. Valuation of the pressure variation at the inlet of the expander

Table IV-19 : Results of valuation of the pressure at the entrance of the expander

P_e (bar)	90	92	94	97
Energy consumed (KWH)	37110	37750	38390	39310
Energy cost (\$/an)	18529765,2	18849330	19168894,8	19628269,2
LPG quantity recovered (T/J)	778,36	788,72	798,36	812,01
Cost of recovered LPG (\$/an)	198870980	201517960	203980980	207468555

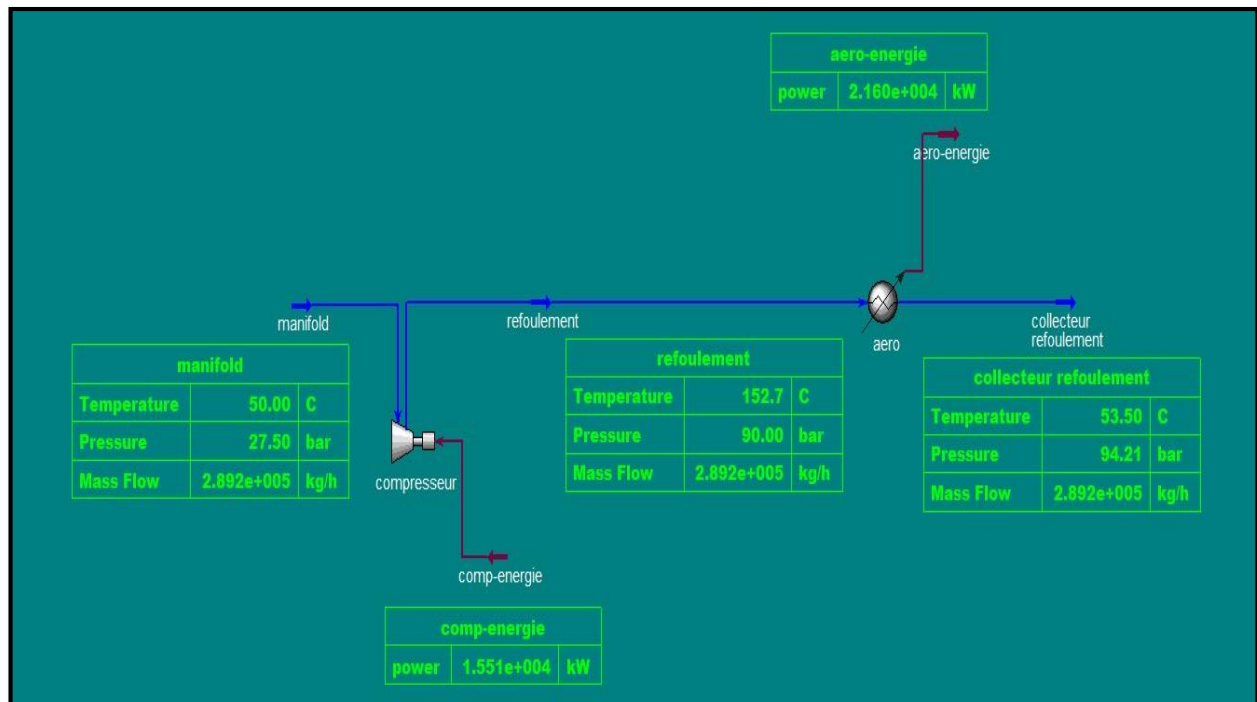


Figure IV.13: Example of pressure variation result obtained by HYSYS.

According to the data in (Table IV.19), it is observed that the increase in pressure is associated with an increase in LPG revenues as well as the cost of energy consumed by boosters and air coolers. However, the increase in income largely covers energy-related expenses. Thus, they are estimated at approximately 2646980 dollars for a variation of 90 to 92 bars, with an energy consumption of approximately 319564 for the same period. It is important to note that the maximum pressure not to be exceeded is approximately 97 bars (due to the design, safety of the installations and climatic conditions, etc.).

IV.7.2. Valuation of the variation in flow rate at the entrance to the expander:

Table IV-20: Result of the valuation of the flow rate at the entrance to the expander

Flow rate Q_m (kg/h)	250644.14	320148,34	392181.723
Energy consumed (KWH)	33460	42740	52360
Energy cost (\$/year)	16707247,2	21340936,8	26144395,2
Quantity of LPG recovered (T/D)	835,58	1068,2	1303,95
Cost of LPG (\$/year)	213490690	272925100	333159225
LPG losses (T/D)	176,37	224,38	279,43
Cost of losses (\$/year)	45062535	57329090	71394365
Gain (\$/year)	168428155	215596010	261764860

The turbo expander has high sensitivity to flow variation, resulting in increased revenue along with increased production and reduced losses. When the throughput exceeds the design value, revenue increases, but losses are considerable. This trend becomes more frequent as we move away from this value (large income/large losses). It is important to note that the manufacturer recommends a flow rate of 320148.34 kg/h in order to improve the performance of the machine while maintaining optimal profitability.

It is also observed that the drop-in flow rate in the LPG2 unit is responsible for the vibration problems in the turbo-expander (speed). Train heating, high temperature at the train inlet (during summer, with high water content), lack of gas or a downstream problem (high stock).

IV.7.3. Valuation of the temperature variation at the entrance to the expander:

Table IV-21: Results of the evaluation of the temperature at the inlet of the expander

T_e (°C)	-2	4	6
Quantity of LPG (T/D)	896,3	847,14	827,69
LPG cost (\$/year)	229004650	216444270	211474795
Losses (T/D)	166,12	175,28	194,72
Cost of losses (\$/year)	42443660	44784040	49750960
Gain (\$/years)	186560990	171660230	161723835

The inlet temperature of the turbo expander plays a crucial role in controlling the outlet temperature, which influences the recovery rate of liquid hydrocarbons. We can observe in (Table IV.21) that the drop in the latter is accompanied by an increase in income linked to the increase in production. Regarding the LPG2 unit, the HV201 and the by-passes of the exchangers E204 and 205/207/208 regulate the inlet temperature. The latter can sometimes be increased to solve the problem of obstruction of the lines and displacement of the shaft at the turbo expander.

IV.8. Conclusion

During this chapter, it is observed that the expansion of the LPG unit 2 of train 1 is not really reliable, because the actual efficiency of the turbo-expansion is 65%, much lower than that of the 82 design. %. Thus, we examined the impact of varying the three parameters on yield and found an increase in yield. For low temperature expansion at the inlet, To increase the flow rate until reaching a maximum efficiency of 87%. By increasing the suction pressure, we observe a drop-in efficiency, but an increase in the recovery rate, this which indicates a decrease in transformed energy, which results in a decrease in ΔH_a in favor of ΔH_i .

Thus, in order to improve the recovery of hydrocarbons in the liquid state, it is necessary to combine high pressure and low temperature at the inlet, as well as a flow rate equal to or close to that expected.

According to the economic study, it is noted that the increase in income largely covers energy expenses in the case of variations in temperature, pressure and flow.

General conclusion

General conclusion

This work developed as part of an end-of-study project with the theme: "Experimental Study and Optimization of turbo-expander operating parameters of the "GPL2 CIS-DP-HMD" unit. This work consisted of studying the malfunctions which can disrupt the liquefaction process at the cryogenic section as well as the proper functioning of the turbo-expander and which influence its efficiency and therefore the production of LPG.

Given the importance of the expander in the cryogenic refrigeration and separation system of the LPG2 unit, it is necessary that it has high thermodynamic efficiency, high reliability and easier integration with other systems. In recent years, the latter's profitability has declined, resulting in a very significant shortfall in production. Thus, we manually evaluated the efficiency of the expansion in the two cases, design and real, with respective values of 80, 30% and 66.66%. The results were confirmed using HYSYS simulation software. The figures obtained in this situation are 82% and 65%.

In addition, three parameters: inlet temperature (T_e), inlet pressure (P_e) and inlet flow rate (Q_m) also have an impact on the expansion efficiency and, therefore, on the LPG recovery rate.

temperature:

When temperatures are low at the entrance to the expansion, it is possible to reach low temperatures at the exit of the expansion, which leads to an improvement in the efficiency of the machine and the recovery rate of the LPG. For example, for a temperature of -2 (°C) at the entrance to the expansion, we obtain a rate of 86.81% and an RTD efficiency of 70%, while for a temperature of 6 (°C) at the start of the expansion, we obtain a rate of 80.16% and an RTD yield of 67%.

Pressure:

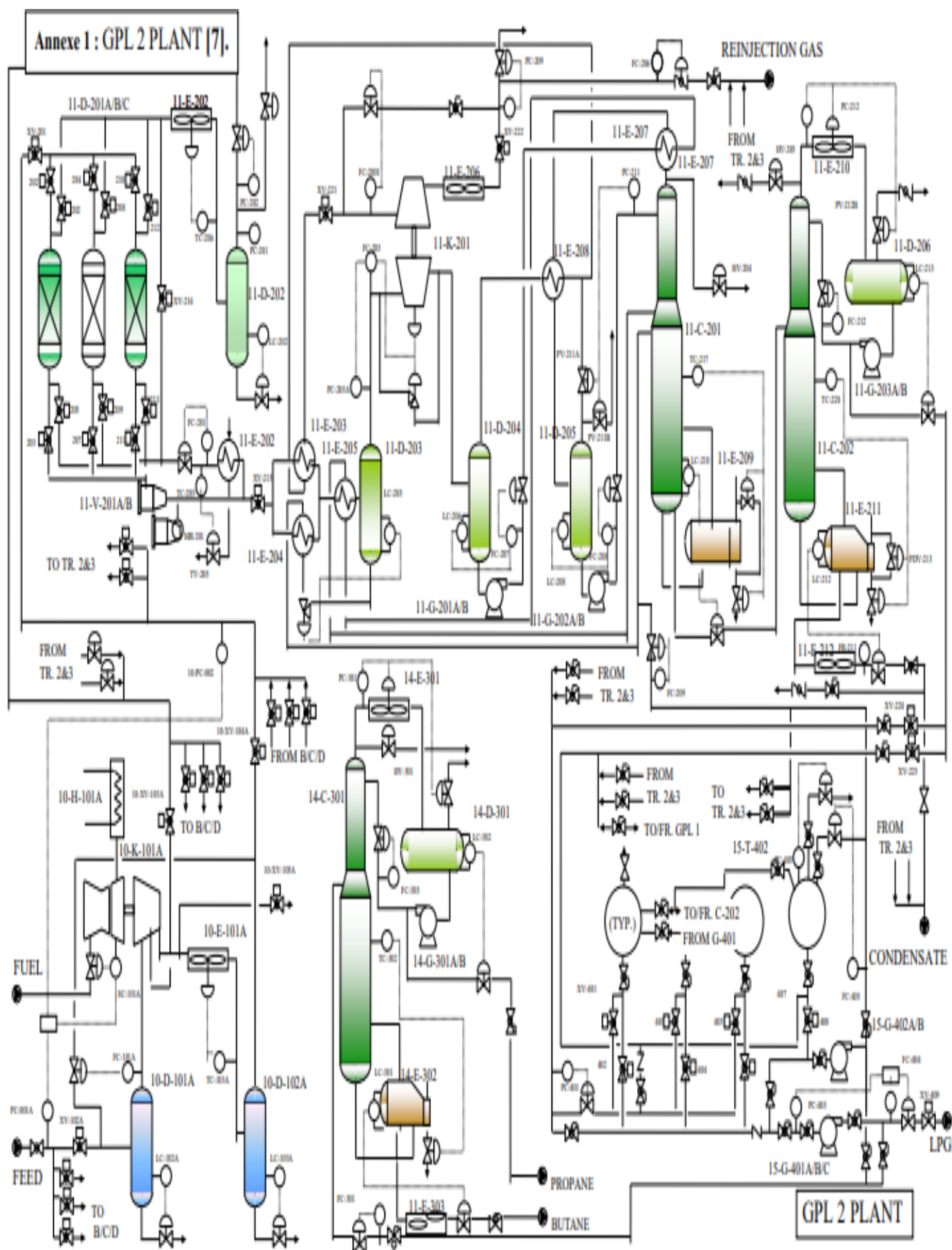
When the pressure increases at the inlet, it causes a drop-in temperature, which promotes better recovery, but also results in a decrease in efficiency because the pressure decreases. The energy transformed by the ΔH_a machine is lower than that stored in the ΔH_{is} gas.

Flow rate:

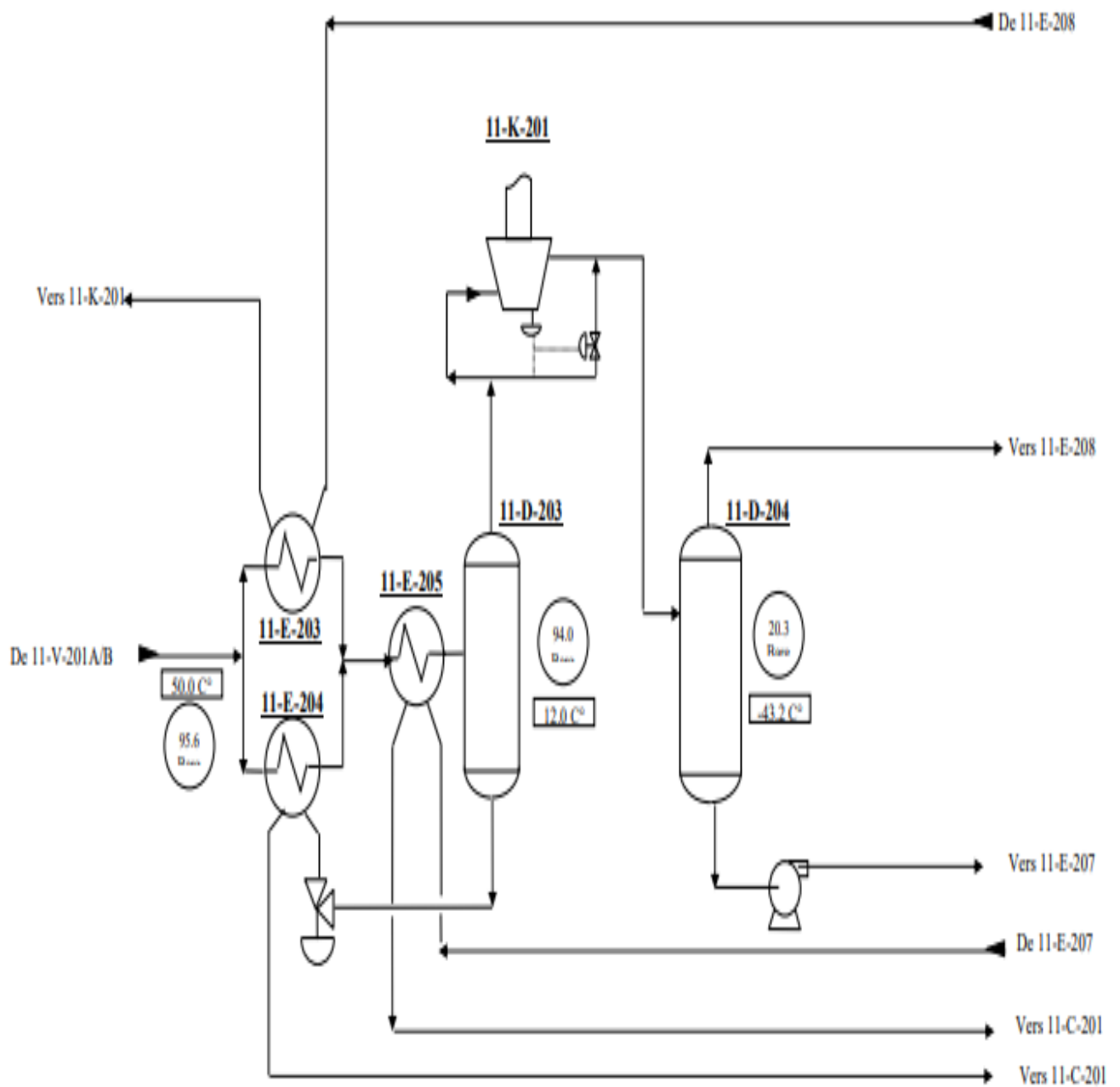
To study the impact of variation in flow rate, we used the characteristic curve provided by the manufacturer. We found that by increasing the flow rate, the yield and recovery rate increase, reaching an efficiency of 87%.

We believe we have achieved the objectives assigned to this end-of-study project and we propose in order to increase the efficiency of the machine as well as the recovery of the LPG to combine a low temperature at the inlet, a high pressure at the inlet limited to 95 bar (the outlet of the Boosting section to ensure good liquefaction at the level of the expander and a good liquefaction rate), and a flow rate close to that of the design while resolving the problem of hydrate formation which can prevent these changes, either by optimizing the injection of methanol, or by resizing the dehydrators or by installing coalescers at the entrance to each train, which is currently in the study phase. To improve the performance of the turbo expander, we also recommend changing and completely renovating the spare parts of the turbo expander (bearing, wheel, shaft, etc.) since low performance is sometimes due to the obsolescence of the turbo expander after several years. of work.

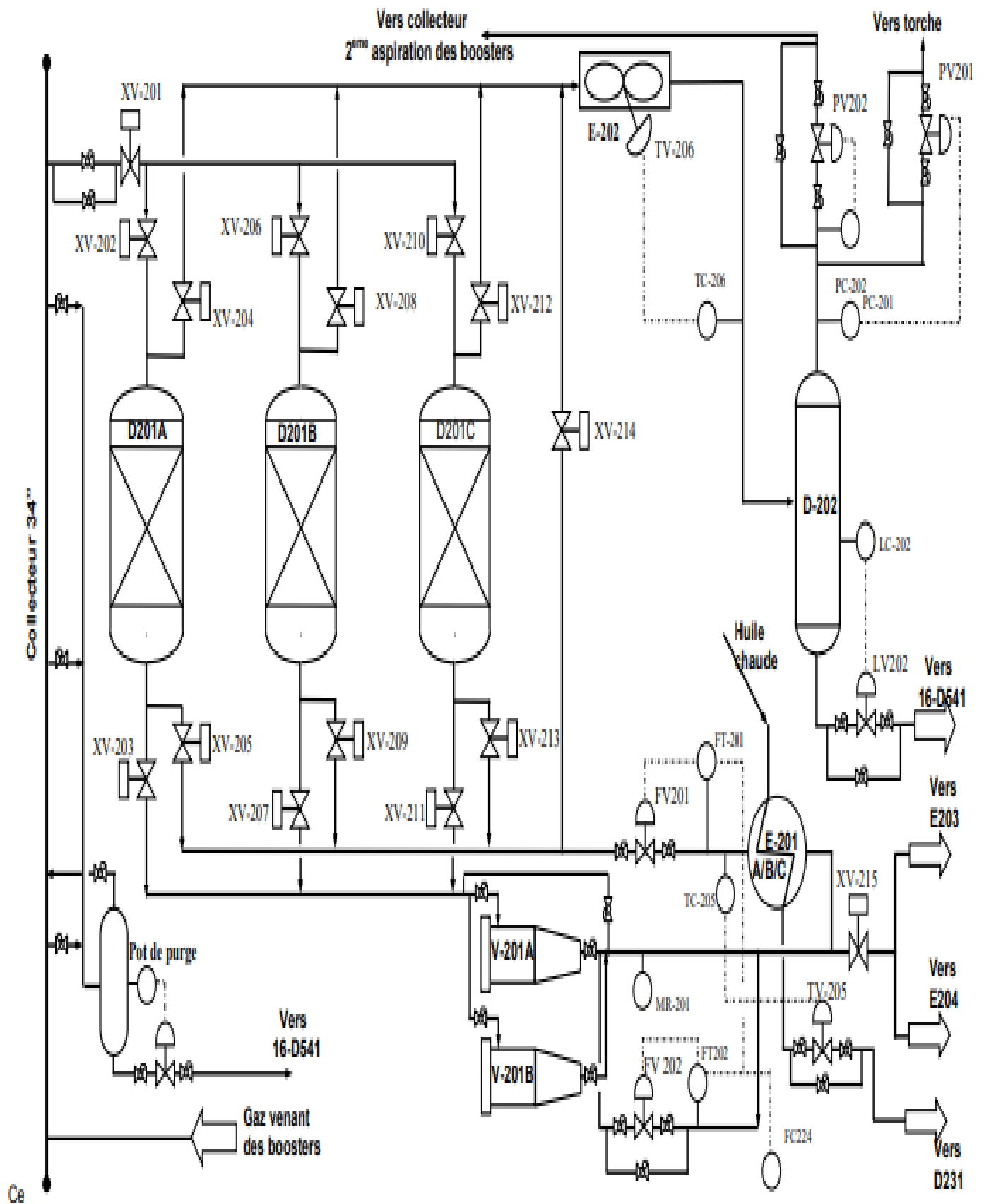
APPENDICES



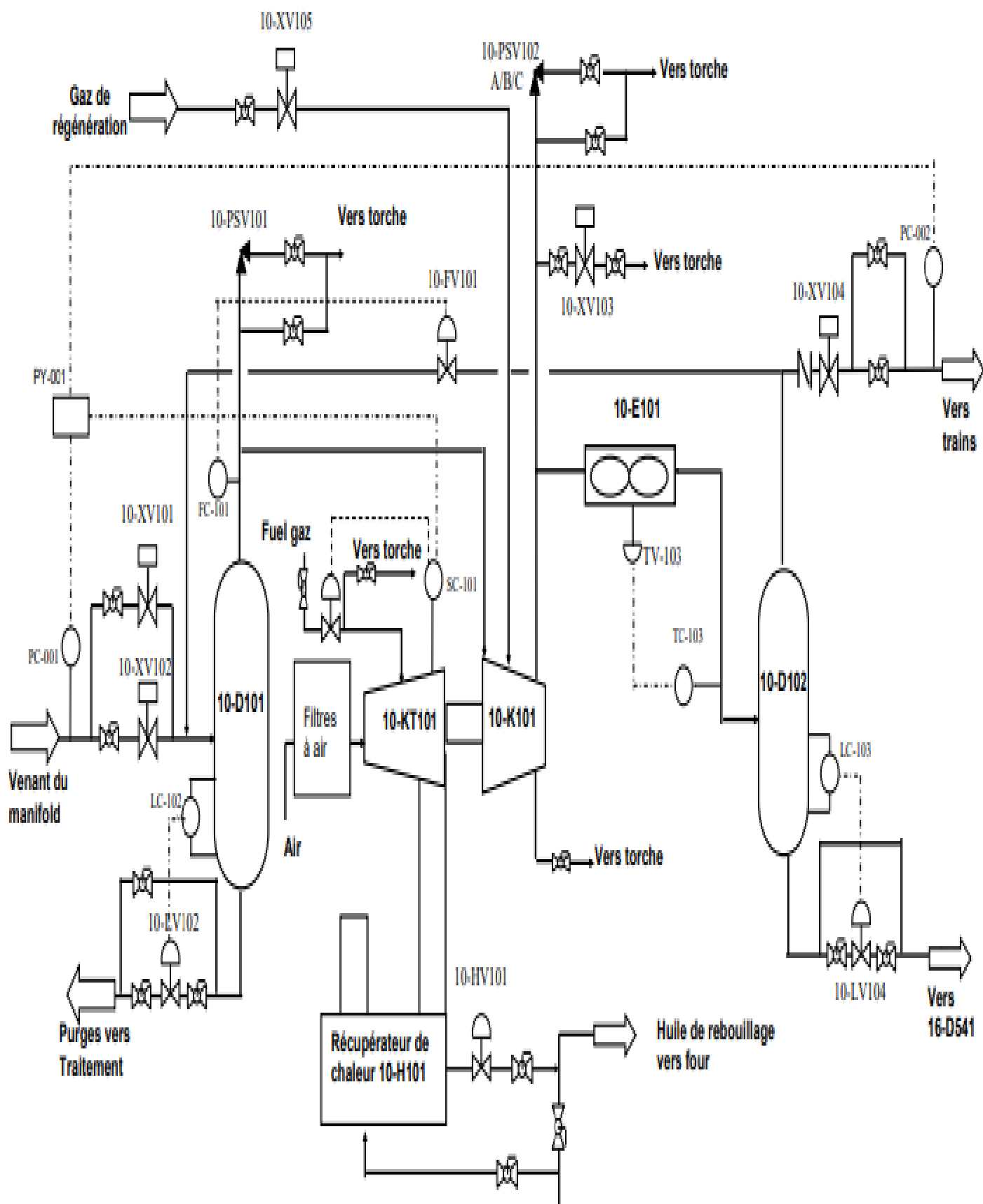
Annexe 2 : SCHEMA DE LA SECTION DE REFROIDISSEMENT ET DETENTE [7].



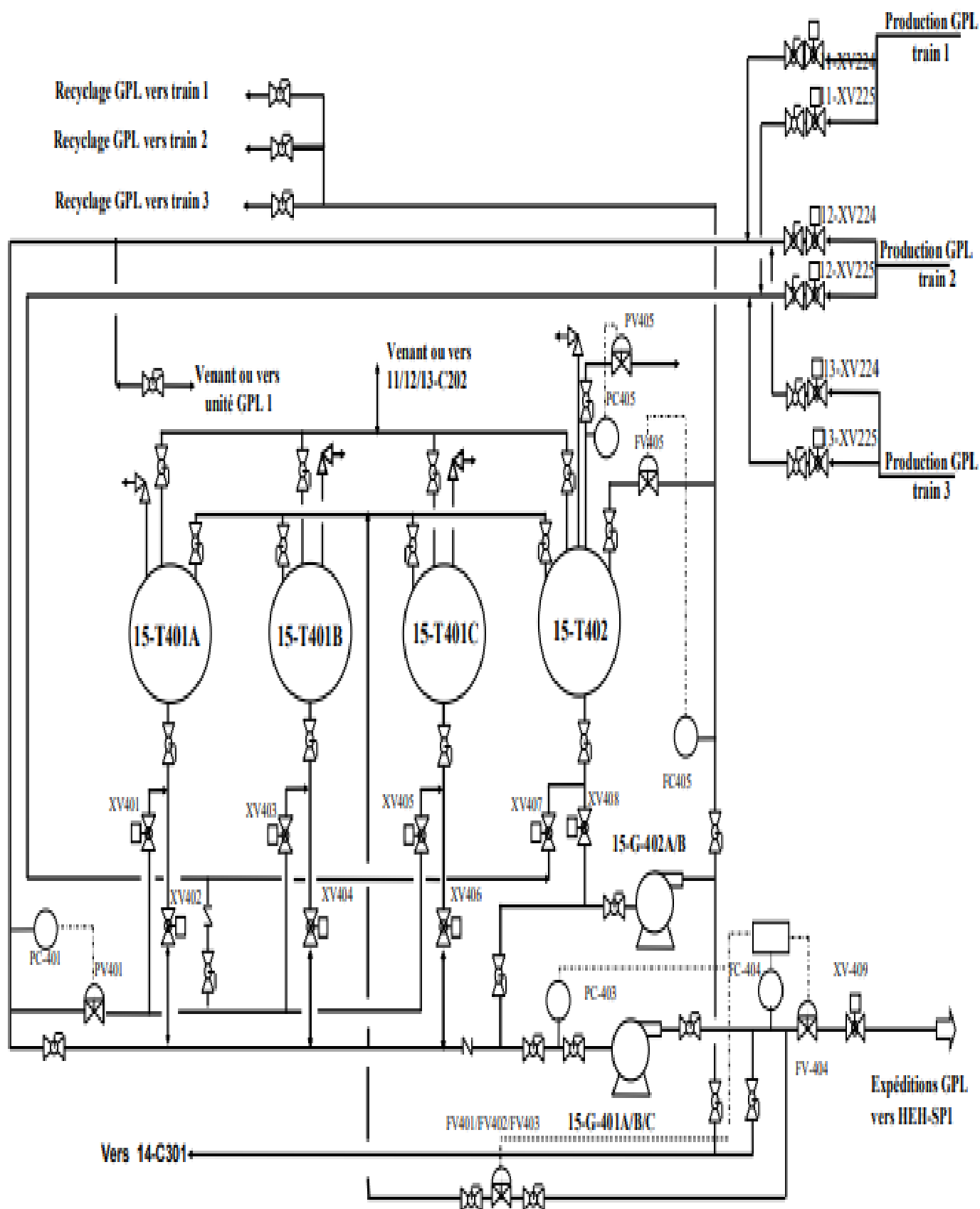
Annexe n 3 : SCHEMA DE PROCESS DE LA SECTION DE DESHYDRATATION [7].



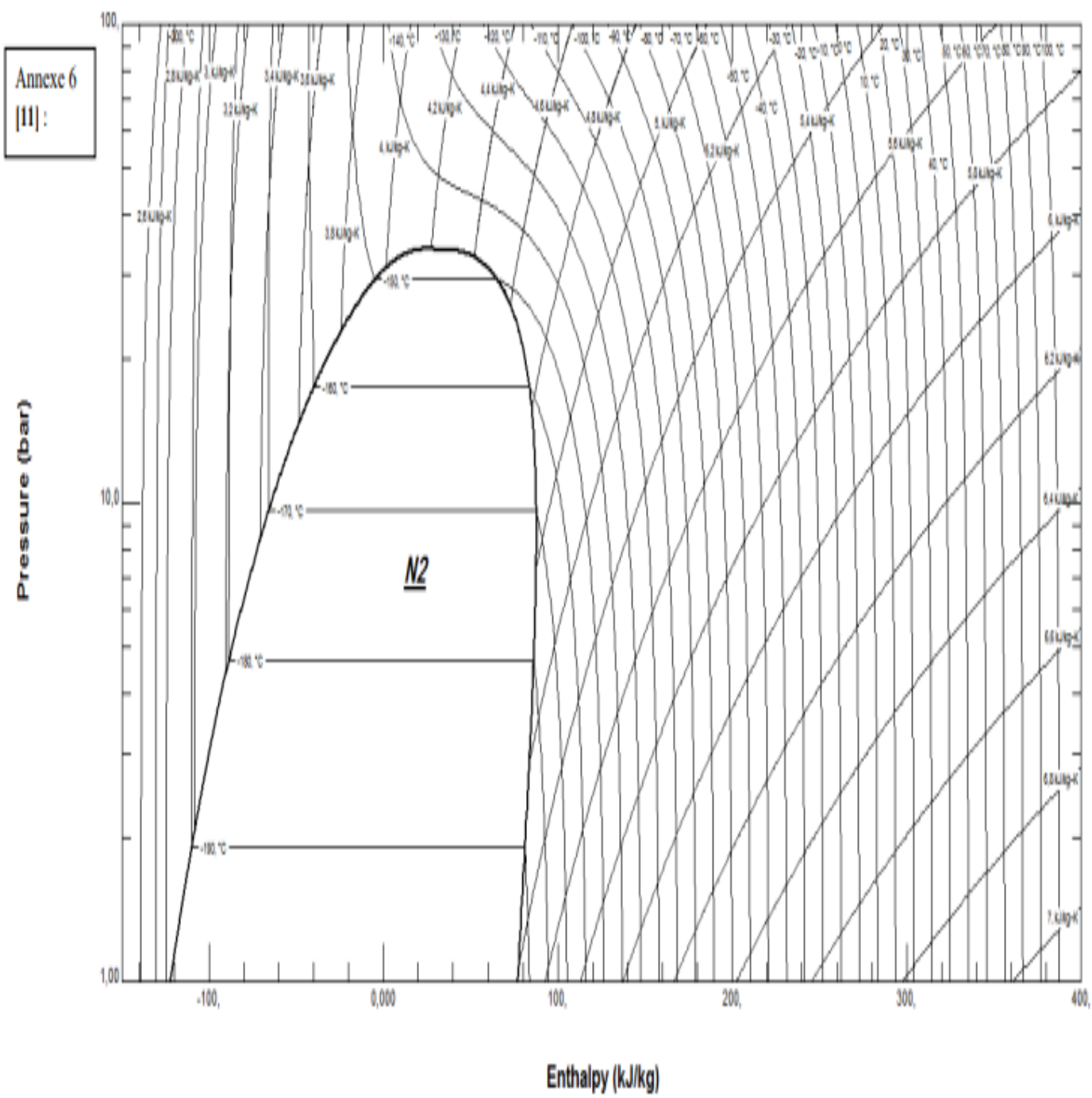
Annexe n 4 : SCHEMA DE PROCESS D'UN BOOSTER (10-KT101)

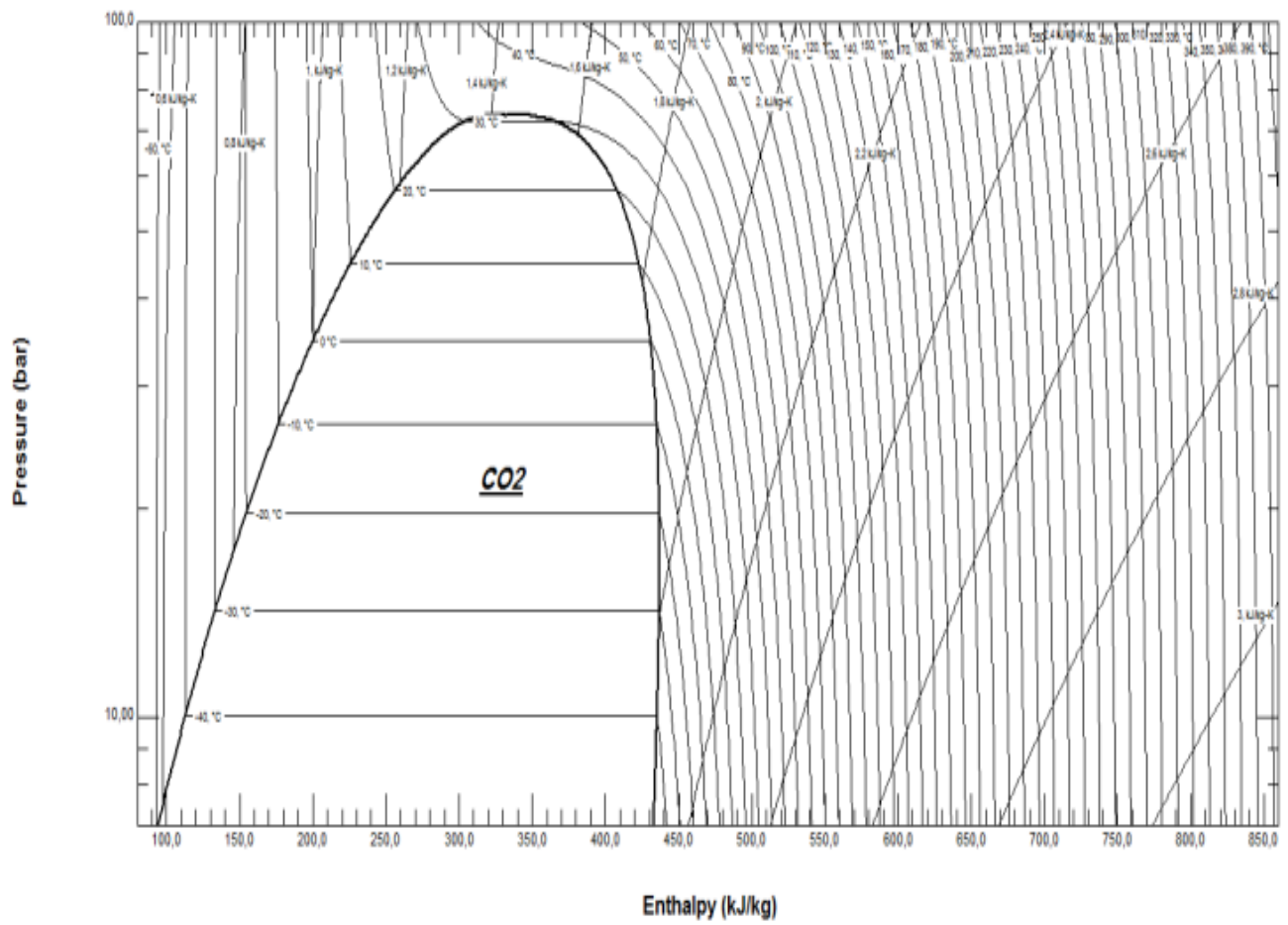


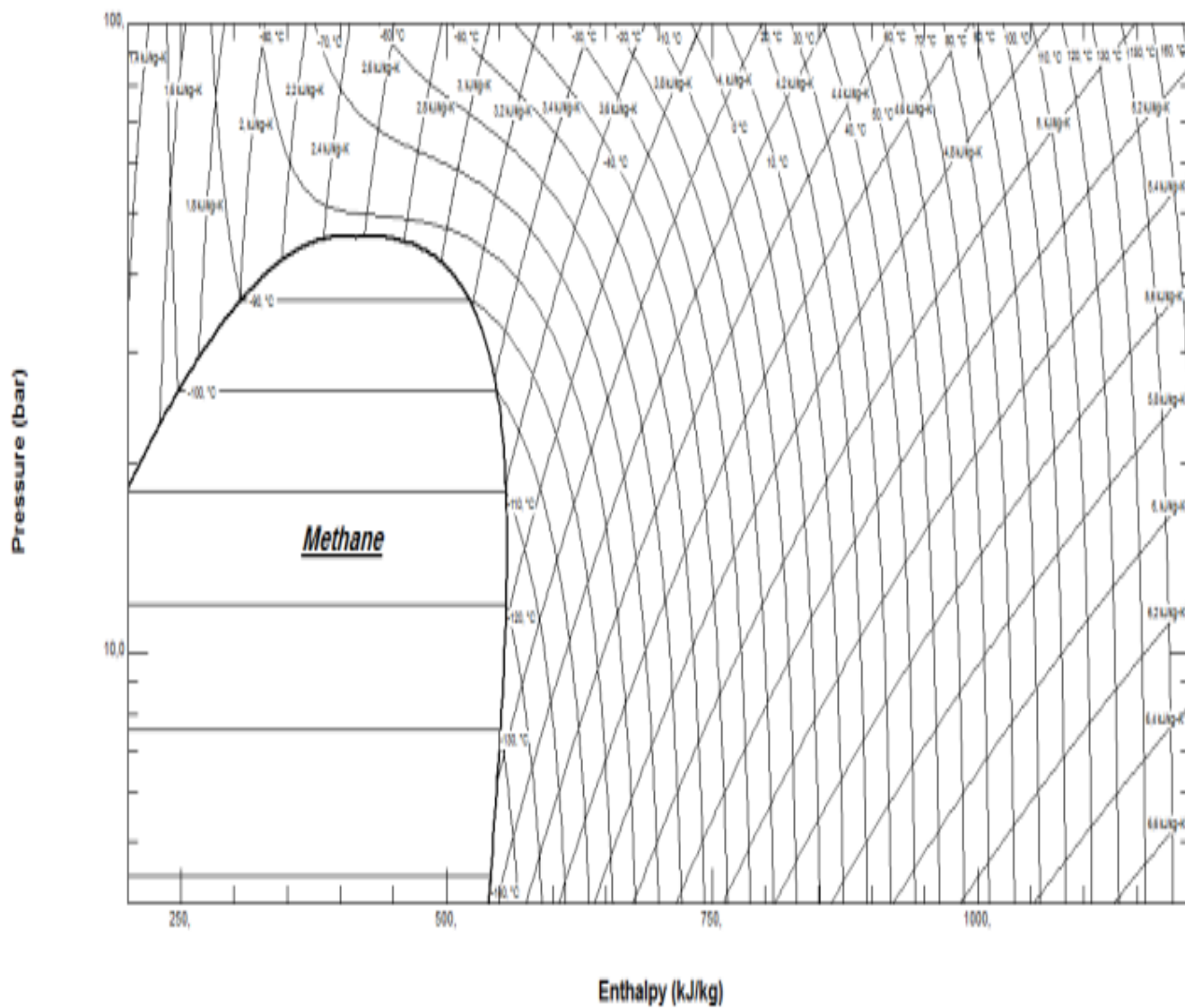
Annexe 5 : SCHEMA DE PROCESS DE LA SECTION DE STOCKAGE-EXPEDITIONS

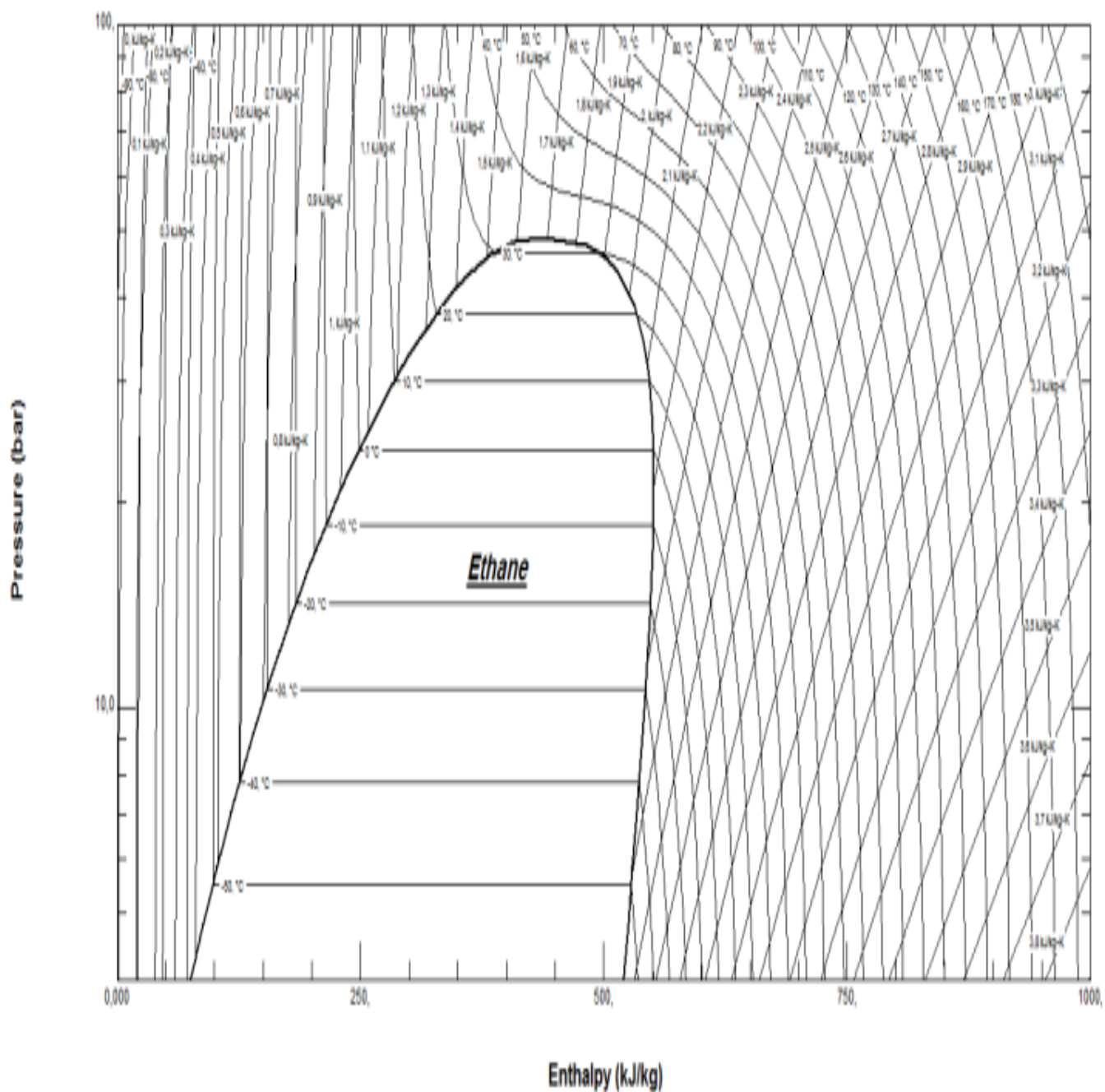


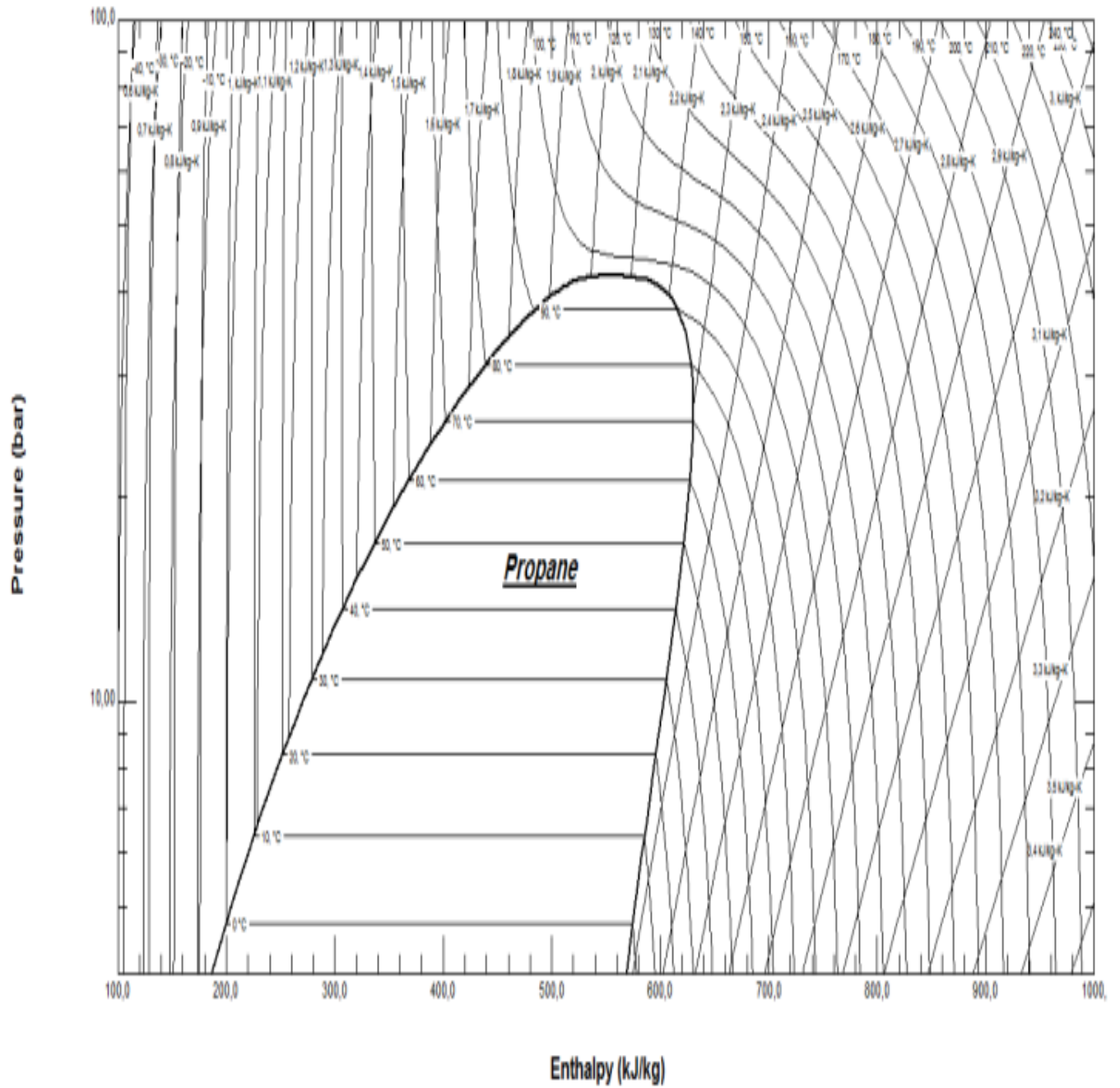
Annexe 6
[II] :

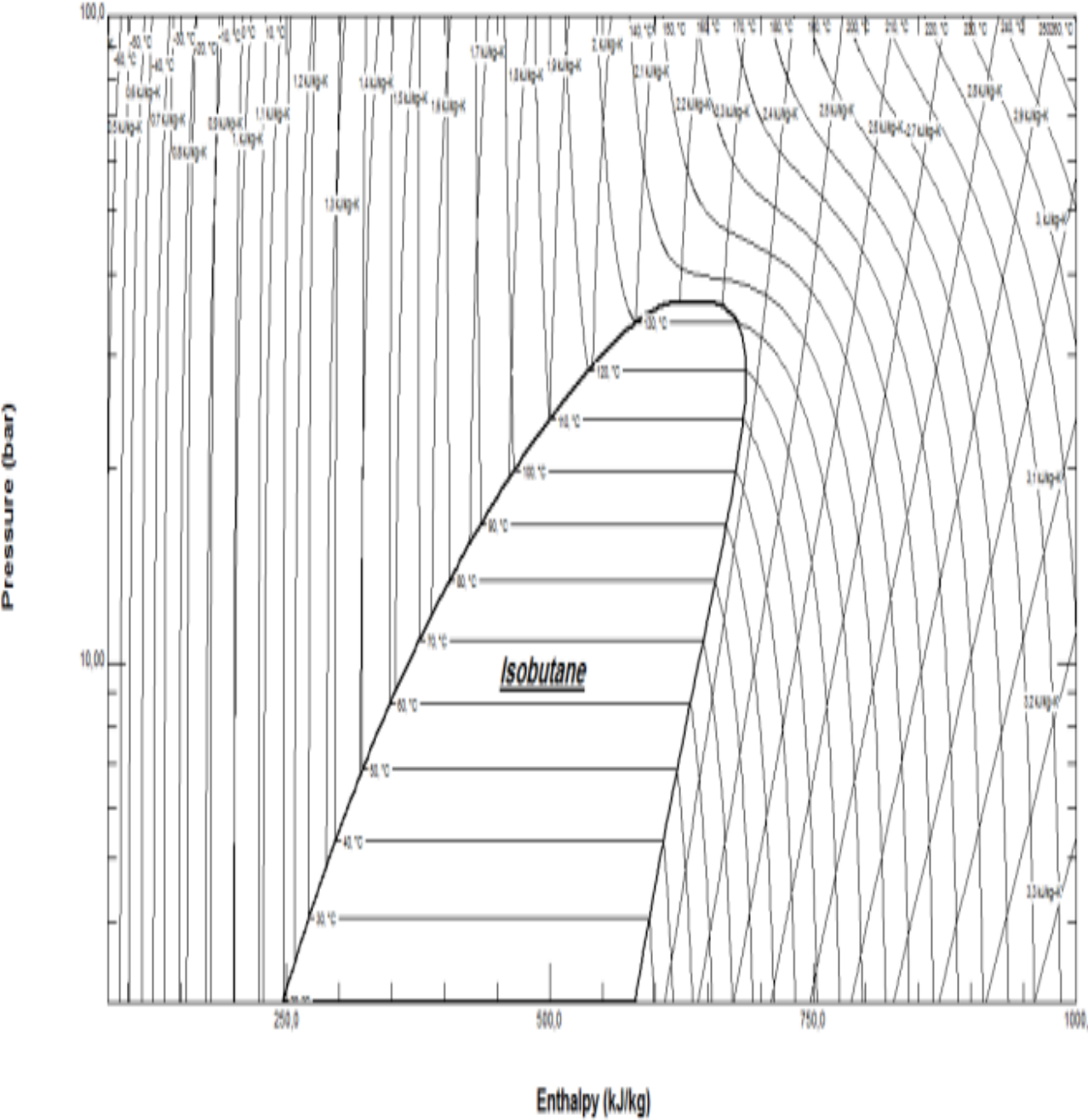


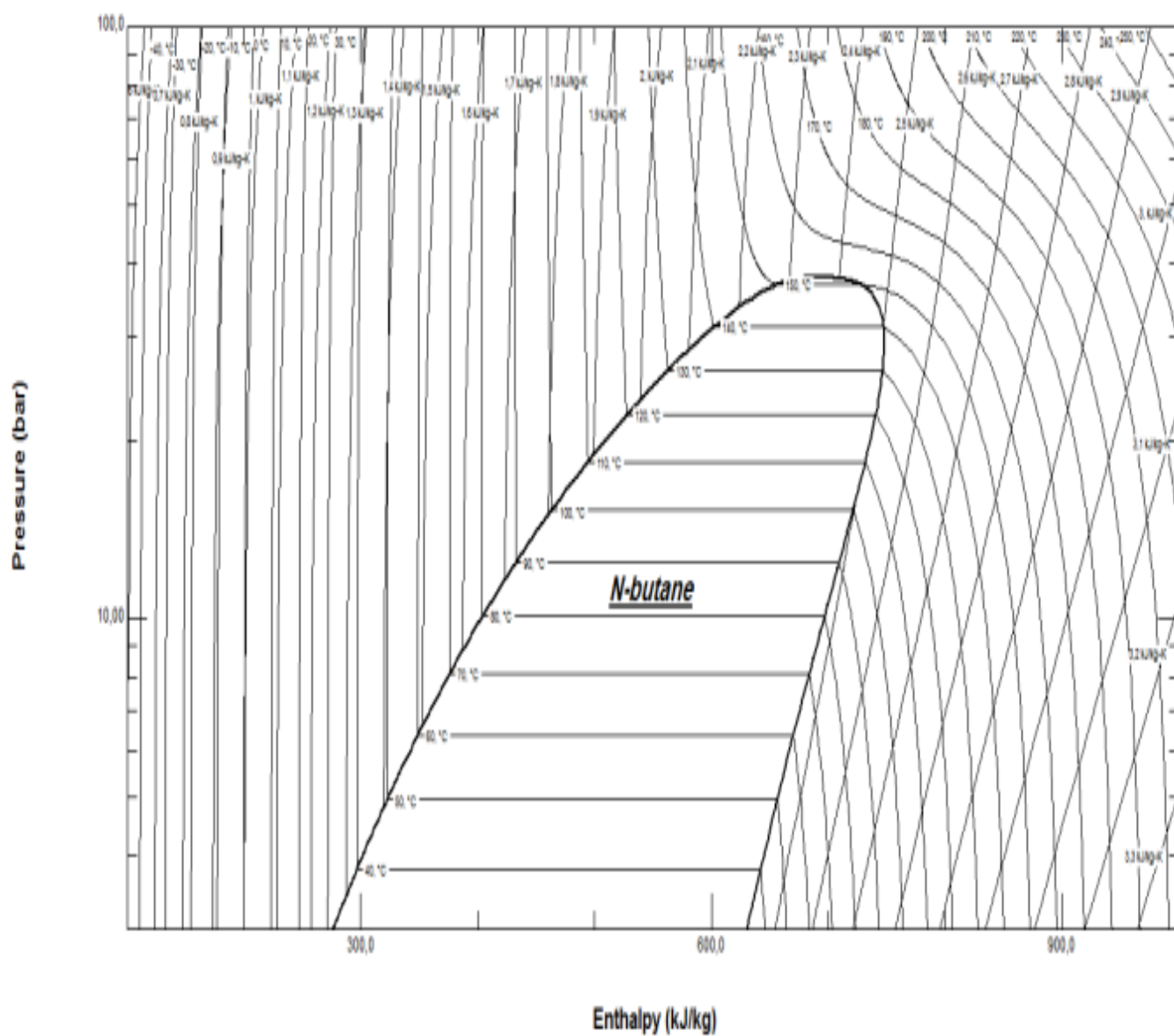


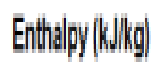


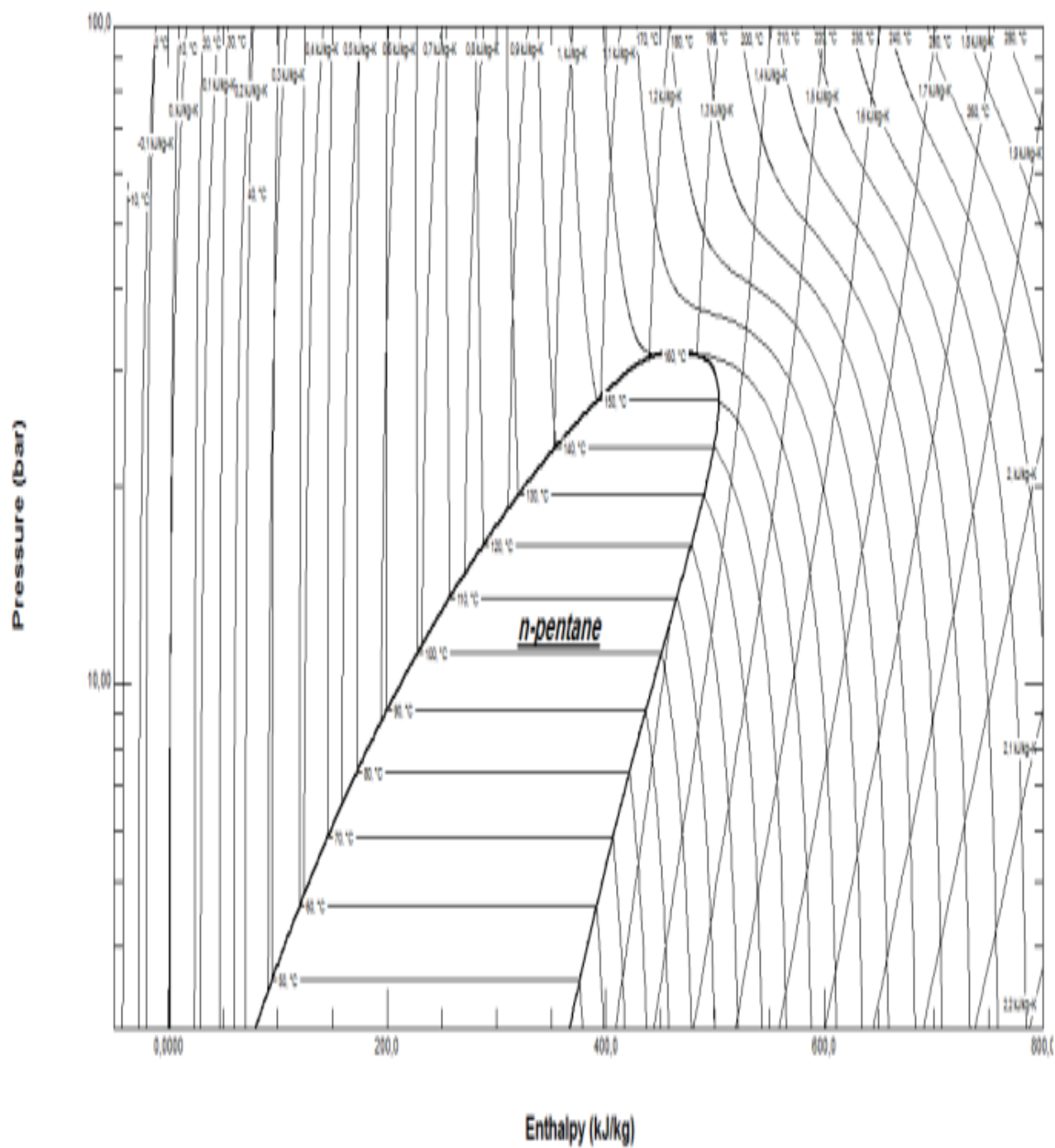


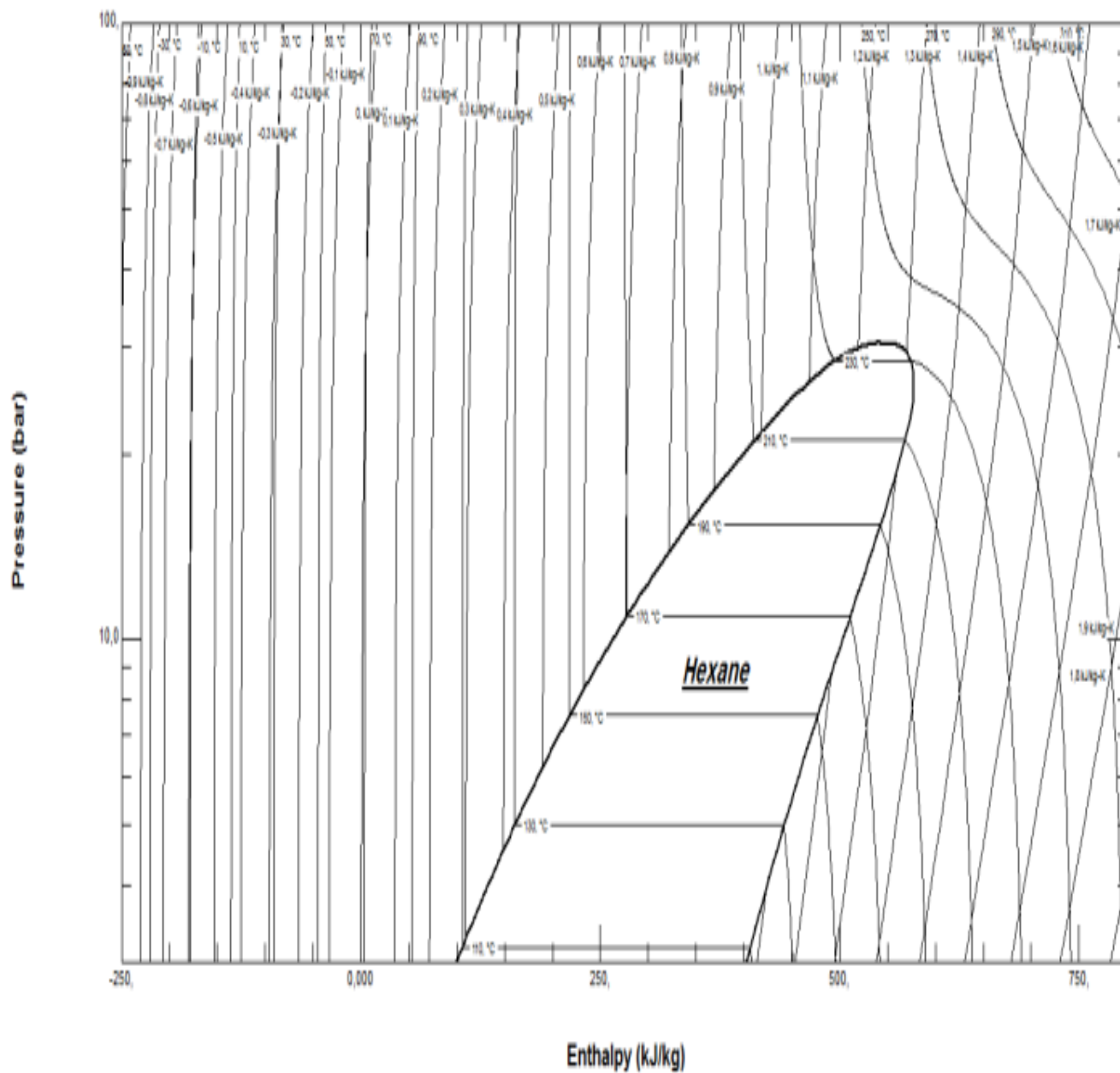






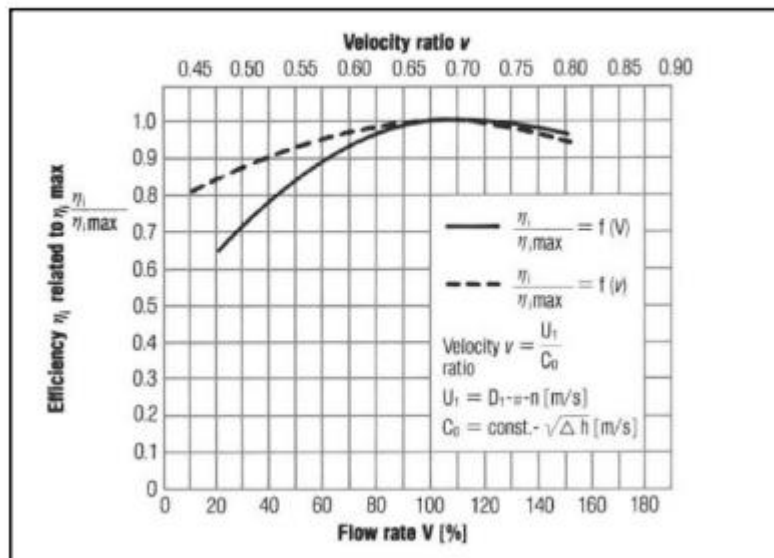








Annexe 7 : Courbe caractéristique fournit par ATLAS COPO -MAFI TRENCH [12].



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