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Optimization of reflux flow rate at the GP1/Z complex Fractionator using Aspen Hysys

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Optimization of reflux flow rate at the GP1/Z complex Fractionator

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Abstract

In this project, attention will be paid to increasing energy efficiency in the fractionation train of the industrial complex GP1/Z (Sonatrach). Using the simulation software package called Aspen HYSYS, this study aims to analyze the effects of changes in the reflux flows on energy consumption and the quality of the final product. It is found that the optimal setting of the reflux flow in case of feeding the fractionator at the load of 240 m^3/h can allow obtaining the energy savings up to 5,355.34 kW. In addition, this thesis will address the possibilities of implementation of new technologies, such as AI and Digital Twins, and develop a model for maintaining the obtained energy efficiency using the proposed concept of "soft sensing."

Keywords: Energy efficiency, Reflux flow optimization, Fractionation, Aspen HYSYS, Soft sensing, Digital Twins, Sonatrach GP1/Z.

ملخص

ركزت هذه الدراسة على زيادة فعالية استخدام الطاقة ضمن سلسلة التجزئة في مركب صناعة GP1/Z (سوناطراك). بناءً على المحاكاة الدقيقة عبر برنامجAspen HYSYS ، تم تقييم تأثير معدلات الارتداد على استهلاك الطاقة ونقاوة الإنتاج. كما أظهرت نتائج هذه الدراسة إمكانية تحقيق طاقة مسترجعة كبيرة بحجم 5355.34 كيلوواط عند زيادة معدل الارتداد في حالة تفريغ يقدر بـ240 م^3/ساعة، وبالتالي خفض النفقات التشغيلية وتقليل البصمة الكربونية. بالإضافة إلى ذلك، تقدم هذه المذكرة رؤى حول تطبيق تقنيات صناعة 4.0، مثل الذكاء الاصطناعي (AI) والتوائم الرقمية. بالنظر في تقديم إطار عمل لمراقبة في الوقت

الكلمات المفتاحية: كفاءة الطاقة، تحسين تدفق الارتداد، عمود التجزئة، Aspen HYSYS، الاستشعار البرمجي(Soft sensing) ، التوائم الرقمية، المركب الصناعي.GP1/Z

Résumé

Cette étude scientifique est centrée autour de l'augmentation de la performance énergétique du train de distillation dans le complexe industriel GP1/Z (Sonatrach). À travers des simulations strictes utilisées dans Aspen HYSYS, l'étude s'intéresse à l'influence de la quantité de reflux sur la consommation d'énergie et la qualité des produits finis. La conclusion obtenue indique que la mise à niveau de la quantité de reflux pour un flux de 240 m^3/h permet une économie importante d'énergie de 5 355,34 kW et une diminution des coûts de fonctionnement. Par ailleurs, ce mémoire traite de l'incorporation de l'industrie 4.0 dans le domaine de l'industrie chimique et plus précisément de l'intelligence artificielle et de la technologie jumeau numérique. Par le biais d'une proposition de cadre de supervision de type « Soft sensing », l'étude propose une voie vers une performance durable des gagnants de cette optimisation d'exploitation dans le complexe industriel GP1/Z.

Mots-clés : Efficacité énergétique, Optimisation du débit de reflux, Aspen HYSYS, Capteur logiciel (Soft sensing), Jumeaux numériques, Complexe industriel GP1/Z.

Dedication

I dedicate this work to my beloved parents, whose unconditional love, endless support, and sacrifices have been the foundation of my success. Your encouragement has always been my greatest motivation.

To my family, for their constant support, patience, and belief in me throughout this journey.

To my friends, who stood by me during the most challenging moments and shared with me the joy of achievement.

To my professors and mentors, whose guidance and knowledge have shaped my academic path.

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My sincere thanks also go to **Dr. Boubegra Naima**, who has done me the immense honor of presiding over the jury for this manuscript. I truly appreciate the time you have taken to evaluate this work.

I am particularly grateful to **Dr. Sefir Yamina**, who kindly accepted to examine this work and provide her critique. Your constructive remarks and suggestions will be of great value in improving this manuscript.

Finally, I wish to extend my warm thanks to all the faculty members at the University, as well as the professional engineers and staff who supported me, provided essential data, or guided me during my practical work and graduation internship.

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General Introduction

Liquefied petroleum gas, known as LPG, of which Algeria is one of the world's leading producers and exporters, is one of the priorities of SONATRACH's development plans and energy policy.

Given the ever-increasing demand for LPG on the domestic and international markets and the significant output from oil fields, each country is developing its own means of implementing a development plan to anticipate substantial increases in production. In this context, SONATRACH already has significant LPG production, transport, and separation facilities that enable it to market and sell LPG on both the local and international markets. However, it would still be essential to opt for maximum exploitation of this installed capacity, within tolerable limits, which would be beneficial in economic terms (cost/revenue) and in terms of production management (flexibility and maintenance). This has led us to carry out a study in this context.

We must try to find the sources of this problem, identify the causes, and seek solutions, without disrupting the normal operation of the complex on the one hand, and without any investment on the other. Our work approach comprises two parts: The first part presents the GP1Z complex, followed by a description of the LPG separation process. The second part is devoted to a practical study based on the simulation of different scenarios, with a comparison and interpretation of the results, and calculation of the energy gain.

Our work approach consists of two parts:

The first part focuses on a presentation of the GP1Z complex and general information on LPG, followed by a description of the LPG separation process, and finally general information on distillation columns.

The second part is devoted to a practical study based on the simulation of different cases, with a comparison and interpretation of the results.

Finally, we conclude our work with a summary of the results obtained, followed by some recommendations

1

Complex Presentation

I.1 Introduction

Southern Algeria has abundant natural resources, including hydrocarbon reserves, which account for the wide range of products related to oil and gas deposits. To separate these products and their derivatives, our country has invested huge sums of money in acquiring and installing large processing complexes, which are divided into several units, as is the case with the GP1/Z complex.

I.2 Presentation of the GP1/Z complex

I.2.1 History

The GP1/Z complex is one of six liquefaction complexes belonging to the downstream division of the national company SONATRACH. It is located between the Mers El Hadjaj thermoelectric power plant to the east and the LNG complexes to the west, covering an area of 120 hectares. It was built with the assistance of a Japanese consortium, IHI-ITOCHU, under a turnkey contract in three construction phases. The first phase was completed on September 2, 1984, the second phase on November 20, 1998, and the third phase on February 24, 2010 **[1].**

In 1983, the complex had four LPG processing trains, enabling it to produce 4.8 million tons per year. Following the acquisition of two additional trains (extension of the complex in 1998), production increased to 7.2 million tons per year. After the start of the third phase, production is estimated at 10.8 million tons per year.

The complex aims to process crude LPG from various fields in southern Algeria in order to produce propane and butane for the domestic and international markets. It is known as JUMBO-LPG due to its large production capacity.

I.2.2 Main facilities of the complex

The main facilities at the GP1/Z complex are:

- 09 LPG processing trains.
- 02 boil-off liquefaction units.
- 22 storage spheres for feedstock, each with a capacity of 1,000 m^3.
- 04 Low-temperature propane storage tanks, each with a capacity of 70,000 m^3.
- 03 Low-temperature butane storage tanks, each with a capacity of 70,000 m^3.
- 01 low-temperature butane/propane storage tanks, each with a capacity of 70,000 m^3.
- 04 Storage spheres for ambient products (propane and butane) with a capacity of 500 m^3 each.
- 01 Gasoline storage spheres with a capacity of 500 m^3.
- De-mercuriation unit.
- 05 control rooms.
- 01 Electrical station powered by SONELGAZ.
- 04 generators providing backup power for the complex.
- 02 Loading docks capable of accommodating ships with a capacity from 4k to 5k tons.
- One truck loading ramp.
- A seawater pumping station.
- A remote surveillance system **[1].**

I.3 Organization of the complex

The description of the structures allows us to understand the geographical location, staffing levels, objectives, and role of each department. This gives us an understanding of how the entire GP1/Z complex operates The GP1/Z complex is managed according to a well-defined organizational chart in order to ensure effective control of tasks. It consists of a general management team, two deputy management teams, and control departments, as shown in the following organizational chart **[1].**

Provides information on the functioning of the GP1/Z complex:

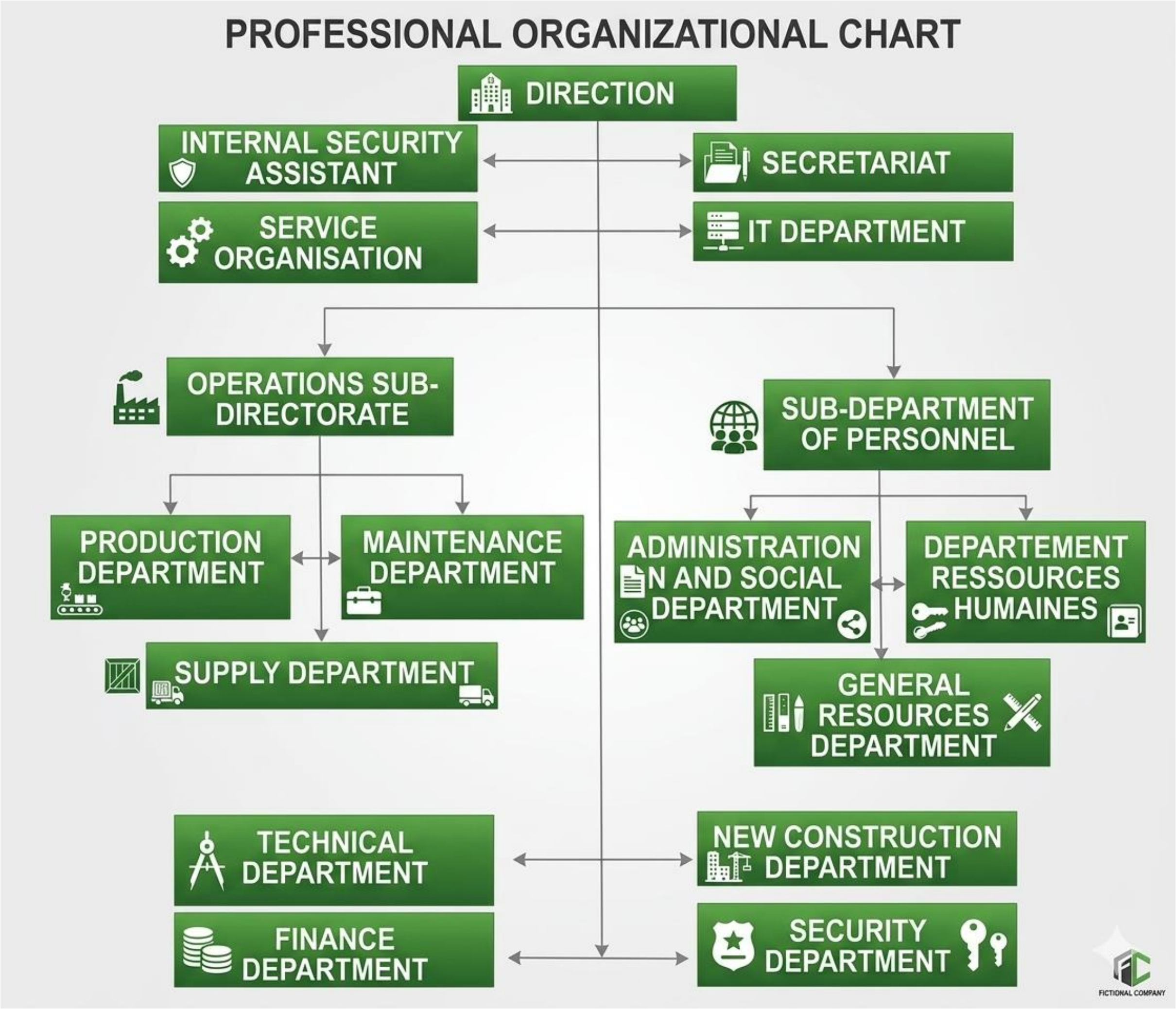


Figure 1 Organization chart of the complex

I.3.1 Technical Department

The technical department reports to the complex management team and acts as the interface between internal and external parties. Its main mission is to study installation projects, monitor operating parameters, and control the quality of equipment, utilities, and finished products. The department comprises four services:

a) **Design department:** This department is staffed by a group of engineers responsible for ensuring that equipment and installations comply with operating parameters.

b) **Inspection Department:** This department is responsible for inspecting technical equipment, monitoring all machines to ensure they are operating optimally, and following up on maintenance work.

c) **DCS "Distributed Control System" service:** This is a digital control and command system (SNCC) responsible for monitoring, improving, and updating (following new technology) the latter.

d) **Laboratory Service:** This service is responsible for controlling finished products (propane and butane) and finished products in circulation at various points in the process.

I.3.2 Production Department

The production department reports to the operations sub-division. This department manages all LPG (propane and butane) production and consists of three services:

a) **Manufacturing department:** responsible for the production of finished refrigerated and ambient propane and butane products. It also monitors the condition and operating status of the facilities at the train levels.

b) **Storage and shipping service**: Responsible for storing the finished product and shipping it by ship and truck. There are two types of storage:

- **Low-temperature storage:** intended for the international market.
- **Room temperature storage**: intended for the domestic market.

***c)* Planning and scheduling department:** This department is responsible for planning monthly production schedules, analyzing production variances between forecasts and actual results, and preparing production reports.

I.4 General information on liquefied petroleum gas (LPG)

I.4.1 History

The discovery of LPG (liquefied petroleum gas) is much more recent than that of petroleum. It dates back to December 24, 1910, in Virginia (USA), when H. Stukeman, an engineer at the Riverside Oil Company, succeeded in obtaining the first 658 liters of liquid LPG.

The first use was for oxycutting (oxy-fuel cutting) in 1911, where LPG proved to be an excellent substitute for acetylene. In 1912, a domestic installation was tested. In the same year, LPG fuel for cars took its first steps **[2].**

I.4.2 Definitions

LPG is a mixture of hydrocarbons consisting mainly of propane and butane. Under normal pressure and temperature conditions, LPG is in a gaseous state, but it is easily liquefied at ambient temperature under an average pressure of 4 to 18 bar. This characteristic makes it easier to store and transport compared to gases that require very high pressures (methane, ethane) **[3].**

I.4.3 Processes for obtaining LPG

Liquefied petroleum gases are mainly obtained from:

- Crude oil refineries, either during the distillation of crude oil or during the cracking or reforming of heavier products.
- During the separation of natural gas (NG) from crude oil in order to collect condensates (propane, butane, light gasoline).
- During the direct recovery of gases separated from crude oil in production fields (gas associated with oil) **[3].**

I.4.4 Properties of LPG

a) **Odor and color:** LPG is colorless and virtually odorless. For safety reasons, it is given a distinctive odor using appropriate substances (mercaptans).

b) **Vapor pressure:** LPG has a vapor pressure at 20°C equal to 2 bar for butane and 8 bar for propane. This value must not exceed a threshold incompatible with safety regulations during periods of high heat (summer).

c) **Boiling point:** The boiling points at atmospheric pressure are -6°C for butane, -42°C for propane, and -25°C for LPG.

d) **Calorific value:** LPG has a high calorific value, equal to 12,200 $Kcal/Nm^3$ for propane and 11,800 $Kcal/Nm^3$ for butane.

e) **Octane rating:** LPG has a naturally high research octane number (RON) that easily reaches 98. In addition, its motor octane number (MON) is slightly higher than that of conventional gasoline.

f) **Density:** Under normal temperature and pressure conditions, LPG is heavier than air, and its density decreases as the temperature rises, e.g., 0.534 at 38°C.

g) **Corrosion:** LPG is non-corrosive to steel and generally corrosive to copper, copper alloys, and aluminum.

h) **Explosiveness and flammability:** LPG is an explosive gas when mixed with air or oxygen. The lower flammability limit of LPG is very low and, as the flash point of LPG is very low, it ignites easily in the event of a leak.

l) **Physiological toxicity:** Inhaling large quantities of LPG can cause a slight narcotic effect; the acceptable concentration in air is 1 ppm for propane **[4].**

I.5 Areas of use for LPG

LPG has a bright future ahead of it, as global demand continues to grow, both for petrochemicals and for its traditional uses as a fuel. Some of the uses of **LPG** include: **[3]**

I.5.1 Domestic applications

This is the most important use of these gases, as they are used in:

- Heating
- Air conditioning

I.5.2 LPG/C (fuel)

L**PG** can be used as a fuel, often referred to as **LPG/C**. Its combustion produces very low pollutant emissions. It is composed of **55%** butane and **45%** propane. It contains no lead, sulfur, or benzene, making it a clean fuel. It is also economical.

I.6 Specifications for commercial propane and butane

The specifications for commercial propane and butane are given in the following table **[5]**:

Table 1 Characteristics of commercial propane and butane at GP1/Z

Characteristics	**Propane**	**Butane**	**Analysis methods (Standards)**
Molar mass (g/mole)	44	58	/
Density at 15°C	0.5068	0.5772	ASTMD 2598-1657
Relative vapor pressure at 37.8°C (kg/cm2)	12.7	3.1	ASTMD 2598-1267
Water content	No water	No water	ASTMD 2713-76
Boiling point at 760 mm Hg (°C)	– 40	0	ASTM D 1837

Figure 2 Panoramic Industrial Overview [5]

Figure 3 Close-up of the Fin-Fan Air Coolers [6]

2

Process description

II.1 Introduction

The GP1Z complex comprises nine (09) trains in the process area, and common facilities for off-site loading, storage, loading, and reliquefication of vapors. Each train in the process area has been designed for a nominal annual production of one million tons of products (commercial propane and butane) **[1].**

II.2 LPG storage section

This section (Fig. 2) is designed to maintain stable operation and ensure autonomy of more than 10 hours to supply the trains with raw LPG in the event of a pumping shutdown. It is also intended to receive either the recycle stream or off-specification product returning from downstream sections **[6].**

The feedstock is delivered by RTO (Région Transport Ouest) to the GP1Z complex in raw LPG from various fields in the south (Hassi Messaoud, Hassi R'mel, Alrar, In Amenas, Tin-Fouye Tabankort, and Rhourde Nouss). It is transported to storage via a 24-inch pipe. Before storage, the raw LPG first passes through a manifold equipped with a pressure controller to maintain stable operating pressure, then through filters, each equipped with a PDI ($\Delta P=0.5$) to signal clogging.

The LPG then passes through the degassers to separate and purge the vapors from the mixture to the feed spheres.

Once the feedstock has been filtered and degassed, it then passes through six (06) mercury strippers to reduce its mercury content to around 5 nanograms/Nm^3.

After passing through the demercurizers, the feedstock passes through rectifiers to create laminar flow in order to obtain an accurate reading of the LPG flow rate and density. The raw LPG is then transported to the feedstock spheres at a pressure of 18-22 kg/cm2 and a temperature of 5-41.8°C.

The load is stored in 22 spherical tanks, each with a capacity of 1000 m^3 , at pressures varying between 7 and 9 bar. The diagram of the LPG load storage section is shown in the following figure.

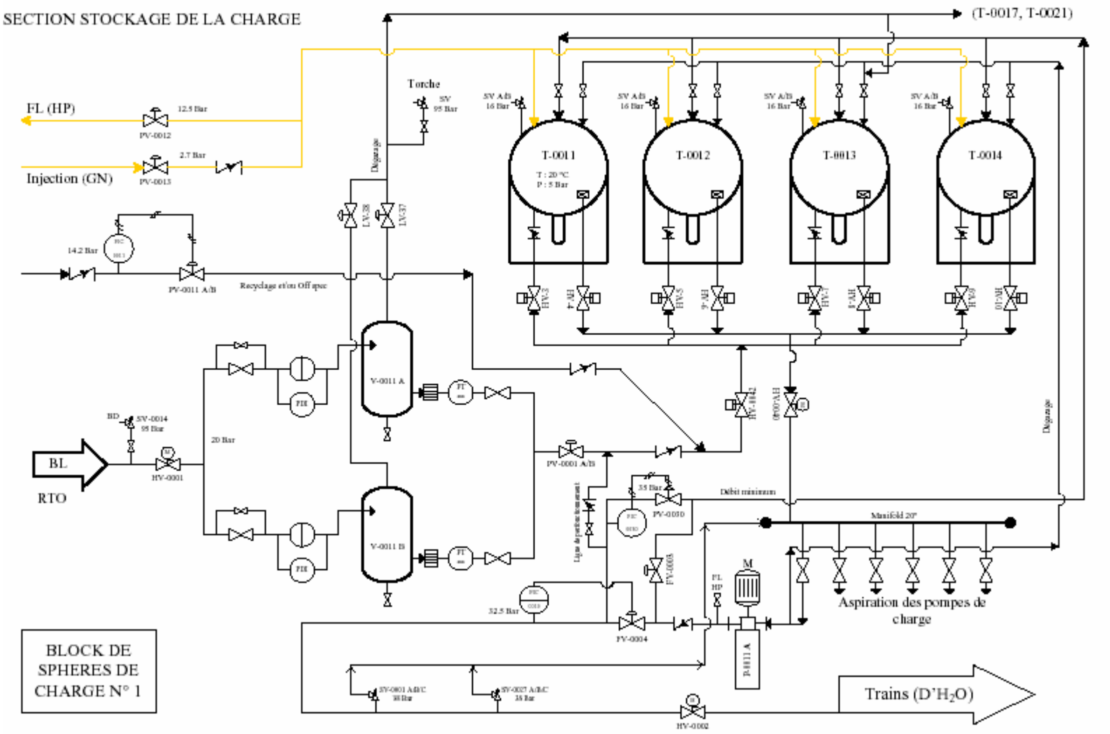


Figure 4 Diagram of the LPG storage section [8]

The raw LPG is then transported to the nine process trains, which operate in parallel. This operation is carried out by 14 multistage centrifugal pumps with sumps, which draw from the sump and discharge into the common manifold to supply the process trains at a pressure of 30 kg/cm2.

II.3 Dehydration section

The purpose of the dehydration section (Fig. 3) is to reduce the dissolved water content in the LPG from 100 ppm to 5 ppm by weight in order to prevent the formation of ice and frost plugs in the cold parts of the installation (refrigeration).

This section comprises three molecular sieve adsorption columns. At any given time, one column is in service (adsorption), another is undergoing regeneration, and the last is on standby. The LPG passes through the dryer from bottom to top, and moisture is extracted as the LPG passes through the molecular sieves for 36 hours. Once this time has elapsed, the dryer automatically switches to regeneration mode. **[9]**

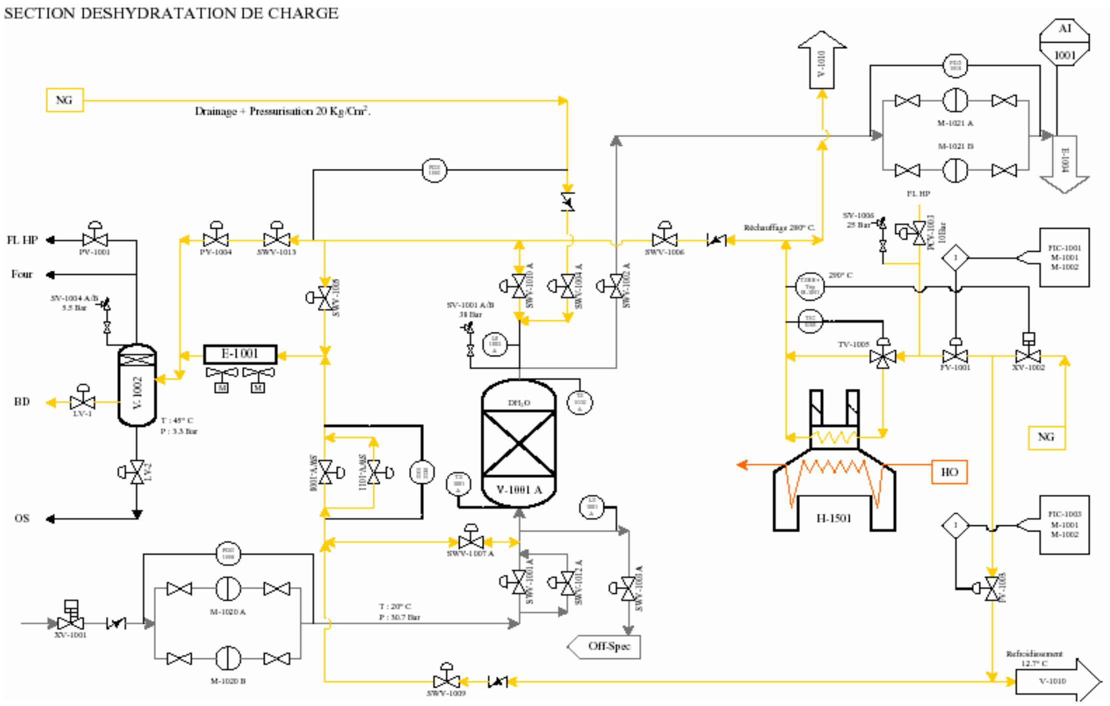


Figure 5 Diagram of the dehydration section [9]

Regeneration involves the following steps:

- **Drainage (duration 1 hour)**: The dryer is drained by injecting natural gas at a pressure of **20 kg/cm^2**. The remaining LPG is transported to the loading spheres.
- **Depressurization (duration 30 minutes):** This sequence serves to reduce the pressure in the dryer from **20 kg/cm^2**to **3 kg/cm^2** by evacuating the NG contained in the dryer to the fuel gas section.
- **Heating (duration 11 hours):** Reheating is carried out using NG heated in the furnace to a temperature of **280°C.** It passes through the dryer from top to bottom to evaporate the water contained in the molecular sieves.
- **Cooling (duration 5 hours):** As the sector is hot after the reheating sequence, it is cooled by NG brought to a temperature of 12 to 45°C and a pressure of **3 kg/cm2**.
- **Pressurization (duration 30 min):** Before filling the column with LPG, an operating pressure of **20 kg/cm^2** must be reached. This is done by introducing high- pressure NG.
- **Filling**: This operation consists of putting the dryer on standby.

II.4 Separation section

The feed rate to the separation section depends on the quality of the feed. Each train must produce 1 million tons per year of commercial propane and butane, so the required feed rate of raw LPG is 1 million tons per year, plus by-products. The higher the ethane and pentane content, the higher the required feed rate. **[7]**

The minimum capacity of each train is 50% of its normal capacity. At this flow rate, each column must be operated with sufficient reflux and reboiling to ensure stable operation. if a product in a train drift and falls outside specifications, all products in that train must be recycled in order to maintain the composition of the load in the spherical tanks as much as possible. However, this is not necessarily true for pentane produced. In other words, if product delivery must be stopped for any reason, all columns must be put into total reflux operation until continuous operation can be resumed. It should be noted that the off-spec product recycling line allows for the recycling of products from one train at full capacity, which is equivalent to the production of two trains operating at 50% of their capacity.

When the C2/(C2 + C3) ratio is equal to or greater than 4.8 mol%, the de-ethanizer must be in operation.

Similarly, when the ratio of C5/(C4 + C5) is equal to or greater than 1.75 mol%, the de-pentanizer must be in operation.

II.4.1 Fractionator

After the dehydration section, the raw LPG enters the separation section, feeding the V-N101 fractionator. The LPG first recovers heat from the propane produced at the bottom of the drift in preheater No. 1, E-N004, then recovers further heat in preheater No. 2, E-N005 A~D, this time from the product at the bottom of the fractionator.

The LPG is finally brought to its bubble point in preheater No. 3, E-N013, which uses the heat transfer fluid with control of the outlet temperature of E-N013. At the outlet of E-N013, the load flow is adjusted according to the set point of the flow controller.

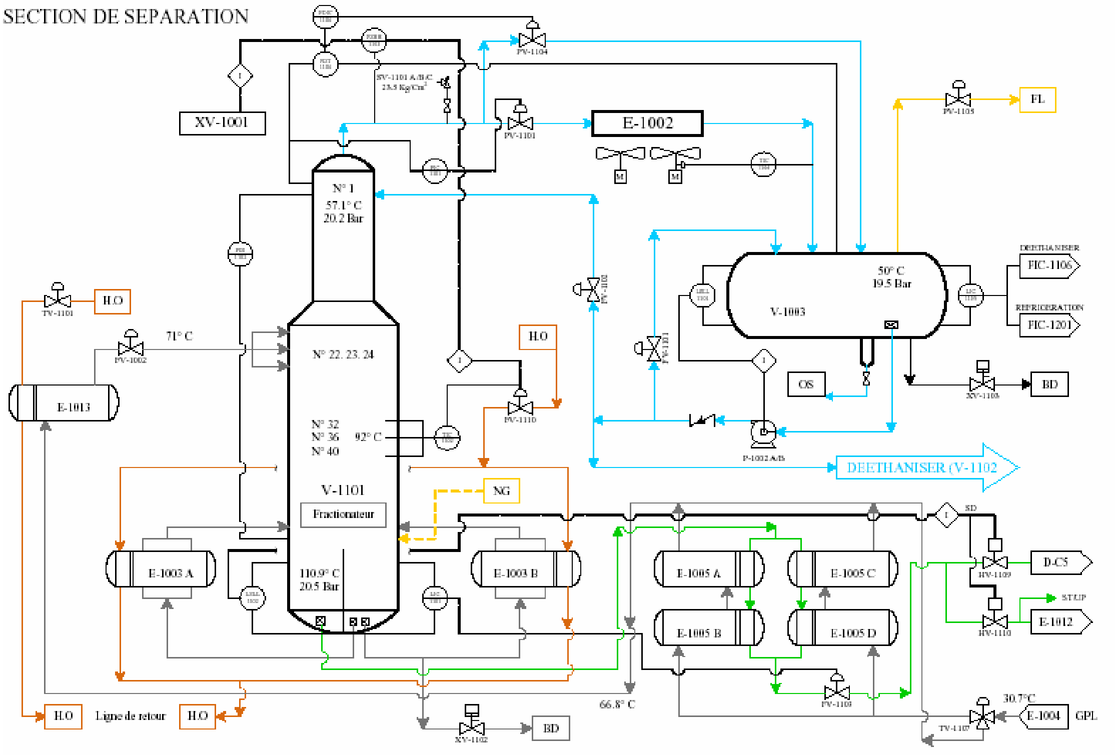


Figure 6 Schematic diagram of the fractionator [9]

In the fractionator, the raw LPG is separated into a butane product at the bottom and a liquid propane product at the top. The column comprises 55 valve trays. The fractionator is adjusted to achieve the desired separation of propane and butane, while maintaining the desired recovery rate. The pressure at the top of the fractionator is kept constant by a valve in the overhead vapor line to the E-N002 air condenser. The pressure in the reflux tank is maintained by a pressure differential controller and a hot gas bypass E-N002. The temperature of the condensates leaving E-N002 is kept constant by adjusting the fan blade pitch.

The head vapors from V-N101 are completely condensed in E-N002. Part of the condensate recovered at V-N003 is taken up by the reflux pump P-N002 and returned to V-N101 as cold reflux, under the control of the excess liquid flow at the outlet of P-N002, namely the head product, is sent to the V-N102 drift under the control of the flow rate controlled by the V-N003 level controller.

The liquid at the bottom of the fractionator is essentially butane with a variable pentane content. Depending on the pentane content of the feed, the butane may or may not undergo depentanization. Under normal operating conditions, the depentanizer is not necessary. This explains the small number of columns planned (02) for the nine trains.

II.4.2 Deethanizer

In order to produce commercial propane of varying purity, the top products from the fractionating column feed into the deethanizer (Fig. 5). The latter is a fractionating column equipped with 25 valve trays. The propane exits at the bottom of the column at a temperature of 62°C and goes directly to the first preheater of the fractionator, then passes to the E-N011 air coolers where it is cooled before entering the refrigeration section, where it is cooled to -38°C, and finally to the storage spheres to be shipped to the domestic market. The ethane-rich gas leaving the top of the de-ethane unit is used as fuel for the furnace.

II.4.3 Depentanizer

There are two common depentanizers (fig. 6) for the 09 trains. The role of a depentanizer is to remove traces of pentane contained in butane. The column consists of 50 valve trays. The butane leaving the top of the depentanizer, mixed with the rest of the non-depentanized butane, is sent to the refrigeration section. The pentane collected from the bottom of the depentanizer is cooled by an air cooler and sent to ambient storage. This operation is often bypassed because the LPG load arrives with a very low pentane content.

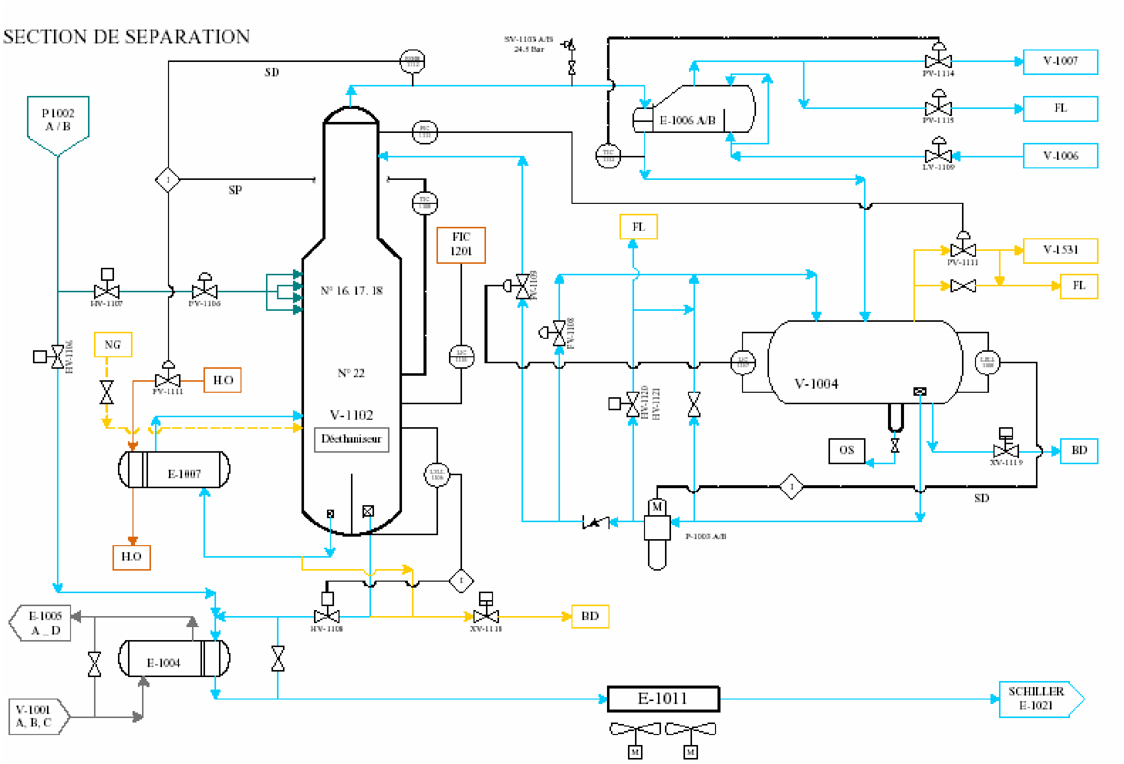


Figure 7 Schematic diagram of the de-ethanizer [9]

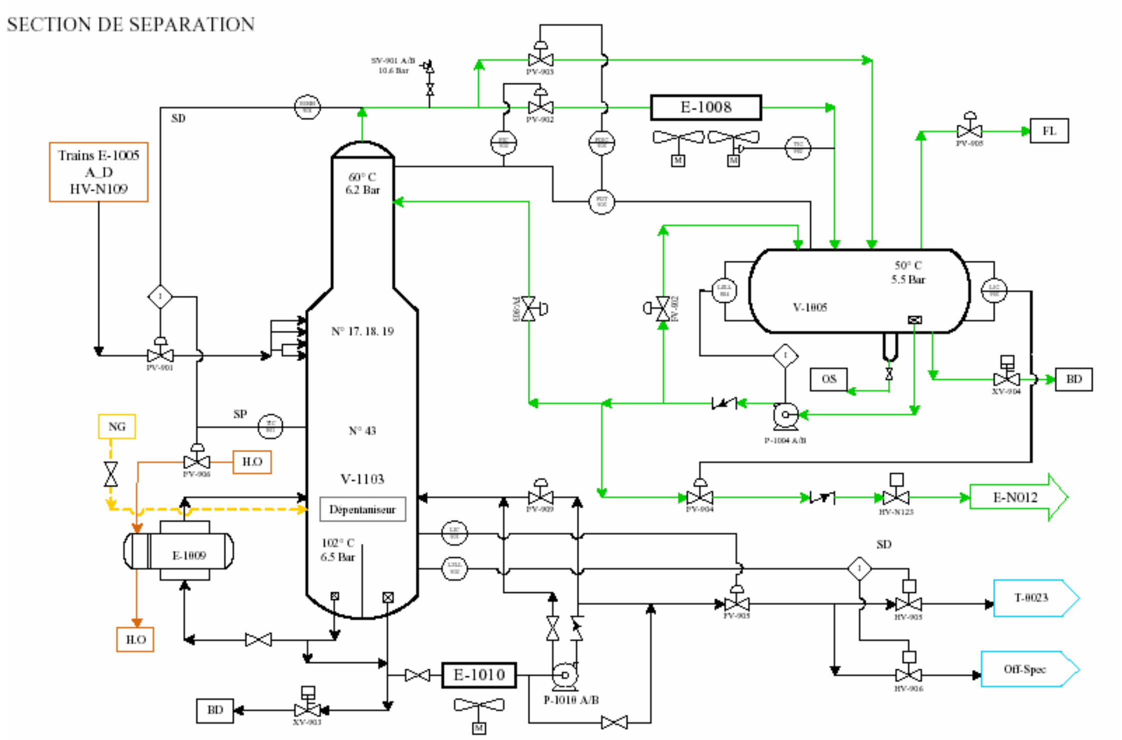


Figure 8 Schematic diagram of the de-pentanizer [9]

II.5 Refrigeration Section

The purpose of this section (Fig. 7) is to cool the finished products to their storage temperature (-38 to -42°C for propane and -8 to -10°C for butane). The products pass through a second dehydrator called a guard dehydrator, which reduces the water content from 5 ppm to 1 ppm, then are refrigerated by three (03) exchangers in a closed cycle forming a refrigeration loop. The fluid used as a refrigerant is pure propane. The latter is evaporated in the heat exchangers. This evaporation causes the temperature of the product to be refrigerated to drop. Part of the refrigerated propane will be compressed and sent to the de-ethanizer as column head refrigerant. The propane vapors generated are compressed by a three-stage centrifugal compressor driven by a gas turbine, then condensed in air-cooled condensers **[9].**

The finished products are then channeled to the storage bins.

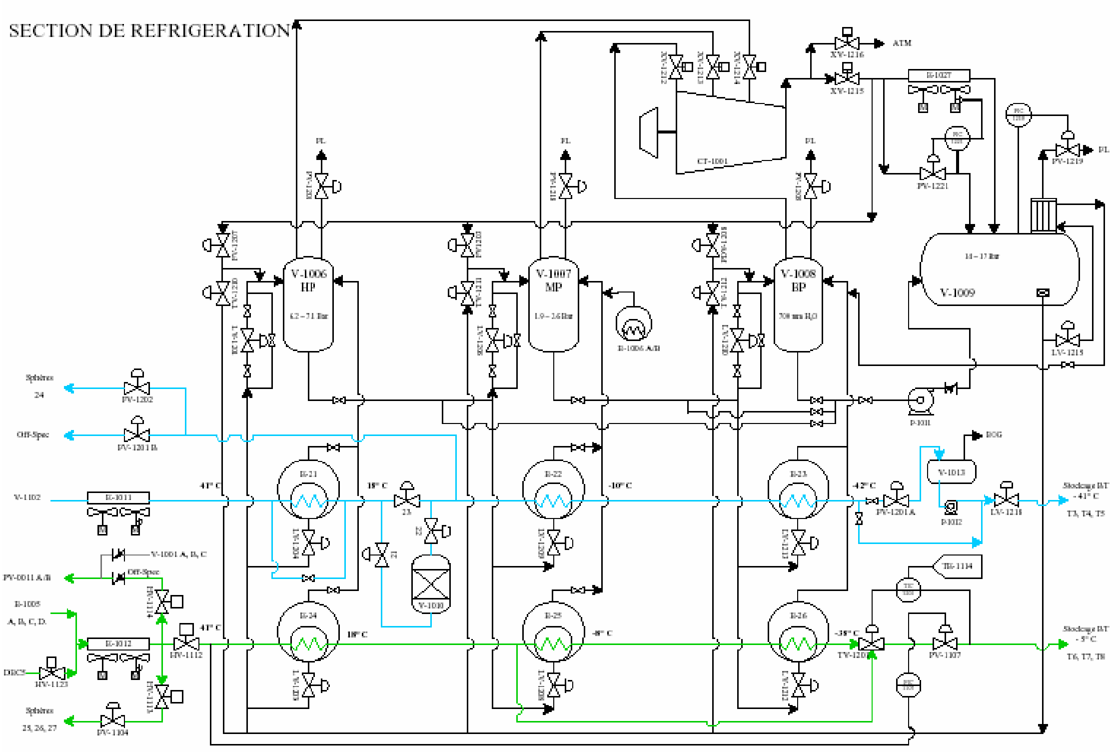


Figure 9 Diagram of the Refrigeration Section [9]

II.6 Hot oil section

This heat transfer oil section (Fig. 8) is used as a heat source for the following equipment:

- The third preheater (E-1013)
- The reboilers in the separation section: (E-1013A/B, E-1007, E-1009).
- The natural gas used for regeneration in the dehydration section.

The oil circuit is also a closed loop, with circulation pumps drawing oil from the expansion tank and returning it to the furnace. At the furnace, the oil is heated first by convection and then by radiation to 180°C, after which it is directed to the various users. On its return, the oil is cooled to 130°C **[9].**

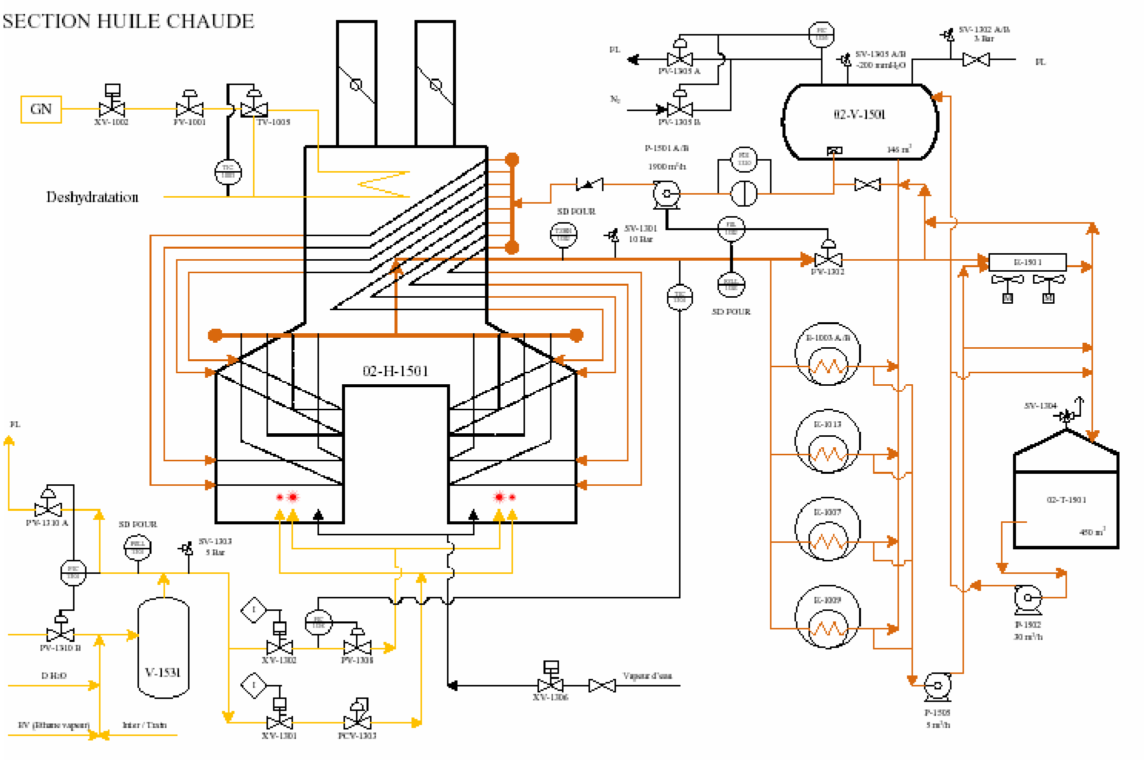


Figure 10 Diagram of the hot oil section [9]

II.7 Utilities area

This area supplies the various production areas with:

- **Fuel** (natural gas): used as fuel.
- **Air:** it is divided into two:
    - ✓ **Air instrument:** This is air that has been dried after moisture removal, intended for use with control loops (pneumatic valves).
    - ✓ **Service air:** Used for cleaning and maintaining equipment.
- **Steam:** produced in the boiler from distilled seawater at 10 kg/cm2, used in heat exchangers.
- **Water:** Production of distilled water, cooling water used for equipment

(pumps) and drinking water.

- **Methanol:** used for de-icing.
- **Diesel fuel:** used for emergency generators.
- **Nitrogen:** Stored in a tank and distributed according to the circuits:
  - ✓ Gas circuit (HELIOS);
  - ✓ Liquid nitrogen circuit (COGIZ).
- **An emergency electric generator**: with a capacity of 25,617 kW.
- A **blow-down** safety system
- **Flares**: two high-pressure and one low-pressure flare are used to burn off gas caused by train malfunctions. **[8]**.

II.8 Storage and shipping section

It handles storage of finished products and shipping by ship and truck.

There are two types of storage:

- **Low-temperature storage section:** (international market)
  - Three (4) tanks for propane, each with a capacity of **70,000m^3**.
  - Three (3) tanks for butane, each with a capacity of **70,000m^3**.
  - One (1) Butane Propane tank with a capacity of **70,000m^3**.
- **Ambient temperature storage section**: (domestic market)
  - One sphere (1) for **500m^3** of propane.
  - Three spheres (3) for butane, each with a capacity of **500** m3.
  - One sphere (1) for pentane, each with a capacity of **500** m3 **[9].**

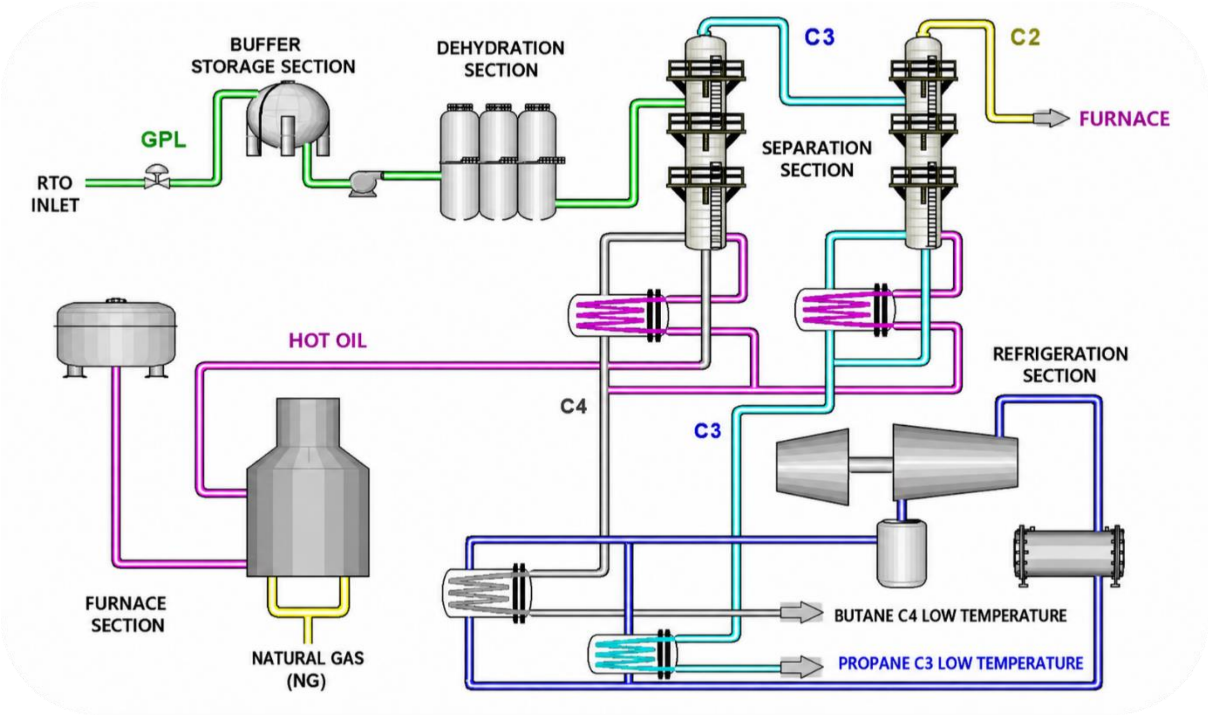


Figure 11 General Process

The Storage and Shipping department manages the following three areas:

II.8.1 BOG (Boil-Off- Gas) Section

The purpose of the vapor reliquefaction section (BOG) is to control the pressure in the low-temperature storage tanks, both during storage and during loading operations. Excess vapors are recovered and compressed so that they can be reliquefied in the form of refrigerated condensates in the low-temperature tanks. Control is provided by two rooms:

- **LCR (Local Control Room):** manages the storage of finished products and the BOG (evaporated gas) recovery section.
- **JCR (Jetty Control Room):** supervises loading operations by ship.

II.8.2 (CN) pier section

Handles pickups by ship; there are two piers:

- D1: for small vessels.
- M6: for large vessels.

II.8.3 Truck Loading Section (CC)

Handles truck pickups at the truck loading ramp (NAFTAL and private operators). The section has five spherical tanks, pumps, and loading arms. These facilities are designed to allow simultaneous loading of propane, pentane, and butane.

3

Simulation

III.1 Introduction

Distillation is the main method used to separate the components of a liquid mixture into fractions of desired purity. This process engineering operation is characterized by the transfer of matter and heat between a liquid phase and a vapor phase. Distillation is a purely physical phenomenon; the components do not react with each other, either in the liquid phase or in the vapor phase.

The main apparatus used to carry out these transfers is usually a separation column, also known as a fractionating tower **[14].**

III.2 Principle of operation

The operating principle of a distillation column is simple: while working at constant pressure, it shifts phase equilibria using a temperature gradient created by a cold source (condenser), which creates a flow of cold liquid descending in the column, and a hot source (reboiler), which generates a flow of hot vapor ascending **[12][13].**

A fractionating column always comprises three distinct systems:

- A vaporization system called a "reboiler"
- A condensation system at the top called a "condenser"
- A contact system that creates a large exchange surface between the two phases using one of the following devices:
  - Packing.
  - Trays: the most commonly used, available in several types: dome, flap, or perforated.

The column is divided into three zones:

- **Feed zone**: this is where the mixture to be fractionated enters.
- **Rectification zone**: located above the feed zone.
- **Exhaust zone**: located below the feed zone.

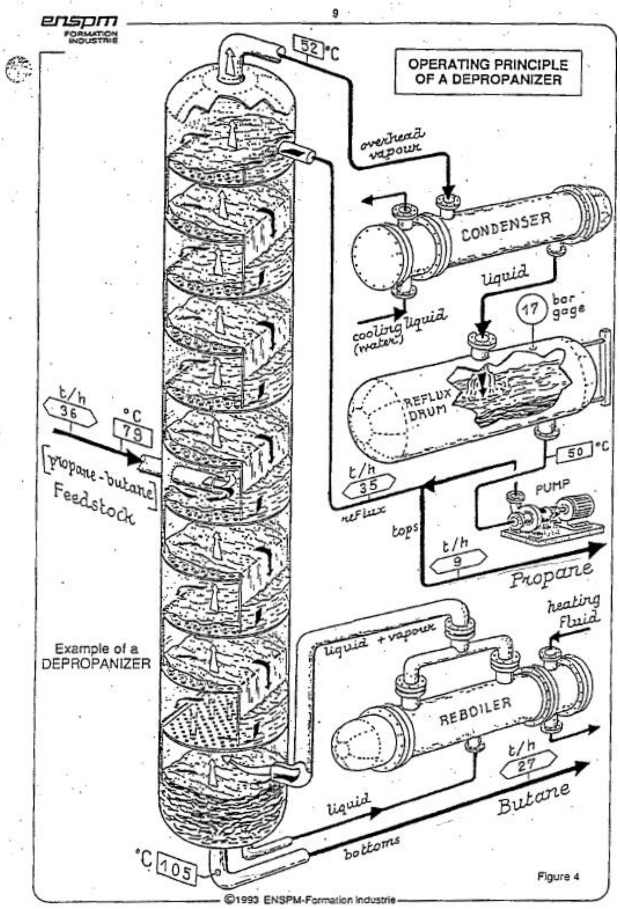


Figure 12 Schematic diagram of the zones in a distillation column [14]

III.2.1 Performance of a distillation column

The purpose of all absorbers is to achieve the best possible exchange of material between a liquid phase and a gas phase in contact. They must therefore be equipped with internal devices that promote the dispersion of the gas phase in the liquid phase and, more specifically, create the largest possible interfacial area. **[11]**

The overall performance of the absorber, in terms of efficiency and selectivity, depends on the phenomena involved, namely:

- thermodynamic equilibria at the interface (solubilities);
- the transport laws in the phases (diffusivities);
- transfer laws in the vicinity of interfaces (transfer coefficients, interfacial areas);
- chemical reaction kinetics (reaction schemes, kinetic constants, reaction orders).

III.2.2 General characteristics of a distillation column

a) Column capacity

Column capacity is defined as the number of theoretical plates, where the boiling liquid and the emitted vapor are in equilibrium.

b) Flow

This is the volume of vapor passing through the column per unit of time. The flow rate depends on the diameter of the column. The flow rate cannot be increased beyond a certain value without causing the column to become clogged.

c) Retention

This is the volume of liquid per unit volume of the column. It is an important factor in the accuracy with which the components are successively separated from the mixture in two ways:

- Dynamic retention: this is the retention volume during operation, i.e. the minimum volume retained in the column and its ancillary parts during distillation.
- Static retention: this is the volume of liquid retained in the column when separation is complete.

d) Efficiency

This is the ratio between the number of theoretical plates and the number of actual plates. For a given column, it depends on the reflux rate and the purity of the product.

e) Fineness

This characteristic allows columns with the same efficiency and separating power for a given mixture to be compared. The column with the highest fineness is the one with the lowest retention volume.

f) Pressure drop

This is the force that the vapor must overcome in its upward movement, mainly the reflux liquid, the feed, and the changes in direction related to the column design.

If this drop is significant, it will lead to a variation in boiling temperature in the column.

g) The equivalent height of a theoretical plate (HEPT)

HEPT is defined as the ratio of the column height (h) to the number of trays in the column operating under total reflux (n). **[11]**

$$TEP = h/n \ldots\ldots\ldots\ldots\ldots (1)$$

III.1 General information on simulation

In general, simulation is a tool used in various fields of engineering and research. It allows the behavior of a system to be analyzed before it is implemented and its operation to be optimized by testing different solutions and operating conditions. It is based on the development of a system model that allows scenarios to be created by deducing the behavior of the physical system being analyzed.

A model is not an exact representation of physical reality, but is only capable of reproducing the most important characteristics of the system being analyzed.

Chemical process simulators traditionally used in the chemical and related industries can be considered knowledge models. They are based on the resolution of mass and energy balances and thermodynamic equilibrium equations, and are capable of providing basic information for design purposes. They are mainly used for the design of new processes in order to optimize them and evaluate the changes to be made to operating conditions **[20].**

III.1.1 Process simulation software

There is a wide range of chemical process simulation software available on the market. The best-known and most widely used industrial simulators worldwide are:

- **Static**: Aspen Plus (Aspen Technologies), Design II (from WinSim). HYSYS (Hyprotech), PRO/II (Simulation Sciences), Prosim, Chemcad.
- **Dynamics**: HYSYS, Aspen Dynamics (Aspen Technologies), Design II (from WinSim). Dymsym (Simulation Sciences Inc).

III.1.2 Presentation of the "HYSYS" software

The HYSYS software was developed by the Canadian company HYPROTECH. It has the advantage of being user-friendly and easy to use once the basic elements are understood.

HYSYS software is a sizing tool used to ensure that optimal designs are identified. It is also used to model existing units and ensure that equipment complies with prescribed specifications, as well as to evaluate and improve existing processes **[17].**

III.1.3 Benefits of simulation

HYSYS was designed to handle a wide range of problems, from simple separation to distillation and chemical transformation. This makes our work easier and reduces engineering costs by:

- ✓ Rapid calculations of different designs using efficient models and optimal techniques.
- ✓ Creation of models that can be applied during unit operation, from conceptual design to detailed design: estimation, training, and optimization.

III.2 Calculation of the fractionation column using the HYSYS simulator

In carrying out our work, we referred to the design parameters specified by the manufacturer, as well as those currently used by the operator, in order to obtain more convincing simulation results by studying several feed load cases for the separation section at different flow rates.

Figure 11 shows the simulation of the fractionation column.
The installation is identical for all nine trains at the complex.

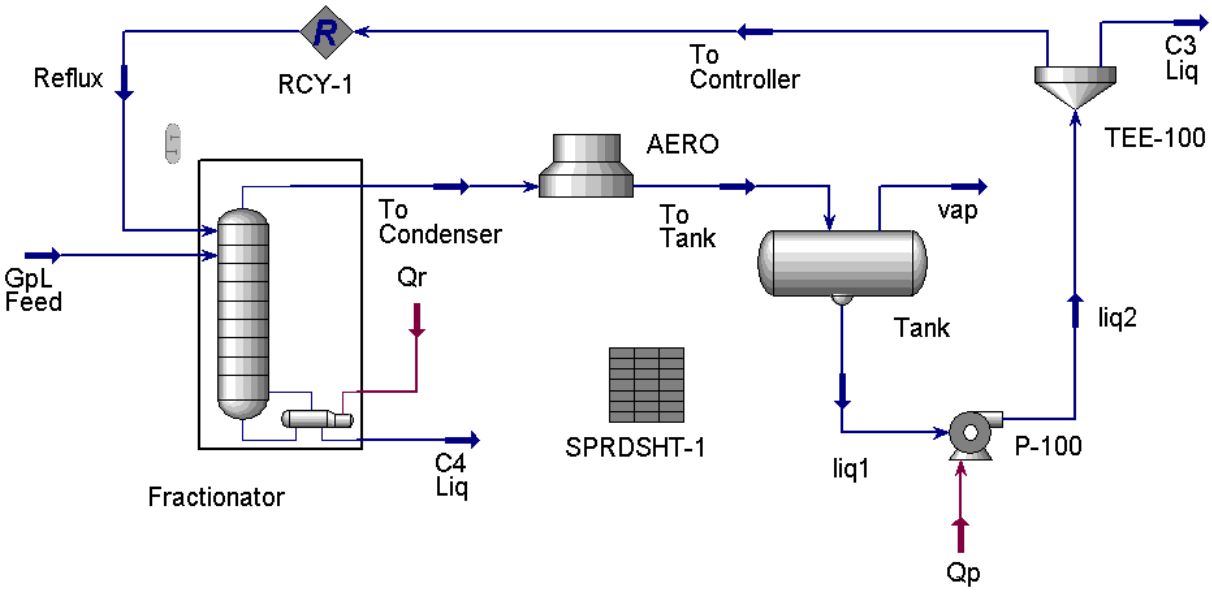


Figure 13 Schematic diagram of the fractionation column simulation

III.2.1 Method followed:

The calculation involves setting the following data:

- Feed data:

- Feed flow rate (m3/h).
- Composition (% molar).
- Temperature (°C).
- Pressure (kg/cm2).

- Column data:

- Number of actual trays.
- Feed tray
- Operating pressure.
- Pressure drop (Condenser).
- Column sections
- Estimation of top and bottom temperatures.
- Specification: temperature of the sensitive tray.

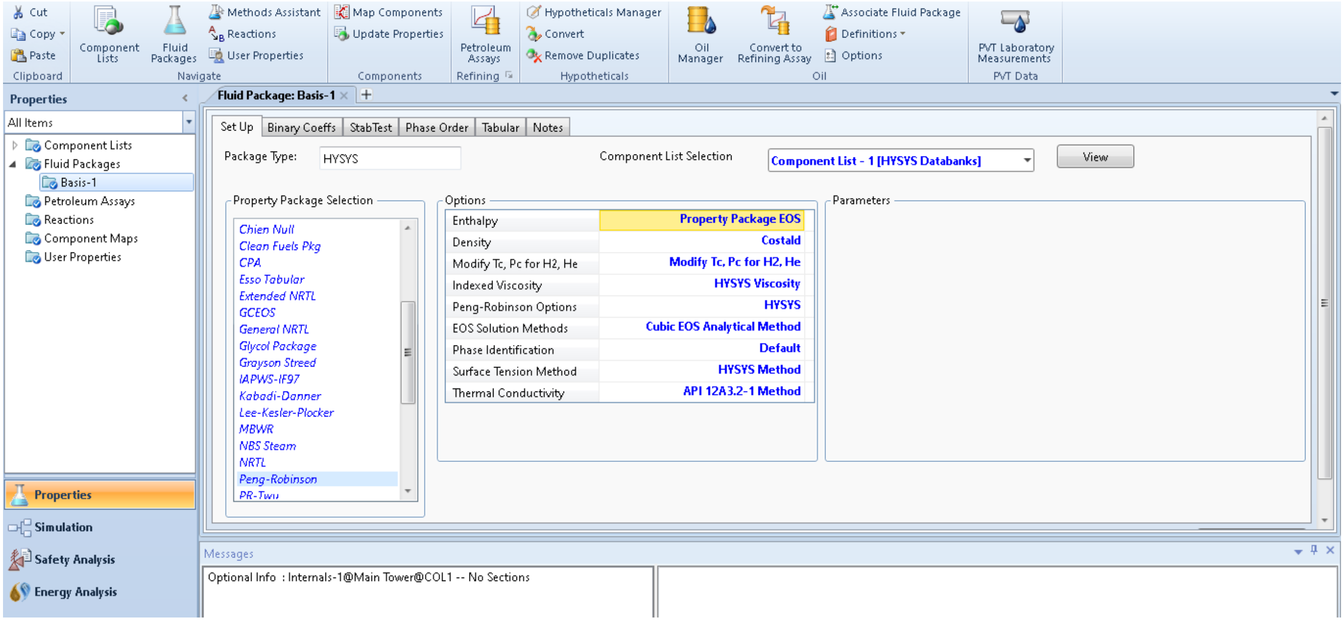
- To obtain:

- Different parameters (flow rate, pressure, and temperature) in each section of the column: Head, Distillate, Reflux, Bottom, and Residue.
- The power of the head condenser.
- Reboiler Wattage.
- The composition of the column's head and bottom products.
- The temperature profile along the column.
- The flow rates, steam and liquid, along the column.

III.2.3 Choice of thermodynamic model

Simulation software provides access to a range of thermodynamic models for gas processing units, enabling the calculation of liquid-vapor equilibrium coefficients, enthalpy and entropy values, and the appropriate thermodynamic properties.

For this study, we used the two most commonly used thermodynamic models for hydrocarbon mixtures, Peng Robinson (PR) and Soave Redlich Kwong (SRK), in order to compare the different models based on equations of state and choose the closest model.



Package Type: HYSYS

Component List Selection: Component List - 1 [HYSYS Databanks]

Options

Enthalpy	Property Package EOS
Density	Costald
Modify Tc, Pc for H2, He	Modify Tc, Pc for H2, He
Indexed Viscosity	HYSYS Viscosity
Peng-Robinson Options	HYSYS
EOS Solution Methods	Cubic EOS Analytical Method
Phase Identification	Default
Surface Tension Method	HYSYS Method
Thermal Conductivity	API 12A3.2-1 Method

Optional Info : Internals-1@Main Tower@COL1 -- No Sections

Figure 14 Fluid Package Choice

III.3 Basic criteria for the study

III.3.1 Feedstock

The plant is designed to process twelve individual feedstocks with different characteristics. The size of each piece of equipment is based on the most difficult feedstocks to process. These are feedstocks containing maximum amounts of ethane and pentane, maximum amounts of butane, and maximum amounts of propane.

The nominal production capacity is estimated at one million tons per year per train, or 240 m3/h of feedstock.

The theoretical feed, which represents the weighted average composition of the twelve feed sources, was used to define normal operation. It is designated as feed No. 13, on the basis of which we compare the results of the HYSYS simulator. The molar composition of the latter **[9]**.

The actual feed is shown in the following table:

Table 2 Molar compositions of feedstocks

Constituent	**Molar composition of feed No. 13**	**Molar composition of current feedstock**
CH_4	0.002	0.1400
C_2H_6	2.009	1.5200
C_3H_8	52.512	60.4400
iC_4H_{10}	16.751	13.2400
nC_4H_{10}	28.258	24.2200
iC_5H_{12}	0.308	0.4000
nC_5H_{12}	0.160	0.0400
Total	**100.00**	**100.00**

Note: The water content in the raw LPG feedstock is 100 ppm by weight

III.3.2 Quality of finished products

Propane and butane as finished products must comply with the standards of the market represented by the international publication **NGPA** (Natural Gas Processing Association), which prescribes the maximum fractions of each element in the final products (propane, butane). These standards are shown in the table below:

Table 3 NGPA standards

Standards	**The content (mol%)**
Maximum ethane content in propane	**4.8**
Maximum content of butane in propane	**2.2**
Maximum propane content in butane	**25**
Maximum pentane content in butane	**1.75**
Maximum butane content in pentane	**10**
Maximum propane content in ethane	**12**

It should be noted that SONATRACH requires more stringent standards than those of NGPA, such as:

Commercial propane

- Ethane ≤ 2.00% molar
- Butane ≤ 1.00% molar

Commercial butane

- Propane ≤ 1.00% molar
- Pentane ≤ 1.75% molar

Ethane to furnace

- Propane ≤ 12.00% molar

III.3.3 Temperatures of finished products

- Commercial propane train outlet: –38°C
- Commercial butane train outlet: – 06 °C

III.3.4 Water content in propane finished product

The water content at the outlet of the guard dehydrator in the finished propane product is less than 1 ppm by weight.

III.4 Effect of operating variables

The separation of propane and butane in the fractionator is an essential operation for achieving the desired recovery rates for each product. However, in order to achieve the required range of product qualities, a number of operating variables must be controlled **[9].**

III.4.1 Temperature

a. Feed: The feed set point must be kept constant at 74.5°C so that the feed to the column is close to its bubble point.

b. Sensitive tray: When studying the column, it appears that the 36th tray is the most sensitive. To ensure the recovery rate with all possible loads, the temperature of this tray should be set to 96°C. This controls the reboiling rate in the fractionator and, in particular, the propane content of the bottom product, as well as the reflux rate.

c. Column outlets: The normal setpoint temperature for the column head is 57.1°C, and that for the column bottom is 110.9°C. These values can be modified slightly but should not be less than 50°C for the head and 96.9°C for the bottom.

III.4.2 Pressure

a. Column pressure: The fractionator is designed to operate at a fixed pressure of 20.2 kg/cm2, with a pressure difference between the bottom and top of the column of 0.3 to 0.4 kg/cm2 or less. Higher readings would be a sign of overload or even clogging.

b. Reflux tank: The pressure in the reflux tank should be set to 19.5 kg/cm2 and kept constant to eliminate any overpressure in the head system that may occur. The head differential pressure is maintained at 0.7 kg/cm2 to ensure stable condenser operation.

III.4.3 Flow rate

a. Feed: Under normal production conditions, the feed to the fractionator is 240 m3/h (100%), corresponding to a nominal production of one million tons per year. Each train also has flexibility that allows it to exceed its nominal capacity and operate at a minimum of 50% of that capacity.

b. Top reflux: during normal operation, the reflux flow rate should be kept constant at 230.6 T/h, or 518 m3/h. This is to ensure the desired recovery rate of propane and butane with all possible feed sources.

III.4.4 Equipment specifications

In addition to the fractionation column, this section must also include certain auxiliary equipment to ensure proper separation. The tables below show the characteristics of this equipment **[15].**

Table 4 Characteristics of heat exchange equipment

Reference	**Service**	**Type**	**Fluid**	**Pressure** Kg/cm2	**Temperature (°C)**	**Maximum capacity (Kcal/h)**
02-E-N002	Head condenser Fractionator	Air-condenser	Propane	20	57.4 ~ 50	$25.23 . 10^6$
02-E-N003 A/B	Reboiler Fractionator	Calender Tube	Butane Hot oil	20.5 5 ~ 3	110 ~ 111 180 ~ 130	$25.23 . 10^6$
02-E-N004	Preheater No. 1	Calender Tube	LPG load Propane	28.5 21.9	5 ~ 20.4 61 ~ 43.2	$1.198 . 10^6$
02-E-N005	Preheater No. 2	Calender Tube	LPG load Butane	27.7 20.3	19.4 ~ 67.7 109 ~ 40.6	$3.693 . 10^6$
02-E-N013 A/B/C/D	Preheater No. 3	Calender Tube	LPG load Hot oil	25.6 3.4	66 ~ 71.1 180 ~ 130	$3.075 . 10^6$

Table 5 Pump characteristics

Reference	Service	Type	Fluid	Pressure Kg/cm2	Temperature (°C)	Max flow rate (m3/h)
07-P-0011	Feed pump Feed	Centrifugal	LPG load	2.75 ~ 34.1	5 – 45	260
02-P-N002 A/B	Reflux pump from the fractionator	Centrifuge	LPG charge	19.5 ~ 25	50 ~ 57	865

III.5 Calculation of the column with a load rate of 100 %

The table below shows the operating parameters for the fractionation column set by the designer for load No. 13 and the current operating parameters.

Table 6 Design and current operating data

Parameters	Design	Current
Feed flow rate (kgmole/h)	2541.8	2613.44
Reflux flow rate (kgmole/h)	5291.23	4131.10
Feed temperature (°C)	74.5	70.5
Peak pressure	21.2	20.2
Pressure in the reboiler	21.6	20.6
Temperature of the sensitive plate (°C)	96	96
Reflux temperature (°C)	50	48.8

The characteristics of the fractionator are given in the following table:

Table 7 Characteristics of the fractionator

Characteristics	Section I	Section II
Number of trays	20	35
Type of trays	Valve	Valve
Number of passes	4	4
Inner diameter (m)	4.100	5.500
Spacing between decks (m)	0.600	0.600
Clogging limit (%)	80	80

III.6 design case verification

The table below shows the fractionation column output parameters calculated by the manufacturer and those obtained by HYSYS. For the latter, we used two thermodynamic models. Based on the results obtained, we can see that the two thermodynamic models are close to the design case. Therefore, for the remainder of this work, we have chosen the SRK model, which is often used for hydrocarbon mixtures. The simulator allows us to represent the profile of the different parameters along the column, namely:

- **Temperature**

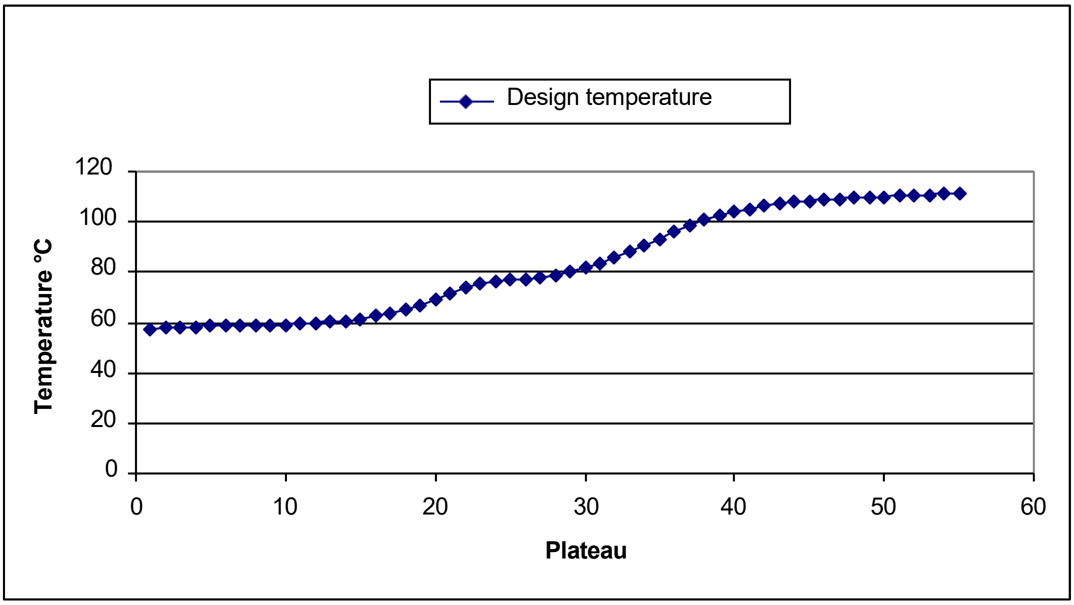


Figure 15 Design temperature profile at 100%

We note that the temperature variation is consistent throughout the column, which indicates that it is functioning properly and is stable.

- **Flow rates**

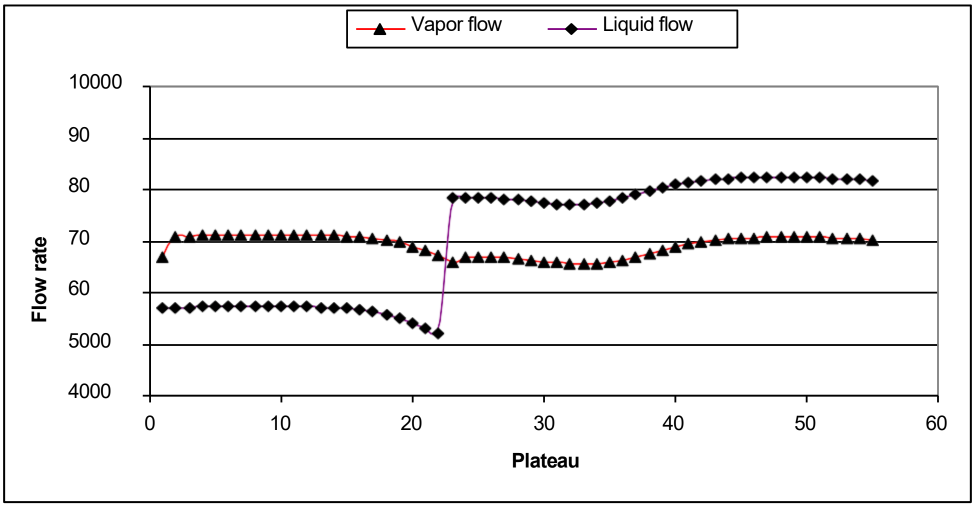


Figure 16 Flow rate profile Design at 100%

The figure shows that the steam flow rate in the enrichment section is higher than that of the liquid, but when it reaches the 23rd tray, the liquid flow rate increases considerably compared to the steam flow rate, because the feed is a boiling liquid.

III.7 Service settings

Table 8 Design parameters

Setting	**Feed**	**Distillate**	**Residue**
T (C)	74,500	57.1	**110.9**
P (kPa)	21.5	21.1	**21.6**
Flow rate (kg mol/h)	2541.80	1376.73	**1164.87**
C_1	0.0000	0.0000	**0.0000**
C_2	0.0201	0.0371	**0.0000**
C_3	0.5251	0.9610	**0.0099**
iC_4	0.1675	0.0017	**0.3635**
nC_4	0.2836	0.0002	**0.6164**
iC_5	0.0031	0.0000	**0.0067**
nC_5	0.0016	0.0000	**0.0035**
SUM	**1.0000**	**1.0000**	**1.0000**

III.8 Design values:

In the table below, we present the design data, the simulation results, and the relative error obtained according to the following relationship:

$$\text{Erreur}=\frac{\left|(V_{\text{Designe}}\text{-V}_{\text{Designe.simulared}})\right|}{V_{\text{Désigne}}}\times 100 \;\ldots\ldots\; (\text{III.1})$$

Table 9 Calculation of design errors

	Design	**simulated design**	**Error (%)**
T_D (°C)	57.1	54.89	3.87
T_R (°C)	110.9	109	1.71
P Top(bar)	20.2	19.81	1.93
P Bottom (bar)	20.5	20.1	1.95
Qc (kcal /h)	19850000	19720000	0.65
Qreb (kcal /h)	21080000	21120000	0.19
C_3 Top	0.98	0.9629	1.74

The error obtained for all parameters is less than 4%, which means that the simulation results are close to the design values and that using the PR thermodynamic model is advantageous.

III.5.9 Verification of the current case

III.5.9.1 Parameters of the current case

The parameters of the current case are obtained during the month of June (100% load).

Table 10 Service settings

Setting	Feed	Distillate	Residue
T (C)	71	56.22	**112.3**
P (kpas)	2089	2010	**2108**
Flow rate (kg.mol/h)	2594	1580	**1013**
C 1	0.0003	0.0005	**0**
C 2	0.0058	0.0095	**0**
C 3	0.6025	0.9887	**0.0004**
iC 4	0.1368	0.0013	**0.348**
nC 4	0.2494	0	**0.6383**
iC 5	0.0036	0	**0.009**
nC 5	0.0016	0	**0.0041**
SUM	**1.00**	**1.00**	**1.00**

III.5.9.2 The simulation results

The current case data, the simulation results for this case, and the relative error obtained from relation (III.1) are summarized in the following table:

Table 11 Calculation of errors in the actual values

	Current case	Simulated current case	Error %
T_D (°C)	56.22	55.38	1.49
T_R (°C)	112.3	109	2.94
P Top (bar)	20.1	19.81	1.44
P bottom(bar)	21.08	20.1	4.65
Q_C (kcal/h)	18.1	18.39	1.60
Q_{reb} (kcal/h)	17.8	18.73	5.22
C_3 Top	0.9887	0.9731	1.58

- We note that the simulation results are close to the actual operating data of the column, which confirms the validity of this simulation and allows us to optimize the reflux flow rate for different loads.

III.10 Optimization of the reflux rate:

The volumetric flow rates of the following feed loads are fixed:

180m^3/h → 75%

210m^3/h → 87.5%

240m^3/h → 100%

264m^3/h → 110%

288m^3/h → 120%

336m^3/h → 140%

And in each load, we vary the reflux flow rate from 210 to 470 with a step of 20 (m^3/h).

Conditions for choosing the optimal R

It is necessary that:

1) The molar percentage of C_3H_8 in the distillate must be greater than or equal to 96% ($C_3\ \%_{\text{in}}\ D \geq 96\%$).
2) The molar percentage of C_4H_{10} in the distillate must be less than or equal to 1% ($C_4\ _{\text{in}}\ D \leq 1\%$).
3) The molar percentage of C_3H_8 in the residue must be less than or equal to 1% ($C_3\ _{\text{in}}\ W \leq 1\%$).
4) The volumetric flow rate of the reflux pump must be greater than or equal to 370 m^3/h ($F \geq 370\ m^3/h$) for proper operation, and not less than 350 m^3/h ($F < 350\ m^3/h$) because the pump will stop.

Now we're going to start finding the optimal reflux:

- For L=180m^3 / h → 75%

Table 12 Optimization of reflux flow rate at L=180m3/h

180 m^3 / h	flow rate (m^3 / h)	Total Q (kW)	C_{4Fond}	C_{3te}
Case 1	210	27530,728	0.997102	0.999246
Case 2	230	29251,9643	0.997933	0.999297
Case 3	250	30973,1919	0.998392	0.999481
Case 4	270	32698,576	0.998706	0.999644
Case 5	290	34423,4729	0.998927	0.999763
Case 6	310	36151,5449	0.999089	0.999843
Case 7	330	37876,2346	0.999211	0.999895
Case 8	350	39603,4816	0.999307	0.999929
Case 9	370	41329,2522	0.999383	0.999951
Case 10	390	43055,8798	0.999445	0.999965
Case 11	410	44782,6114	0.999496	0.999975
Case 12	430	46508,7713	0.999538	0.999981
Case 13	450	48236,7556	0.999574	0.999986
Case 14	470	49963,1797	0.999604	0.999989

The optimal reflux in this load is: 210m3 / h Carle molar percentage of the C3 fraction in the head 99% greater than 96%.

The results obtained by the simulation are shown in the figure below:

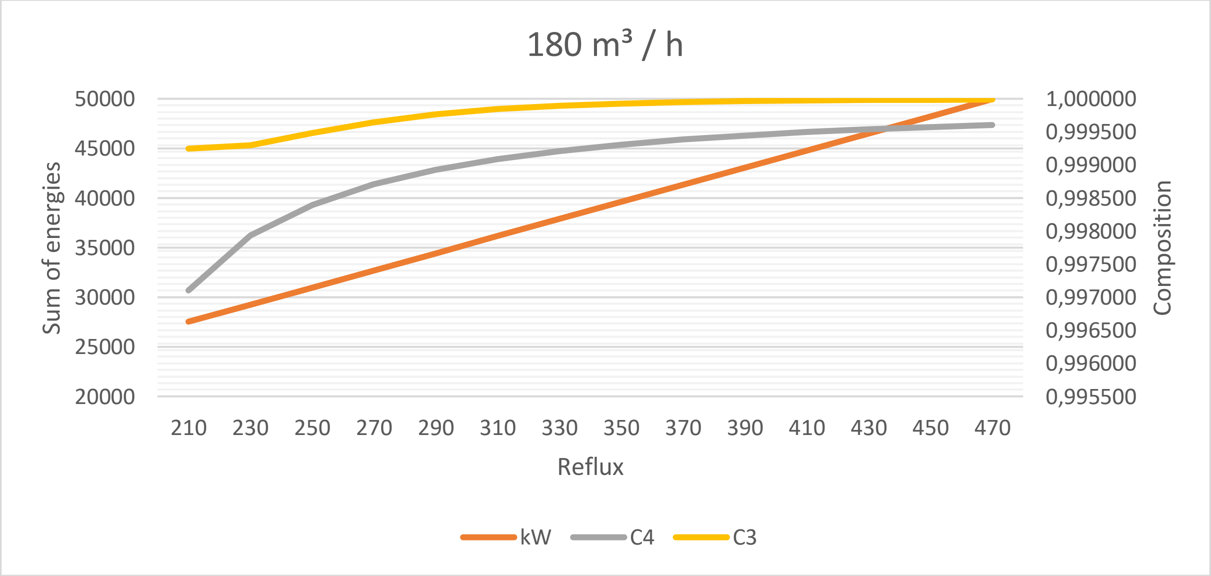


Figure 17 The sum of energy as a function of reflux flow rate at L=180m 3 /h

We observe that the sum of energies and the purity of C3, C4 $_{\text{increase}}$ proportionally with the increase in reflux flow rate:

- For L=210m^3 / h → 87.5%

Table 13 Optimization of reflux flow rate at L=210 m 3 /h

210 m^3 / h	**Reflux flow rate (m^3 / h)**	**Q_T (kW)**	**C_4**	**C_3**
Case 1	210	29319,626	0.995172	0.988366
Case 2	230	30868,8169	0.996318	0.996552
Case 3	250	32568,8694	0.997352	0.997536
Case 4	270	34277,0572	0.997943	0.998407
Case 5	290	35995,0928	0.998353	0.999004
Case 6	310	37718,0007	0.998642	0.999383
Case 7	330	39442,2301	0.998853	0.999616
Case 8	350	41167,6813	0.999012	0.999758
Case 9	370	42893,7399	0.999135	0.999844
Case 10	390	44620,3722	0.999233	0.999897
Case 11	410	46346.84	0.999313	0.999931
Case 12	430	48073,7799	0.999378	0.999952
Case 13	450	49800.6119	0.999432	0.999965
Case 14	470	51526,9607	0.999478	0.999974

- The optimal reflux in this load is: 210m^3 / h because the molar percentage of the C3 fraction in the head is 98%.

The results obtained by the simulation are shown in the figure below:

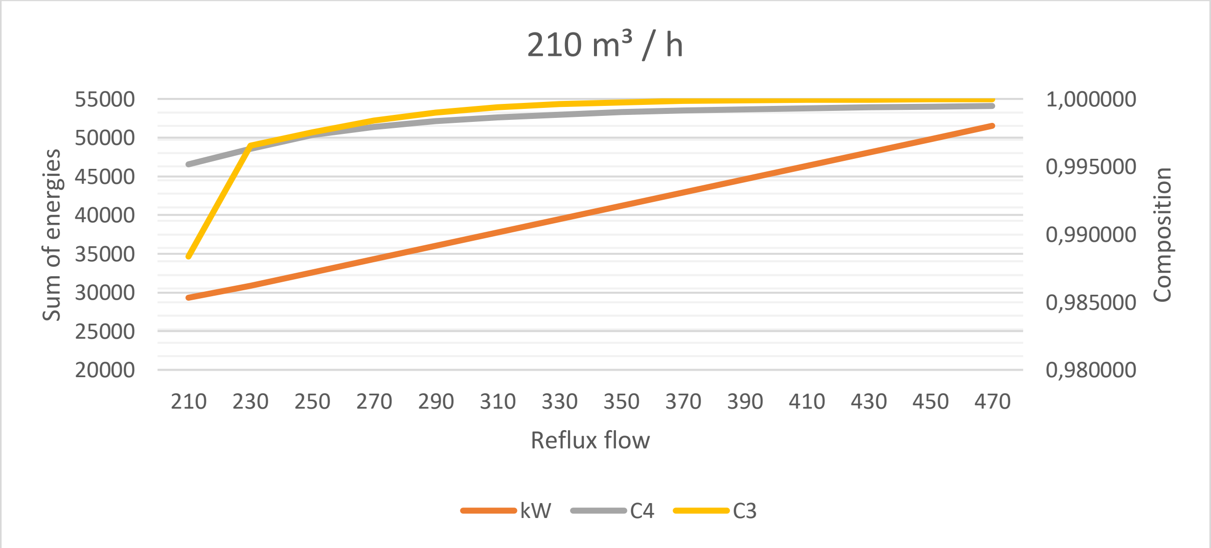


Figure 18 The sum of energy as a function of reflux flow rate at L=210 m^3 /h

We note that the sum of energies and the purity of C3, C4 increase proportionally with the increase in reflux flow rate.

- **For L=240m³ / h** → 100%

Table 14 Reflux flow optimization at L=240m³ / h

240 m³ / h	**Reflux flow rate (m³ / h)**	**Q_T (kW)**	**C_4**	**C_3**
Case 1	210	31483,2913	0.994161	0.966717
Case 2	230	32806,7911	0.994787	0.982437
Case 3	250	34252,0478	0.995665	0.993415
Case 4	270	35869,6194	0.996666	0.997667
Case 5	290	37580,2466	0.997481	0.998232
Case 6	310	39292,0613	0.997972	0.998790
Case 7	330	41011,7879	0.998332	0.999201
Case 8	350	42735,1747	0.998594	0.999478
Case 9	370	44459,0393	0.998792	0.999657
Case 10	390	46183,5843	0.998947	0.999772
Case 11	410	47911,0562	0.999069	0.999846
Case 12	430	49636,6781	0.999168	0.999894
Case 13	450	51363,4372	0.999249	0.999924

- The optimal reflux in this load is: 230m³ / h because the molar percentage of the C3 fraction in the head is 98%.

The results obtained by the simulation are shown in the figure below:

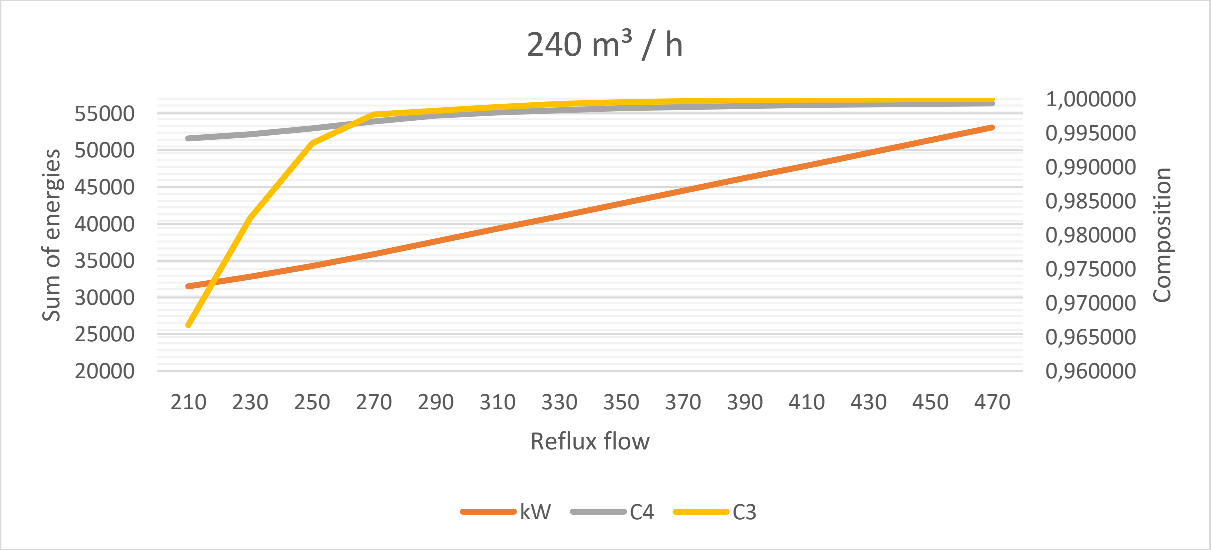


Figure 19 The sum of energy as a function of reflux flow rate at L=240m³ / h

We note that the sum of energies and the purity of C3, C4 increase proportionally with the increase in reflux flow rate

- **For L=264m³ / h** → 110%

Table 15 Reflux flow optimization at L=264m 3 /h

264 m³ / h	Flow rate Backflow (m³ / h)	Q_T (kW)	C_4	C_3
Case 1	210	33337,2406	0.993811	0.949777
Case 2	230	34569,1443	0.994146	0.966229
Case 3	250	35882,1088	0.994686	0.980493
Case 4	270	37298,0951	0.995438	0.991521
Case 5	290	38874,8622	0.996364	0.996827
Case 6	310	40575,3165	0.997207	0.997586
Case 7	330	42279,5621	0.997737	0.998346
Case 8	350	43994,8943	0.998130	0.998908
Case 9	370	45713,5858	0.998421	0.999287
Case 10	390	47437,4635	0.998643	0.999532
Case 11	410	49160,041	0.998814	0.999690
Case 12	430	50890,2353	0.998952	0.999790
Case 13	450	52616,2004	0.999063	0.999855
Case 14	470	54342,2316	0.999155	0.999897

- The optimal reflux in this load is: 250m³ / h because the molar percentage of the C3 fraction in the head is 98%.

The results obtained by the simulation are shown in the figure below:

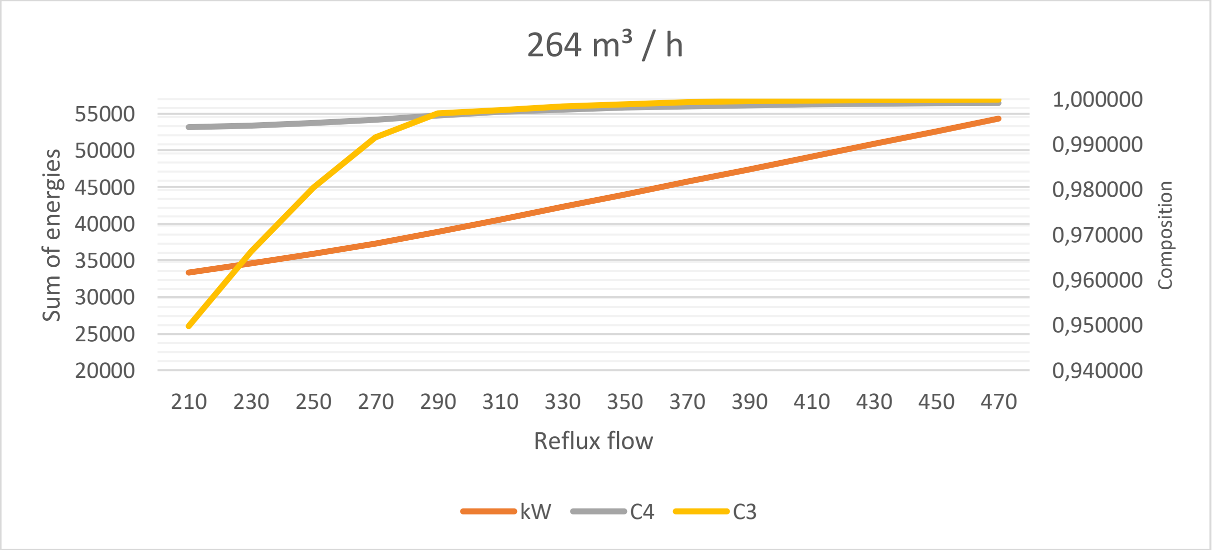


Figure 20 The sum of energy as a function of reflux flow rate at L=264m ³ /h

We observe that the sum of energies and the purity of C3, C4 increase proportionally with increasing reflux flow rate.

- **For L=288m³ / h** ⟶ 120%

Table 16 Optimization of reflux flow rate at L=288m3 /h

288 m³ / h	**Reflux flow rate (m³ / h)**	**Q_T (kW)**	**C_4**	**C_3**
Case 1	210	35235,0794	0.993680	0.934540
Case 2	230	36422,6319	0.993819	0.950765
Case 3	250	37653,5147	0.994124	0.965584
Case 4	270	38960,8574	0.994610	0.978811
Case 5	290	40354,8363	0.995259	0.989622
Case 6	310	41890,8998	0.996094	0.995818
Case 7	330	43576,6714	0.996940	0.996799
Case 8	350	45270,8127	0.997503	0.997801
Case 9	370	46980,7149	0.997928	0.998548
Case 10	390	48697,7605	0.998247	0.999052
Case 11	410	50419,6542	0.998491	0.999379
Case 12	430	52142,4928	0.998681	0.999588
Case 13	450	53867,2912	0.998834	0.999721
Case 14	470	55593,3603	0.998956	0.99907

- The optimal reflux in this load is: 290m³ / h because the molar percentage of the C3 fraction in the head is 98%.

The results obtained by the simulation are shown in the figure below:

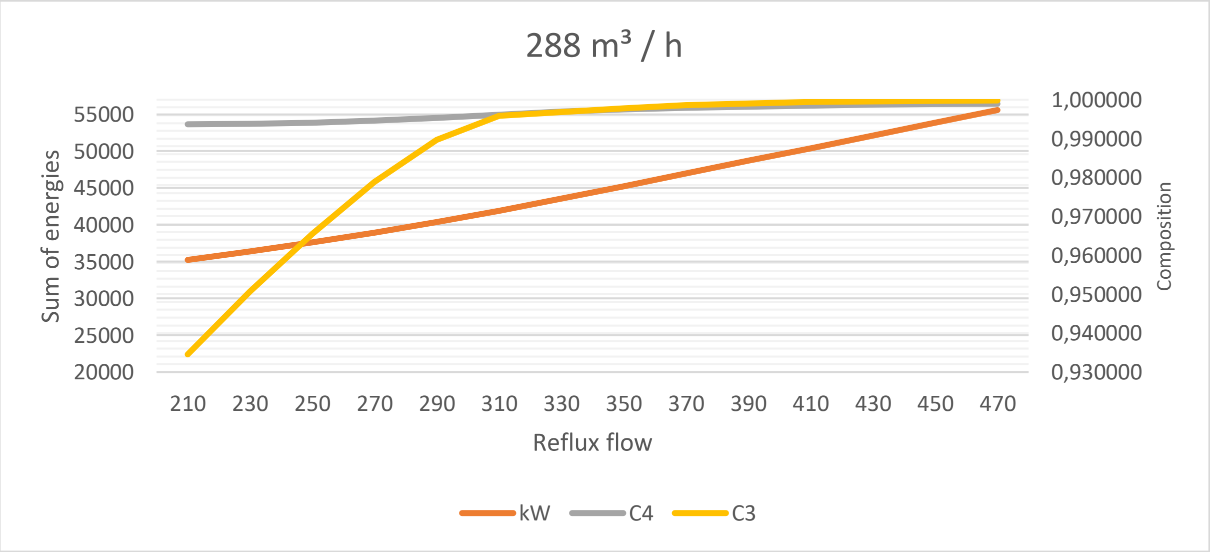


Figure 21 The sum of energy as a function of reflux flow rate at L=288m³ /h

We observe that the sum of energies and the purity of C3, C4 increase proportionally with increasing reflux flow rate.

- **For L=336m^3 / h** → 140%

Table 17 Reflux flow rate optimization at L=336m3 /h

336 m^3 / h	**m^3 / h**	**kW**	**C$_4$**	**C$_3$**
Case 1	210	39010,6155	0.993609	0.910138
Case 2	230	40214,9928	0.993641	0.924380
Case 3	250	41402,5496	0.993700	0.938304
Case 4	270	42595,4145	0.993843	0.951847
Case 5	290	43823,8097	0.994096	0.964551
Case 6	310	45120,0657	0.994495	0.976098
Case 7	330	46484,6882	0.995002	0.986113
Case 8	350	47952,7443	0.995660	0.993328
Case 9	370	49571,2635	0.996357	0.995691
Case 10	390	51239,3237	0.996996	0.997540
Case 11	410	52952,6809	0.997544	0.998220
Case 12	430	54665,4952	0.997903	0.998759
Case 13	450	56382,0832	0.998184	0.999146
Case 14	470	58102,2209	0.998409	0.999410

- The optimal reflux in this load is: 330m^3 / h because the molar percentage of the C3 fraction in the head is 98%.

The results obtained by the simulation are shown in the figure below:

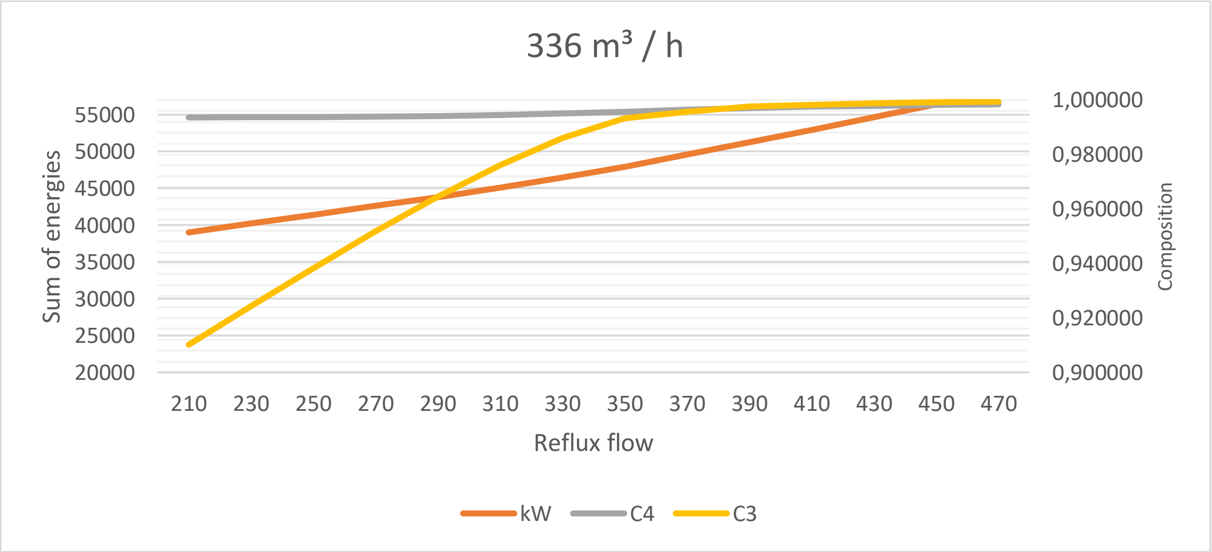


Figure 22 The sum of energy as a function of reflux flow rate at L=336m^3 /h

We note that the sum of energies and the purity of C3, C4 increase proportionally with the increase in reflux flow rate.

4

Energy Savings

IV.1. Introduction:

With the technical analysis and simulation modeling discussed in the previous chapter, the fifth chapter of the present document is focused on the evaluation of the results and the quantification of the improvements in terms of energy efficiency. In accordance with the objectives outlined in the general introduction of the present document in relation to the industrial performance of the GP1/Z complex, the present chapter aims to demonstrate the impact of the transition from a fixed to a variable and optimized flow rate on the energy footprint of the complex.

With the analysis of the thermal and electrical consumption of the most critical equipment of the complex, such as the air condenser, the reboiler, and the reflux pumps, the present section aims to highlight the benefits in terms of energy efficiency of the optimization of the process. In the context of the present analysis, the load of 240 m^3/h is proposed as the primary case study to highlight the deviation of the current operation standards in comparison to the optimized conditions proposed by the simulation tool HYSYS.

The next sections will elaborate on the breakdown of the energy balance comparison, highlighting the differences between the current consumption of 38,162.13 kW and the optimized value of 32,806.79 kW. Through the recorded value of 5,355.34 kW for the total energy recovery, the chapter affirms the hypothesis for the importance of reflux control in enhancing industrial efficiency. The findings serve as a guide for possible modifications that could improve the economic and environmental efficiency of the separation section of the GP1/Z complex.

IV.2. Calculation of energy gain:

To demonstrate the benefits of optimizing the reflux flow rate, we will calculate the energy gain using the following relationship:

$$\textbf{The Energetic Gain} = Q_{actuel} - Q_{optimized} \qquad \textbf{(IV.1)}$$

The energy currently consumed at a reflux flow rate of approximately 470m³ / h and the energy consumed after the optimization of the reflux flow rate determined by HYSYS.

For this, we took a load of 240m³ / h as an example to calculate the energy gain.

We found:

Table 18 Calculation of energy gain

Current Q	**Q optimized**	**Energy gain**
38162.1335 kW	32806.7911 kW	5355.3424KW

Data drawn from table 5.1 is provided for establishing the definitive, quantitative validation of the optimization strategy being proposed for the GP1/Z complex. Comparison of the existing operations to the optimized parameters identified through HYSYS indicates a substantial reduction in energy demand among all fractionation train utilities (reboiler, air condenser and reflux pumps). Adding the total energy usage of the fractionation train utilities -- (38,162.13 kW) to that of the reboiler (32,806.79 kW) at a standard feed load of 240 m^3/hr. demonstrates an overall recovery of 5,355.34 kW of energy from the reboiler through the operation's continued use of a fixed reflux flow rate of 470 m^3/hr., which inherently demonstrates the inefficiency of maintaining constant reflux flow rates independent of changes in load. Therefore, when applying real-time load demands in conjunction with dynamic reflux flow rate management, the complex has achieved a significant reduction in its energy consumption footprint without sacrificing any product purity. Accordingly, this table serves as both an economic and technical justification for the completion of this study to demonstrate the importance of accurately managing reflux flows as a means for reducing operation costs and improving the overall industrial efficiency of the separation section.

5

Future Perspectives

V.1 Introduction

The optimization of the fractionation unit at the GP1/Z complex, as demonstrated in the previous chapters, relies on steady-state simulations to identify ideal reflux flow rates. While Aspen HYSYS provides a high degree of mathematical accuracy, industrial processes are subject to "stochastic" variables—unexpected changes in feed composition, ambient humidity affecting air condensers, and equipment aging. This chapter explores the transition from static engineering models to **Industry 4.0** frameworks. By integrating **Artificial Intelligence (AI)** and **Machine Learning (ML)**, the GP1/Z complex can move beyond manual set-points toward a self-optimizing, autonomous operational model **[17]**.

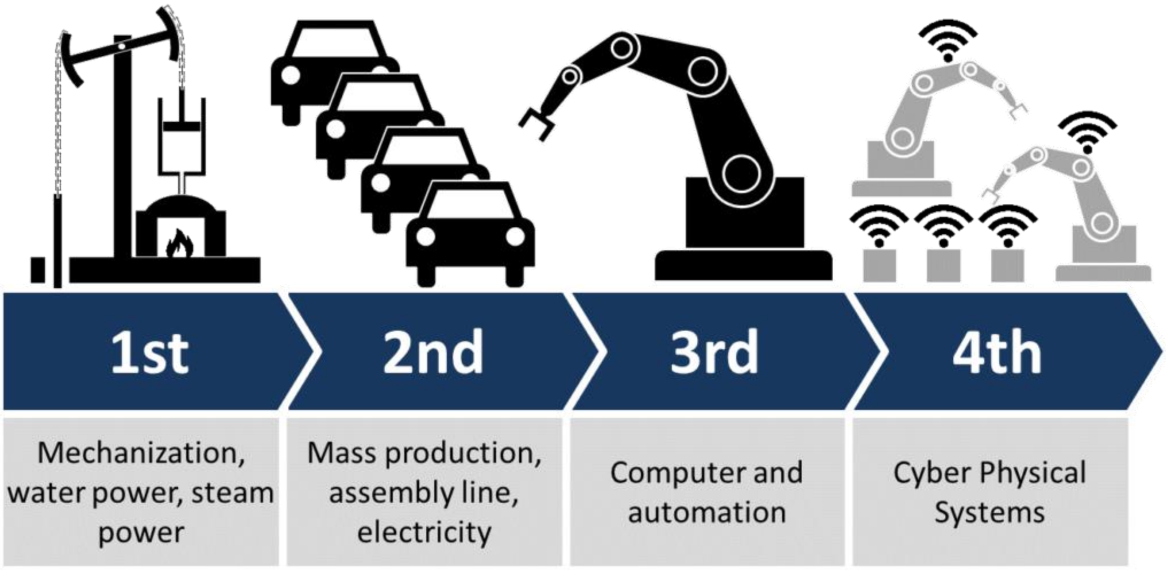


Figure 23 The development of the industry

V.2 The Role of AI in Distillation Control and "Soft Sensing"

Traditional control systems, such as Proportional-Integral-Derivative (PID) controllers, are designed for stability rather than global optimization. Distillation is a highly non-linear process where a change in one variable (reflux) impacts multiple others (top purity, bottom temperature, and pressure).

AI offers a revolutionary solution through **"Soft Sensing."** In many petrochemical plants, verifying product purity requires physical sampling and laboratory analysis, which introduces a significant time delay. An AI model, trained on historical plant data, can act as a virtual sensor. By processing real-time data from temperature and pressure transmitters, the AI can predict the C3/C4 concentration instantly. This allows for proactive adjustments to the reflux flow rate, ensuring the 5,355.34-kW energy gain is maintained without ever risking product off-specification **[19] [20]**.

V.3 AI-Powered Hybrid Modeling with Aspen HYSYS

The future of process engineering lies in **Hybrid Modeling**. Standard HYSYS models are "First-Principle" models based on the laws of physics and thermodynamics. While accurate, they cannot easily account for "hidden" variables like tray fouling, heat exchanger scaling, or minor valve leaks.

By utilizing **Aspen Hybrid Models™**, the GP1/Z complex can combine the reliability of chemical engineering equations with the pattern-recognition power of AI.

- **Neural Network Training:** The simulation results generated in this thesis can be used to train a Neural Network. Once trained, this AI "surrogate" can run complex optimization scenarios in milliseconds, compared to the minutes required by traditional solvers.
- **Prescriptive Maintenance:** Beyond energy optimization, AI can analyze vibration and thermal data from the reflux pumps and reboiler to predict equipment failure before it occurs, reducing unscheduled downtime at the complex. **[18] [20].**

V.4 Implementation Roadmap: Toward a Digital Twin

To transition from the theoretical optimization presented in this thesis to a live AI system at GP1/Z, a structured roadmap is required:

1. **Data Historiography:** The first step involves consolidating historical data from the plant's Distributed Control System (DCS). This data provides the "ground truth" for training Machine Learning algorithms.
2. **Developing the Digital Twin:** A Digital Twin is a live, virtual replica of the fractionation column that stays synchronized with the physical unit. This twin uses the HYSYS-AI hybrid model to constantly test "What-If" scenarios to find the lowest possible energy consumption for the current load.
3. **Closed-Loop Automation:** Initially, the AI provides "recommendations" to the operators (Open-Loop). Once the model's reliability is proven, it can be granted direct control over the reflux valves (Closed-Loop), allowing for real-time energy recovery as feed loads fluctuate between 75% and 140%. **[21]**

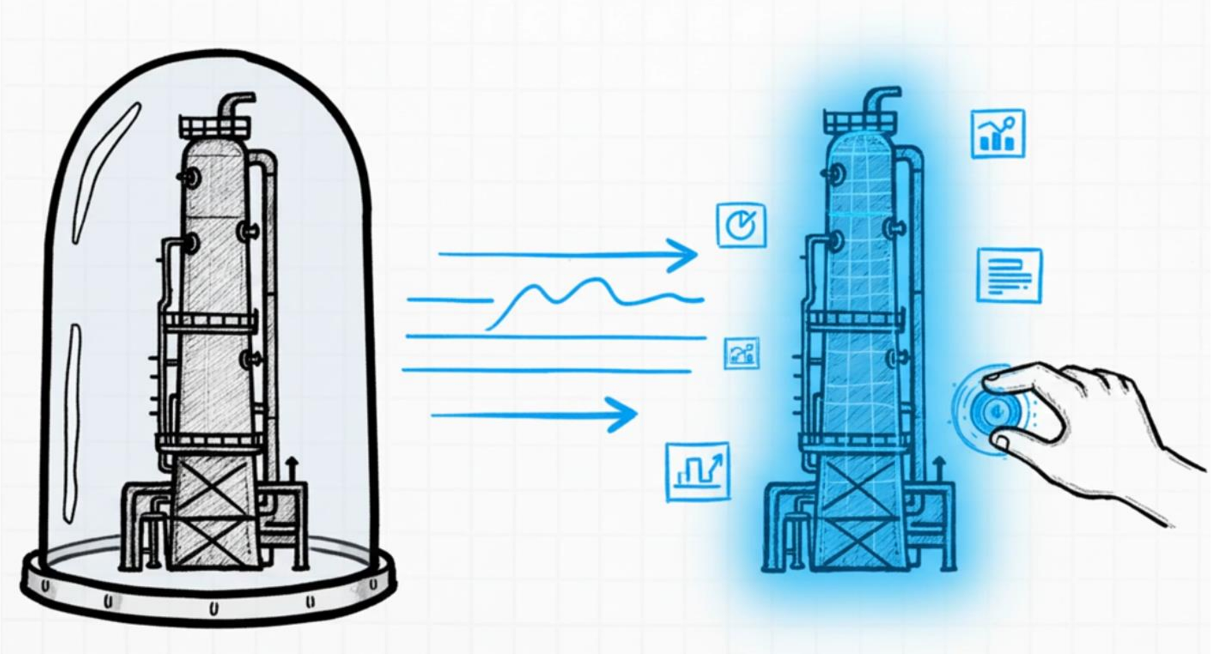


Figure 24 The Digital Twin

V.5 Socio-Economic and Technical Challenges

Despite the clear energy benefits, implementing AI at the GP1/Z complex faces specific challenges. Technical hurdles include the need for high-speed data integration and cybersecurity for industrial networks. Furthermore, there is a human element: the transition requires training the technical staff to work alongside AI tools. However, the economic incentive is undeniable. As energy costs and environmental regulations become stricter, the ability to shave 5.3 MW off a single train's consumption through software-driven optimization represents a massive competitive advantage for the Algerian energy sector **[18] [21].**

V.6 Conclusion

Integrating AI into the fractionation process is a strategic necessity that provides the operational vehicle to sustain theoretical gains. By embracing these future perspectives, the GP1/Z complex can transform from a traditional facility into an intelligent, data-driven leader in the global LPG market

General Conclusion

The aim of this work was to assess and optimize the energy consumption of both thermal and electrical within the fractionation train of the GP1/Z complex. In this regard, the technical shortcomings of the existing process where the GP1/Z complex operates at a fixed rate were addressed by considering the energy-intensive components of the process, namely the air condenser, reboiler, and pumps. The results of the analysis revealed that a constant rate of 470 m^3/h of the reflux process at different feed loads results in considerable energy "drift" and thermodynamic waste. Through Aspen HYSYS software, the optimization of the process was validated by simulating a dynamic approach to the process, where the reflux process adjusts in correlation to changes in feed loads. The results of the optimization are conclusive. In the case of a feed load of 240 m^3/h, considerable energy recovery of 5,355.34 kW was realized. These results offer a roadmap for the production department of the GP1/Z complex to modernize its fractionation process, enabling the complex to reduce its energy costs while enhancing industrial efficiency without compromising product specifications. "This study also goes beyond the current limitations of operation and proposes a transition to Industry 4.0 from the inclusion of Artificial Intelligence and Real Time Monitoring. The steady state Simulations in Aspen HYSYS demonstrated substantial energy savings at 5,355.34 kW; however, by using AI Supported Soft Sensing and Hybrid Modeling we create an appropriate platform to continuously sustain these benefits dynamically. The GP1/Z operating model can evolve from a conservative, fixed-rate operation model to a highly accurate, autonomous operating model through adopting a Digital Twin approach and real-time AI agents. This evolution will position the Algerian Petrochemical sector as a leader in Global Technological innovation with long term economic viability and lower carbon footprint."

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