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Innovating Air Cooling Systems for Efficient Liquefied Petroleum Gas (LPG) Production in High Ambient Air Temperature: A Case Study of the ZCINA Gas Treatment Plant in Algeria

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Dedication:

I dedicate this modest work to myself, my dear mother, my sister, my maternal grandmother, my maternal aunt, my maternal uncles and my friends who have supported me throughout this work.

To my partner in this work, whose collaboration and contribution have been invaluable in the completion of this project.

OULD KADA Radjaa Rekia

Dedication:

To all those I have immense gratitude for, especially my dear family

To my partner in this work, whose collaboration and contribution have been invaluable in the completion of this project.

MEBARKA Houssem Eddine

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Abbreviations

ACHE : Air Cooled Heat Exchanger
CAGR: Compound Annual Growth Rate
CINA : Centre Industrial Naili Abdelhalim
CIS : Centre Industriel Sud
CSTF : the Storage and Transfer Center, :the Storage and Transfer Center
HHV: High Heating Value
HYSYS : Hyprotech Systems
IEA : International Energy Agency
LDHP : Ligne Directe Haute Pression
LPG : Liquefied Petroleum Gas
NGL: Natural Gas Liquids
SP : Pumping Station
STP : Standard Temperature and Pressure
STPE : the Company of Transport of Energy Products
WSAC : Wet-Surface Air Coolers
ZCINA : Zone Centre Industrial Naili Abdelhalim

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Abstract

This dissertation examines the impact of ambient air temperature on the liquefaction process of Liquefied Petroleum Gas (LPG) in the ZCINA gas treatment plant situated in the Algerian desert. The objective is to enhance the efficiency and reliability of LPG production by addressing the challenges posed by high temperatures. Advanced engineering tools, specifically HYSYS simulation software, are employed to evaluate the performance of conventional cooling systems and propose modifications or alternative technologies to improve heat transfer efficiency. The research includes an investigation into the factors affecting the efficiency of existing cooling systems, a review of solutions from diverse industries facing similar challenges, identification of innovative approaches for LPG liquefaction, and the execution of experimental studies and simulations to assess proposed solutions. The dissertation specifically highlights the addition of extra fans to the air cooler unit as a key adjustment to enhance the liquefaction process. By leveraging the capabilities of HYSYS simulation software, the performance of the modified cooling system is rigorously analyzed.

Key words: Liquefied Petroleum Gas (LPG); liquefaction process; heat transfer; air-cooling system; high ambient air temperatures.

Résumé

Ce mémoire examine l'impact de la température de l'air ambiant sur le processus de liquéfaction du gaz de pétrole liquéfié (GPL) dans l'usine de traitement de gaz ZCINA située dans le désert algérien. L'objectif est d'améliorer l'efficacité et la fiabilité de la production de GPL en relevant les défis posés par les températures élevées. Des outils d'ingénierie avancés, en particulier le logiciel de simulation HYSYS, sont utilisés pour évaluer les performances des systèmes de refroidissement conventionnels et proposer des modifications ou des technologies alternatives pour améliorer l'efficacité du transfert de chaleur. La recherche comprend une étude des facteurs affectant l'efficacité des systèmes de refroidissement existants, un examen des solutions de diverses industries confrontées à des défis similaires, l'identification d'approches innovantes pour la liquéfaction du GPL, et l'exécution d'études expérimentales et de simulations pour évaluer les solutions proposées. La dissertation met particulièrement en évidence l'ajout de ventilateurs supplémentaires à l'unité de refroidissement de l'air comme un ajustement clé pour améliorer le processus de liquéfaction. En exploitant les capacités du logiciel de simulation HYSYS, les performances du système de refroidissement modifié sont rigoureusement analysées.

Mots clés : Gaz de pétrole liquéfié (GPL) ; processus de liquéfaction ; transfert de chaleur ; système de refroidissement par air ; températures ambiantes élevées.

ملخص

تبحث هذه الرسالة في تأثير درجة حرارة الهواء المحيط على عملية تسييل غاز البترول المسال (LPG) في محطة معالجة الغاز ZCINA الواقعة في الصحراء الجزائرية. الهدف هو تعزيز كفاءة وموثوقية إنتاج غاز البترول المسال من خلال مواجهة التحديات التي تفرضها درجات الحرارة المرتفعة. يتم استخدام الأدوات الهندسية المتقدمة، وتحديداً برنامج محاكاة HYSYS، لتقييم أداء أنظمة التبريد التقليدية واقتراح تعديلات أو تقنيات بديلة لتحسين كفاءة نقل الحرارة. يتضمن البحث دراسة العوامل التي تؤثر على كفاءة أنظمة التبريد الحالية، ومراجعة الحلول من الصناعات المتنوعة التي تواجه تحديات مماثلة، وتحديد الأساليب المبتكرة لتسييل غاز البترول المسال وتنفيذ الدراسات التجريبية والمحاكاة لتقييم الحلول المقترحة .تسلط الأطروحة الضوء بشكل خاص على إضافة مراوح إضافية إلى وحدة تبريد الهواء كتعديل رئيسي لتحسين عملية الإسالة. من خلال استغلال قدرات برنامج محاكاة HYSYS، يتم تحليل أداء نظام التبريد المعدل بدقة.

الكلمات المفتاحية: غاز البترول المسال (LPG)؛ عملية التسييل؛ انتقال الحرارة؛ نظام تبريد الهواء؛ درجات حرارة محيطة عالية.

General Introduction

General Introduction

Liquefied Petroleum Gas (LPG) has emerged as a versatile and efficient energy source, playing a significant role in meeting global energy demands. Composed primarily of propane and butane, LPG is derived from the refining of crude oil and natural gas processing. Its high energy content, portability, and clean-burning characteristics make it a preferred fuel for a wide range of applications, including residential, commercial, and industrial sectors [1].

Among the prominent regions contributing to global LPG production, Algeria stands out as a significant player. Situated in North Africa, Algeria boasts extensive natural gas reserves and a well-established petroleum industry. With advanced infrastructure and strategic positioning, Algeria plays a crucial role in the production and export of LPG. The country utilizes its abundant natural gas fields and employs modern processing and refining techniques to extract propane and butane, the key components of LPG [2]. Within this framework, the ZCINA gas treatment plant assumes a fundamental role, serving as a crucial facility within Algeria's energy infrastructure dedicated to the essential tasks of LPG liquefaction and purification.

ZCINA is a gas processing facility situated in the northern region of the Hassi Messouad field, located in the heart of the Algerian desert. the plant serves as a vital component in the production chain, ensuring the extraction and treatment of natural gas to obtain high-quality LPG. By efficiently processing and purifying natural gas, the plant facilitates the production of LPG that adheres to stringent quality standards.

LPG production undergoes various essential stages, and among them, a significant step is the process of liquification. This particular step relies on the fundamental principle of heat transfer.

Heat transfer is the phenomenon of thermal energy flowing from a region of higher temperature to a region of lower temperature. In the context of LPG production, it involves the transfer of heat to cool down and condense the LPG gas, causing it to transform into a liquid. Conventionally, this process heavily relies on refrigeration systems like air coolers that utilize cooling mediums, such as water or air, to extract heat from the gas and facilitate liquefaction. However, during summer when ambient air temperatures are excessively high, the efficiency of conventional cooling systems can be significantly compromised. The inability to effectively cool and condense LPG in such conditions not only hinders its storage and transportation but also leads to energy inefficiency and potential economic losses.

By addressing this issue, our objective is to ensure a reliable and efficient production process, even when temperatures are high. To achieve our objective, we will employ advanced engineering tools, such as HYSYS simulation software. This software will allow us to model and analyze the LPG liquefaction process in the ZCINA gas treatment plant under various ambient air temperature conditions. Through simulation-based approaches, we will evaluate the performance of the existing air-cooling system and propose potential modifications or alternative technologies that can enhance heat transfer efficiency, particularly in hot summer climates.

This dissertation aims to achieve the following objectives:

1. Investigate the impact of high ambient air temperatures on LPG liquefaction, analyzing the factors that affect the efficiency and performance of conventional cooling systems.
2. Review existing technologies and methods employed in various industries to overcome similar challenges related to liquefaction and cooling processes under elevated temperatures.
3. Identify potential innovative solutions for LPG liquefaction, such as advanced refrigeration systems, heat exchange techniques, thermal energy storage, and alternative cooling mediums.
4. Conduct experimental studies and simulations to evaluate the effectiveness and feasibility of the proposed solutions.

Our research is divided into two parts. The theoretical part provides a comprehensive understanding of LPG, heat transfer principles, and their relevance to LPG production. Additionally, we examine the ZCINA LPG plant, specifically focusing on the debutanization section and its process description, laying the groundwork for our practical investigation.

In the practical part, we empirically analyze the effects of high ambient air temperature on LPG plants' efficiency and productivity. We explore potential solutions, considering aspects such as plant design, process modifications, and operational adjustments. By evaluating and comparing the proposed solutions, we aim to identify the most suitable approach to mitigate the challenges caused by the rise in ambient air temperature.

At the end of this dissertation, a general conclusion summarizes the work accomplished and the main findings of our research.

Overall, our dissertation aims to make a significant contribution to the LPG industry in Algeria by providing practical solutions to overcome the challenges related to the rise in ambient air temperature. We hope that this research will stimulate further discussions and pave the way for ongoing improvements in LPG production, supporting sustainable development and the prosperity of the gas industry in Algeria

Part I : Theoretical background

Chapter I:

LPG: A Comprehensive Overview and Heat Transfer Insights

I.1. Liquified Petroleum Gas Overview

I.1.1. Introduction

Liquefied petroleum gas (LPG) is a versatile and frequently used energy source that has risen to prominence in the global energy scene. This chapter offers a thorough examination of LPG, concentrating on worldwide and Algerian usage patterns for LPG production, storage, transit, and consumption. By examining the dynamics of LPG in these contexts, we aim to gain insights into its importance, challenges, and potential for sustainable development.

LPG, which is mostly made of propane and butane, has grown to be a vital source of energy for a variety of applications, including residential, commercial, industrial, and transportation. Its high energy density, clean combustion qualities, and ease of use have all contributed to its widespread adoption as a dependable and efficient energy source.

At a global level, the chapter gives a thorough overview of LPG production, highlighting the major producing nations and regions. Shifting the focus to Algeria, a key player in the LPG market, we will explore the country's production capabilities, storage facilities, and transportation systems. Algeria has considerable natural gas deposits, which serve as the principal feedstock for LPG manufacturing. We will delve into Algeria's role as a major LPG producer, discussing production volumes, key regions, and the domestic and international market dynamics that shape its LPG industry. The chapter also looks into the usage patterns of LPG both globally and in Algeria, examining the demand drivers, market trends, and consumption patterns across different sectors, offering insights into the wide range of LPG applications.

Through this chapter, we aim to provide a comprehensive understanding of LPG, its production, storage, transportation, and consumption patterns, at both the global and Algerian levels. By analyzing the issues and opportunities associated with LPG, we hope to add to the knowledge base around this crucial energy source, paving the way for informed decision-making and long-term growth in the LPG sector.

I.1.2. Liquified Petroleum Gas (LPG)

LPG is a flammable mixture of hydrocarbon gases used as a fossil fuel closely linked to oil, almost two third of the LPG that is used is extracted directly from the Earth in the same way as Natural gas. The rest is manufactured indirectly from petroleum drilled from the Earth in wells (Crude oil). LPG is considered to be a mixture of two flammable nontoxic gases known as propane (C_3H_8) and butane (C_4H_{10}). Propylene and butylene are present in small concentrations too. Mainly the LPG gas is of no odor which makes it hard for people to detect the leakage if it happens, so a small amount of a pungent gas such as ethanethiol are added to help people smell potentially dangerous gas leaks [1].

I.1.3. Fuel Properties of LPG

LPG is a mixture of gases produced commercially from petroleum and stored under pressure to keep it in a liquid state. At atmospheric pressure, the boiling point of LPG varies depending on its composition, ranging from 229 K for propane to 273 K for butane, so that the pressure required to liquefy it is considerable and the containers for it must be of heavy steel. Additionally, LPG in its liquid state has a coefficient of expansion of approximately 0.25% per degree Celsius (or 0.14% per degree Fahrenheit), which means that its volume will expand when the temperature increases. This must be taken into account during storage (the spheres should never be completely filled).

LPG is composed primarily of propane with some butane, propylene, butylene, and other hydrocarbons, unlike gasoline, which is a complex mixture of hydrocarbons. The composition of LPG mixes and the higher heating value of each component are given in Table 1.

LPG's average octane value is 104, which is higher than gasoline's range of 84 to 97. The higher-octane value can produce significantly better vehicle performance than the lower octane gasoline [3].

With an approximate density of 0.55-0.58 kg/L at standard conditions (1 atm pressure, 15°C temperature), LPG is as twice as heavy as air and half as heavy as water and it is colorless and odorless. LPG produces less air pollutants and carbon dioxide than most other fuels; it helps to reduce the emissions of the typical house Fractionation of NGL to produce LPG [1].

The high energy content of LPG, as indicated by its high calorific value or heating value, is one of its most significant characteristics. The calorific values of different LPG gases vary, with normal butane having a calorific value of 29622 kcal/kg, isobutane having a calorific value of 29460 kcal/kg, and propane having a calorific value of 22506 kcal/kg [4].

In terms of pressure, 10 to 15 bar is typically the range for LPG in its liquid state. However, depending on the precise gas composition, LPG has a different vapor pressure. While butane has a vapor pressure of only around 2 bar at ambient temperature, propane has a vapor pressure of roughly 8 bar [2]. It's important to note that the vapor pressure of LPG increases as the temperature increases.

To ensure its safe usage, LPG must adhere to a set of quality requirements in terms of purity. Sulfur is among the most crucial pollutants to keep an eye on. LPG should have a sulfur concentration of 0.005% by mass or below. Water is another important impurity to monitor, as it can cause corrosion in LPG storage tanks and other equipment.

Assuming standard temperature and pressure (STP) of 15 °C and 1 atm, one liter of liquid propane will produce approximately 0.27 cubic meters (270 liters) of propane gas. Comparably, 0.22 cubic meters (220 liters) of butane gas can be created from one liter of liquid butane.

Table I.1.: Composition of LPG mixtures and HHVs of pure substances [2].

Component	% By volume	HHV ($MJkg^{-1}$)
Propane (C_3H_8)	60–85	50.4
Butane (C_4H_{10})	14–38	49.6
Pentane (C_5H_{12})	0–6	49.1
Isopentane (C_5H_{12})	0–0.2	49.0
Cyclopentane (C_5H_{12})	0–0.1	45.5
Ethylene (C_2H_4)	0–1.5	49.6
Other hydrocarbons	0–2	—

I.1.4. Versatile Applications of LPG as an Energy Source

LPG is very flexible in its use and, like natural gas, offers the particular advantage of being a clean fuel [5]. Its main uses are:

- LPG can be used as an alternative fuel to natural gas (methane) in residential and commercial sectors.
- In industries that require a clean fuel for their applications, such as glass and ceramic manufacturing and grain drying.
- It serves as one of the feedstocks in the production of olefins through steam cracking in petrochemical manufacturing. When LPG is heated to high temperatures during the steam cracking process in the presence of steam and a catalyst, it causes it to disintegrate

into smaller molecules, including olefins. These olefins can then be refined and processed further to create a variety of petrochemical products.

- It is sold as an alternative automotive fuel to petrol.

I.1.5. Global LPG Production

There are two sources of LPG: the recovery of propane and butane from oil and natural gas fields represents 60% of the resources. The production on fields is particularly important:

- In the United States, where there is a long tradition of extensive use. The production and consumption are balanced.
- In the Middle East, the production of LPG developed considerably at the end of the 1970s when the increase in the price of energy made it attractive to recover propane and butane. Previously, these products were burned with associated gas. The Middle East is currently the main source of LPG exports in the world.
- In North Africa and particularly in Algeria where LPG is mostly recovered from natural gas in liquefaction units. LPG is mostly recovered from natural gas in wet gas processing units. Refinery production provides the balance. Propane and butane are recovered from atmospheric distillation of crude oil and from cracking of heavy molecules in most processing and conversion units [6].

The main flows of LPG are from the Middle East to Japan and Southeast Asia. The world production of LPG has increased from 177.8 million tons in 1997 to 210 million tons in 2002, and up to 230 million tons in 2007 [7].

I.1.6. LPG Production in Algeria

Algeria is one of the major producers and is the second largest exporter of LPG in the world. Its production dropped to 8.4 million m^3 in 2006 against 8.6 million m^3 in 2005. 85% of the production comes from the gas units of the fields: Hassi R'mel, Stah, Adrar, Tin Fouyé, Tabenkort, Hamra, Rhoude Nouss, Hassi Messaoud, Berkaoui, and Oued Noumer. The total production of LPG is transported via the pipes, linking Adrar to Hassi R'mel with a length of 1000 km to collect the LPG produced in the gas fields of the south of the country to transport them to the storage and transfer center (CSTF) located in Hassi R'mel. There, they are cleaned of any traces of water before being sent to the SP4 pumping station and then forwarded to the separation complexes of Arzew and Bethioua. The rest of the production comes from the rest of the production comes from the Skikda and Bethioua LNG units and from the refineries.

Our country exported 8.04 million tons of these materials in 2003 and supplies 23 countries.

On the national market, the quantities sold amount to 1.85 million tons. The growth rate of the growth rate recorded during the year 2005 on the LPG market is 1.5%.

The national consumption of LPG (mainly butane at 90%) is satisfied through the territory, by the national consumption of LPG (90% of which is butane) is met through the territory, by transporting the product to the different regions by tanker trucks, by ships and recently by rail through the company of transport of energy products (STPE).

During the last decade, the Algerian LPG industry has experienced profound changes, especially in terms of production, export and shipping [2].

I.1.6.1. LPG Storage

LPG is stored using several techniques.

- Storage under pressure: LPG is stored in a liquid state under a pressure of 14 to 14.5 bars at room temperature and this pressure is maintained with fuel gas, in order to avoid the loss of LPG vapors which are released by boiling and which allows to have a smaller volume (over of 250 times). The tanks used for storage are spherical or cylindrical with horizontal axis (cigar) with different capacities, coated with a paint that reflects the heat and equipped with a safety valve.
- Refrigerated storage: under pressure, where liquefied gases are stored at temperatures close to or below 0°C. This allows for a significant reduction in storage pressure, as in the case of volatile products (e.g., propylene, butadiene stored at 0°C and 4.5 bar).
- Cryogenic storage: for non-condensable gases at room temperature. The storage pressure is slightly higher than the atmospheric pressure, the temperature is then close to the normal boiling temperature of the product [8].

I.1.6.2. LPG transportations

- Transport by pipelines: This mode of transport is used in the case of transferring large quantities of LPG from their point of recovery to separation units or to large storage facilities.
- Transport by tank car: For smaller quantities, it is preferable to use the railway. In this case the train consists of several tank cars with a unit capacity of 50 tons. The tank cars are pressurized and manufactured according to controlled standards. This mode of

transport is mainly used for the delivery of LPG from refineries to primary storage or from primary to secondary storage.

- Transport by ship (maritime transport): This mode of transport is frequently used for international trade. In this case, LPGs are stored in refrigerated tanks (down to -50°) or under pressure.
- Transport by truck - tanker: This is the most commonly used mode of transport for the transportation of small quantities of LPG over short distances from storage centers to users [8].

I.1.7. LPG Operation and Consumption

I.1.7.1. On a Global Scale

Based on data from the International Energy Agency (IEA) for the year 2019, the global consumption of LPG was distributed among several sectors:

- Residential: Approximately 114 million metric tons of LPG were consumed in the residential sector, accounting for around 37% of total global LPG consumption.
- Industrial: The industrial sector consumed around 95 million metric tons of LPG, representing approximately 31% of total global LPG consumption.
- Transportation: LPG consumption in the transportation sector was around 23 million metric tons, accounting for approximately 7% of total global LPG consumption.
- Commercial: LPG consumption in the commercial sector was around 22 million metric tons, representing approximately 7% of total global LPG consumption.
- Agriculture: The agricultural sector consumed approximately 19 million metric tons of LPG, accounting for around 6% of total global LPG consumption.

By the year of 2020, the global LPG market attained a volume of about 325.44 million metric tons. The market is further expected to grow in the forecast period of 2023-2028 at a CAGR of 1.7% to reach 354.06 million metric tons by 2026 [9].

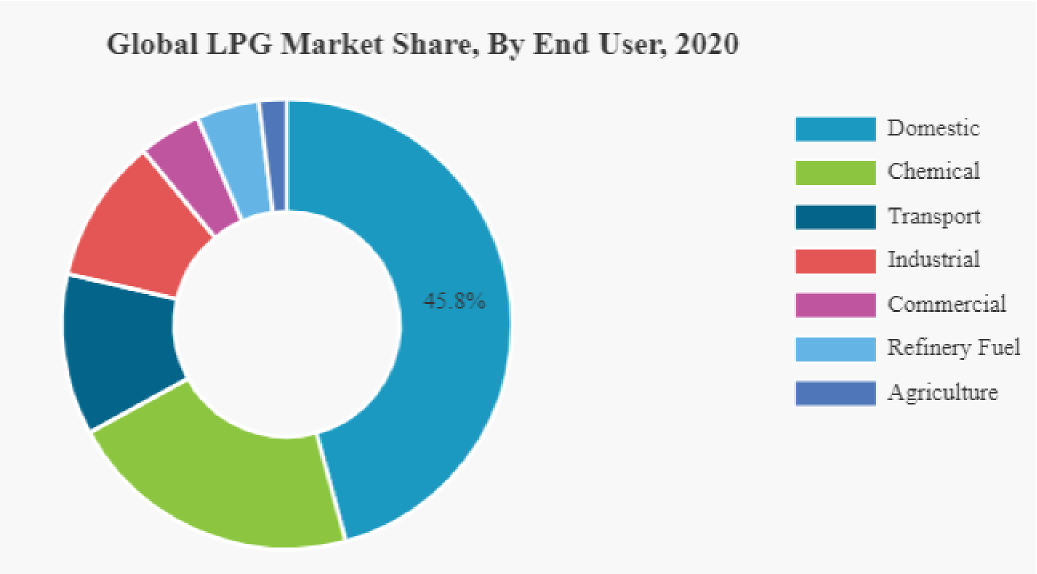


Figure I.1. The global LPG consumption per sector, 2020 [10].

I.1.7.2. In Algeria

According to NAFTAL sources, the level of national demand for LPG in Algeria is 1.4 million tons, of which 90% is butane, 5% is propane and 5% is LPG fuel (LPG/c) [8]. This demand is distributed as follows between the three main regions of the country:

- Western Region: LPG demand in the Western Region is approximately 336,000 tons, which represents 24% of the total national LPG demand.
- Eastern Region: The region accounts for the largest share of the national LPG demand, with about 516,000 tons, representing 37% of the total demand.
- Central Region: LPG demand in the Central Region is approximately 401,000 tons, or about 29% of total demand.

These figures indicate a high demand for LPG in Algeria, with a fairly balanced geographical distribution between the Eastern and Central regions, while the Western region represents a relatively smaller share of total demand. This may be due to factors such as population density and economic development levels in each region, as well as energy consumption patterns.

I.1.8. Conclusion

It's crucial to understand that the manufacturing of LPG is strongly related to heat exchange since the conversion of natural gas into a liquid form requires cooling and liquefaction, which consumes a lot of energy and produces a lot of heat.

Heat exchange plays a vital role in maximizing the energy efficiency of the production process. Efficient heat exchange systems are essential for capturing and transferring heat during the cooling and liquefaction process. This leads to more effective LPG production with less energy loss and environmental impact.

I.2. Heat Transfer

I.2.1. Introduction

Heat transfer is a fundamental concept in the study of thermodynamics and plays a crucial role in many engineering and scientific fields, it involves the transfer of thermal energy from one location to another, and can occur through various mechanisms, including conduction, convection, and radiation.

The understanding of heat transfer is critical for designing systems that involve the exchange of energy, including heat exchangers and their important role in the field of industry today. Additionally, heat transfer can explain natural phenomenon and their occurrence, condensation for example, is a convection process of changing a vapor medium to a liquid state and generally occurs when a saturated vapor comes into contact with a cold solid surface at a temperature less than the saturation temperature of the vapor.

In this chapter, we will explore the nature of heat transfer and its mechanics, and its contribution in engineering process, giving an overall idea about the equipment that is based on heat transfer as a processing concept, and their fields of applications.

I.2.2. Understanding Heat Transfer

Heat transfer is the term applies to a study in which the details or mechanisms of the transfer of energy in the form of heat are identified and modeled [10].

The basic requirement for heat transfer is the presence of a temperature difference. It flows from regions of higher temperature to regions of lower temperature. There can be no net heat transfer between two mediums that are at the same temperature. The difference is the driving force for electric current flow and pressure difference is the driving force for fluid flow [11].

Heat transfer occurs by three basic mechanisms or modes, conduction, convection, and radiation. The following figure is a perfect example of a real-life experience including the three modes of heat transfer:

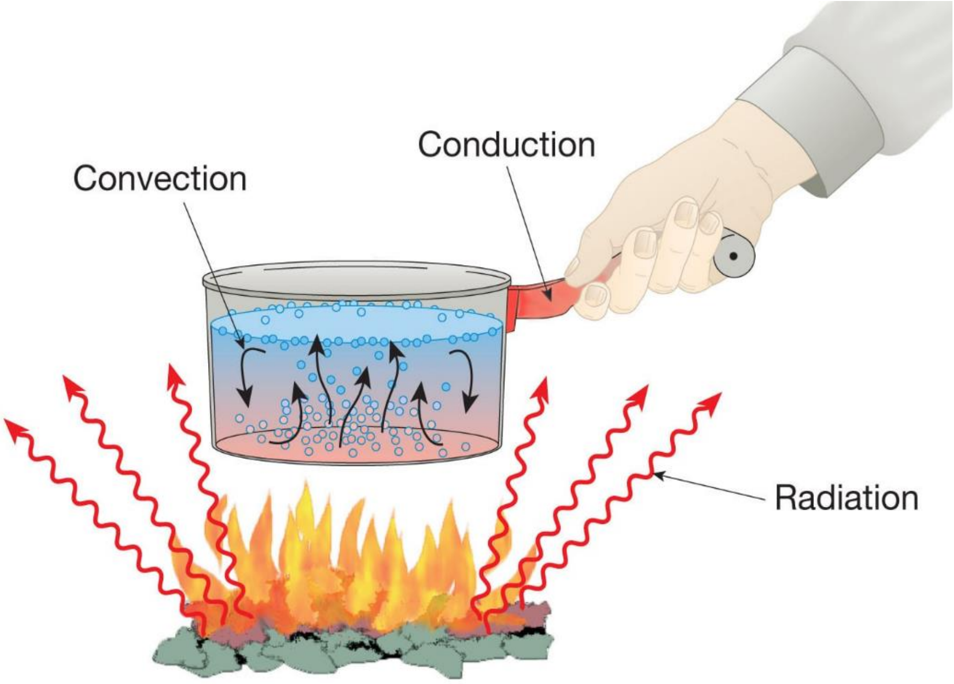


Figure I.2. Conduction, Convection and Radiation happening concurrently as a pot of water heats up over a fire [16].

I.2.3. Mechanisms of Heat Transfer

I.2.3.1. Conduction

Conduction is a mode of heat transfer from a region of high temperature to a region of low temperature within a solid, liquid or gas medium or between different mediums which are in physical contact with each other [12].

At steady state the rate of heat transfer depends on the nature of the material and the temperature differences and is expressed by Fourier's law as:

$$q_x = -kA\frac{dT}{dx} \quad \frac{J}{s} = W \quad \textbf{Eq I.1}$$

where q_x is the rate of heat transfer in the x direction [W]; A is the area normal to the direction of heat flow [m^2]; dT/dx is the temperature gradient in the x direction [K/m]; and k is the thermal conductivity, defined as the heat going through a cube of the material in question 1 m on a side resulting from a temperature difference on opposite faces of 1 °C [13].

An important parameter in heat transfer by conduction is the thermal resistance of the material. Thermal resistance is a quantification of how difficult it is for heat to be conducted. Thermal resistance is represented as the quotient of the temperature difference between two given points by the heat flow between the two points (amount of heat flow per unit time). This means that the higher the thermal resistance, the more difficult it is for heat to be conducted, and vice versa.

$$R_\theta = \frac{\Delta T}{P} \quad \text{.....................................} \quad \textbf{Eq I.2}$$

R_θ: Thermal Resistance [$°C/W$]

ΔT: Temperature Difference [°C]

P: Heat Flow [W]

For conduction heat transfer, thermal resistance is presented as follow [14]:

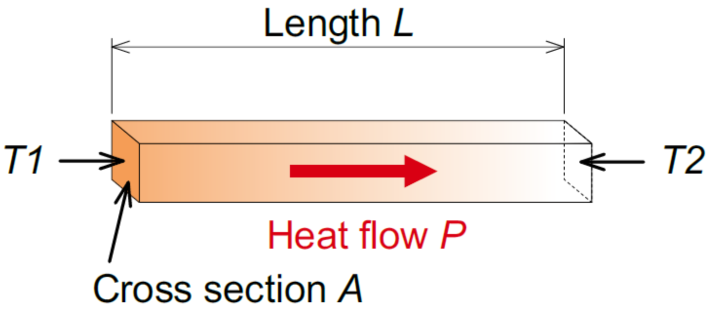


Figure I.3. thermal resistance of conduction heat transfer.

$$R_\theta = \frac{L}{\lambda \times \, Cross\ section\ A} \quad \text{.....................................} \quad \textbf{Eq I.3}$$

R_θ: Thermal Resistance [$°C/W$]

L: Length [m]

λ: $Th\ ermal\ conductivity$ [W/m.k]

A: Cross section [m]

In engineering applications, heat transfer by conduction is commonly encountered in materials science, manufacturing, and thermal management of electronic devices, such as:

- Heat sinks
- Boilers and heat exchangers
- Thermoelectric cooling

- Welding and metalworking

I.2.3.2. Convection

The convection mode of heat transfer actually consists of two mechanisms operating simultaneously. The first is the energy transfer due to molecular motion, that is, the conductive mode. Superimposed upon this mode is energy transfer by the macroscopic motion of fluid parcels. The fluid motion is a result of parcels of fluid, each consisting of a large number of molecules, moving by virtue of an external force. This extraneous force may be due to a density gradient, as in natural convection, or due to a pressure difference generated by a pump or a fan, or possibly to a combination of the two [15].

Heat transfer by convection can be described mathematically using the following equation:

$$Q = hA(Ts - Tf) \quad \textbf{Eq I.4}$$

Q: rate of heat transfer [W/m^2]

h: the convective heat transfer coefficient [W/m^2.k]

Ts: the surface temperature [°C]

Tf: the fluid temperature [°C]

As the convective transfer heat mode consist of an exchange of heat between a surface and a moving fluid, a thin layer of fluid near the surface is affected by the fluid motion and temperature gradients. This layer is known as the boundary layer δ. The boundary layer thickness increases with distance from the surface, and heat transfer by convection is most efficient near the surface where the boundary layer is thinnest.

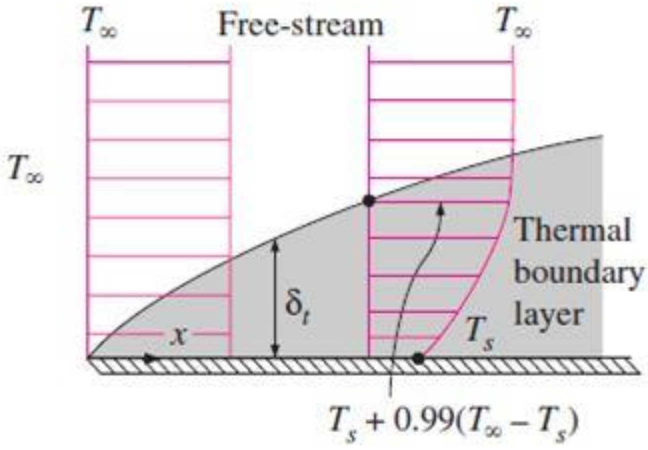


Figure I.4. Thermal Boundary Layer [10].

Consider the flow of a fluid at a uniform temperature of T∞ over an isothermal flat plate at temperature Ts. The fluid particles in the layer adjacent to the surface will reach thermal equilibrium with the plate and assume the surface temperature Ts. These fluid particles will then exchange energy with the particles in the adjoining-fluid layer, and so on. As a result, a temperature profile will develop in the flow field that ranges from Ts at the surface to T∞ sufficiently far from the surface. The flow region over the surface in which the temperature variation in the direction normal to the surface is significant is the thermal boundary layer. The thickness of the thermal boundary layer δ_t at any location along the surface is defined as the distance from the surface at which the temperature difference T−Ts equals0.99(T∞−Ts) [16].

I.2.3.3. Radiation

Radiation, or more correctly thermal radiation, is electromagnetic radiation emitted by a body by virtue of its temperature and at the expense of its internal energy. Thus, thermal radiation is of the same nature as visible light, x rays, and radio waves, the difference between them being in their wavelengths and the source of generation [17].

The quantity of energy leaving a surface as radiant heat depends on the absolute temperature and the nature of the surface. A perfect radiator, which is referred to as a blackbody, emits radiant energy from its surface at a rate as given by

$$q_r = \sigma A_1 T_1^4 \quad \text{.................................... \textbf{Eq I.5}}$$

The heat flow rate q_r is in watts if the surface area A, is in square meters and the surface temperature T_1 is in Kelvin; σ is a dimensional constant with a value of 5.67 x 10^{-8} [W/m^2 K^4] [15].

If we consider a black body with surface temperatures T_1 which radiates to another black body with surface temperature T_2 that completely surrounds it, the second black body completely absorbs the incident energy and emits radiant energy that is proportional to T_2^4. The net rate heat transfer by thermal radiation is then given by [18]:

$$q = \sigma A(T_1^4 - T_2^4) \qquad \textbf{Eq I.6}$$

I.2.4. Condensation

I.2.4.1. A Defining Overview

Condensation is a convection process associated with a phase change of a fluid. This process occurs at solid-fluid interfaces, and latent heat transfer effect are involved. In condensation, the magnitude of the heat transferred at the solid surface is sufficient to sustain the phase change.

It was remarked that condensation is convection process. It is classified as such because there is a fluid motion near a solid surface. The change in phase, however, is unique and occurs without a change in fluid temperature. Heat transfer rates (and coefficients) are much higher than those encountered in other convection problems [10].

I.2.4.2. Condensation Heat Transfer

Consider a solid surface at some temperature T_w in contact with a vapor at an elevated temperature T_∞. If the surface temperature T_w is less than the saturation temperature of the vapor, then the vapor will begin to condense on the surface. That is, the vapor will undergo a phase change, forming a liquid that will flow downward along the surface under the action of gravity. If the liquid does not wet the surface, the condensate takes the form of droplets that fall downward in a random fashion (just like water droplets along the side of a waxed automobile surface). This is called *dropwise condensation*; the droplets do not exhibit an affinity for the surface and do not coat it. Steam is the only pure vapor known to condense in a dropwise manner, and special conditions must be met for this to occur.

Another way in which a vapor condenses on a surface is by forming a smooth film. The liquid wets the surface, which becomes completely covered with liquid. During the process, known as filmwise condensation, the liquid film falls under the action of gravity and grows in thickness with increasing distance. A temperature gradient exists across the film from the surface temperature to the saturation temperature at the free surface. The film thus represents a thermal resistance to heat transfer [10].

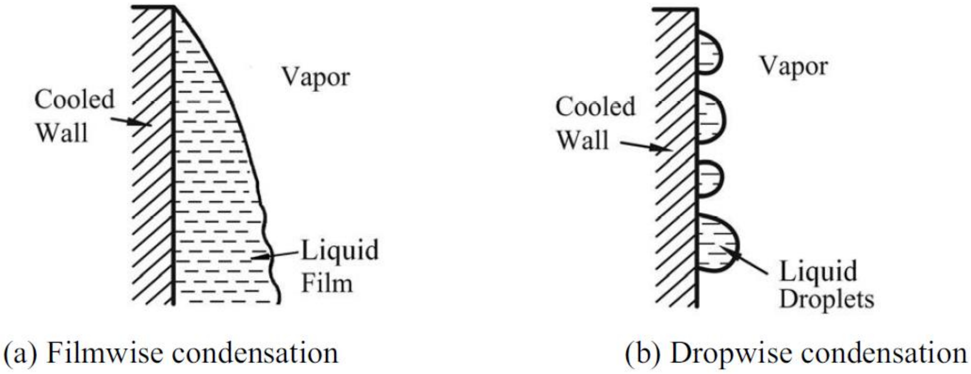


Figure I.5. Filmwise & Dropwise condensation [17].

I.2.5. Heat Exchangers

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more environments using a working fluid and a working surface having different temperatures. Heat transfer can occur between a solid surface and a liquid, between solid particles and a liquid, etc.

Heat exchangers play an important role in technological processes, energy, oil refining, manufacturing, transportation, air conditioning, cryogenic and recovery systems. They also serve as key components of many industrial products available on the market. All heat exchangers can be classified according to various criteria [19].

I.2.5.1 Heat Exchangers Fields of Applications

Heat exchangers are used in many different technological processes, their versatility makes them a valuable component in many different industries. Following, we have some types of heat exchangers and their main purpose [19].

- Chiller: a heat exchanger that uses refrigerant to cool a liquid through a vapor compression or absorption refrigeration cycle.
- Condenser: condenses steam or a mixture of vapors with or in the presence of non-condensing gases.
- Cooler: cools a liquid or gas, usually using water.
- Heat exchanger: cools one liquid while heating another.
- Heater: transfers heat to a liquid or gas by contact with a heated surface.

- Reboiler: generates steam through fractional distillation. Heating occurs with the help of a heating element, as a result of which condensation of steam occurs.

I.2.5.2. Classification of Heat Exchangers

I.2.5.2.1. «Pipe-in-pipe» Heat Exchangers

Pipe in pipe heat exchangers, also known as double pipe heat exchangers, are a type of heat exchanger that consists of two concentric pipes of different diameters, with one pipe inside the other. The space between the two pipes is the heat transfer area where the two fluids exchange heat. The inner pipe carries the hot fluid while the outer pipe carries the cold fluid. The hot fluid transfers its heat to the cold fluid through the pipe wall. The two fluids flow in opposite directions to maximize the temperature difference and heat transfer rate. The flow rate and temperature of the two fluids can be adjusted to optimize the heat transfer efficiency.

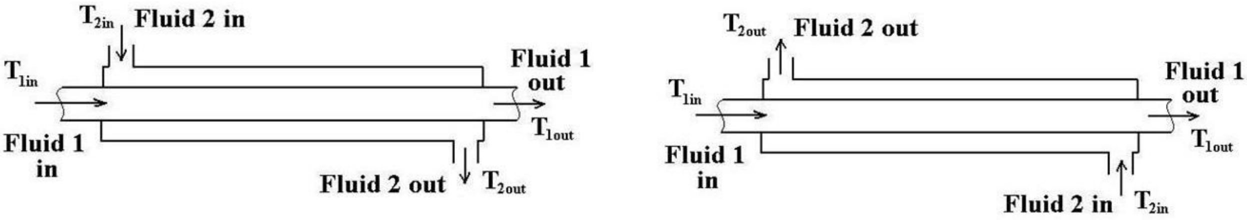


Figure I.6. Parallel & counter-flow double pipe heat exchangers [18].

- **Advantages «pipe-in-pipe» heat exchangers**
  - High flow rate of the coolant.
  - Ease of maintenance.
  - Versatility.
- **Disadvantages of «pipe-in-pipe» heat exchangers**
  - difficulties due to dimensions and large size.
  - high cost.
  - difficulties in the design [19].

I.2.5.2.2 Shell-and-tube Heat Exchangers

The shell-and-tube heat exchanger includes a tubular tank and an integrated tubing section. The heat carriers in the heat exchanger are directed both parallel and towards each other. Shell-and-tube heat exchangers are used in the chemical, food, oil and gas and other fields. They are used as evaporators and condensers. Depending on the operating conditions of the equipment, it is installed in a vertical or horizontal position [19].

The fluids can flow in a variety of configurations, including parallel flow, counterflow, and crossflow, depending on the application and desired heat transfer efficiency. In parallel flow, both fluids flow in the same direction, entering and exiting the heat exchanger at the same end. In counterflow, the two fluids flow in opposite directions, entering and exiting at opposite ends of the heat exchanger. In crossflow, the two fluids flow perpendicular to each other, with one fluid flowing through tubes and the other flowing across the tubes in a shell.

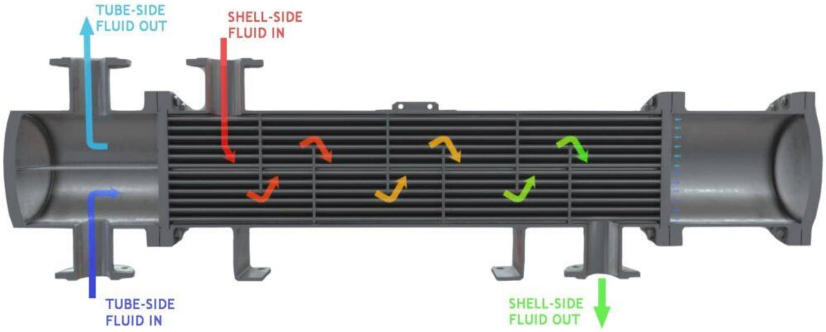


Figure I.7. Shell-and-tube Heat Exchanger.

- **Advantages of Shell-and-tube heat exchangers**
  - Internal reliability.
  - Possibility of power regulation.
  - Long service life.
- **Disadvantages of Shell-and-tube heat exchangers**
  - Large dimensions.
  - Vulnerability of the outer part of the case.
  - Energy losses due to efficiency.

I.2.5.2.3 Plate Heat Exchangers

Plate heat exchangers are a type of heat exchanger that consists of a stack of metal plates with alternating corrugations that create channels for the two fluids to flow through. The plates are sealed together with gaskets or brazing to prevent leaks. The direction of flow is counter-current. The power of the heat exchanger is determined by the number of plates installed inside. Service, cleaning and repair of the device is done by disassembling it. Areas of use: housing and public utilities, shipbuilding, metallurgy, oil and gas, pharmaceutical industries and so on. The choice of material of the heat exchanger must be carried out depending on the technological process, the type of coolants in the system, temperature load and pressure. The most universal in application: plate heat exchangers made of stainless steel with copper pipes [19].

Figure I.8. Plate Heat Exchanger [19]

- **Advantages of plate heat exchangers**
  - High efficiency.
  - Compactness.
  - Multifunctionality.
  - The cost of the device depends on the number of plates installed in it.
- **Disadvantages of plate heat exchanger**
  - Short service life [19].

I.2.5.2.4. Air-cooled heat exchangers

Air-cooled heat exchangers use ambient air to cool and condense the working medium. They are usually used in places where there is a shortage of cold water. Air-cooled heat exchangers are commonly used when the temperature at the outlet of the heat exchanger is at least 20° C higher than the ambient temperature. They can be designed for closer temperatures, but often become expensive compared to a combination of a cooling tower and a water-cooled heat exchanger. Air-cooled heat exchangers use electric fans to move air through a series of pipes [19]. There are two main mechanisms:

- Induced draft fans draw air through the tube blocks.
- Fans blow air through a series of pipes.

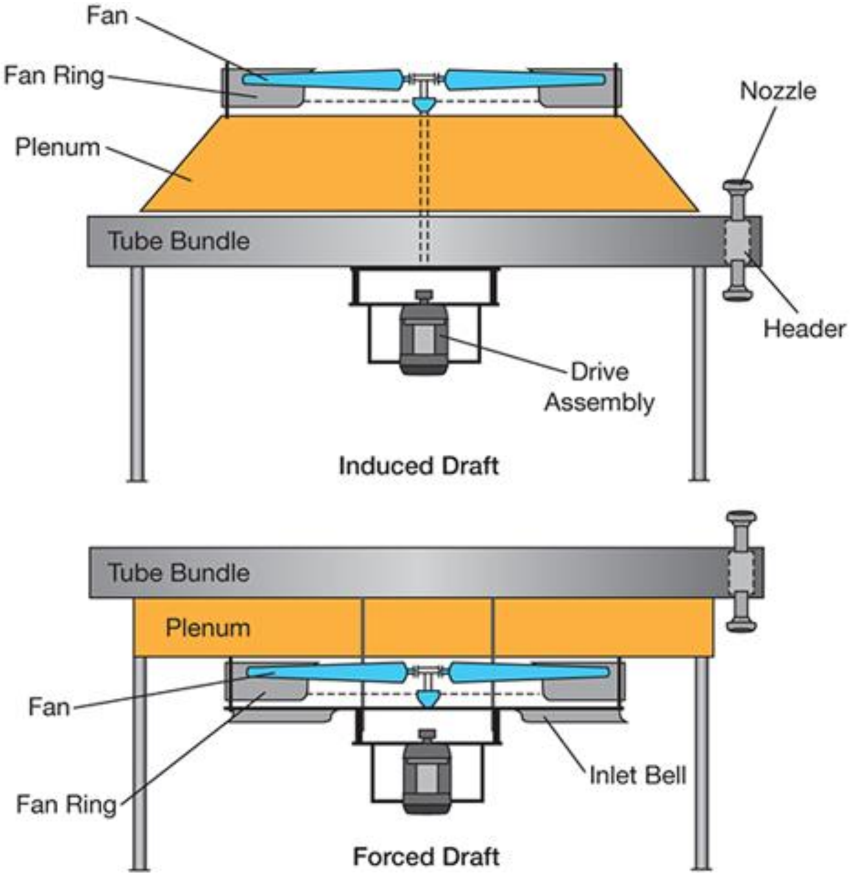


Figure I.9. Types of Air Fin Fan Coolers.

- **Advantages of air-cooled heat exchangers**
  - No Water Required.
  - Environmentally Friendly.
  - Lower Operating Costs.
  - Increased Safety.
- **Disadvantages of air-cooled heat exchangers**
  - Requires a large area of the site.
  - Ribs may become clogged in dirty environments.
  - Lower Heat Transfer Efficiency.
  - Noise and Vibration.

I.2.6. Different strategies to improve industrial heat exchange

To enhance industrial heat transfer, process and equipment designers have access to a variety of strategies. These strategies encompass various approaches, ranging from the development of efficient heat exchanger designs to the integration and intensification of processes. Heat transfer enhancement, is the process of enhancing or intensifying the performance of heat transfer. In the present day, a considerable number of researchers in thermal engineering are actively exploring novel methods to enhance heat transfer between surfaces and the surrounding fluid.

Bergles [20] categorized the mechanisms of heat transfer enhancement into two types: active and passive methods. Active methods refer to those that rely on external power to maintain the enhancement mechanism. An active enhancement method includes agitating the fluid or vibrating the surface was studied by E. I. Nesis et. Al. [21].

On the other hand, passive enhancement methods are characterized by not relying on external power to maintain their effectiveness. These methods encompass a broad spectrum of approaches and techniques, such as (a) treating surfaces, (b) utilizing rough surfaces, (c) employing extended surfaces, (d) incorporating displacement enhancement devices, (e) using swirl flow devices, (f) employing coiled tubes, (g) utilizing surface tension devices, (h) incorporating additives for fluids, and numerous others.

The mechanisms of heat transfer enhancement can be at least one of the following:

- Use of a secondary heat transfer surface.
- Disruption of the unenhanced fluid velocity.
- Disruption of the laminar sublayer in the turbulent boundary layer.
- Introducing secondary flows.
- Promoting boundary-layer separation.
- Promoting flow attachment/reattachment.
- Enhancing effective thermal conductivity of the fluid under static conditions.
- Enhancing effective thermal conductivity of the fluid under dynamic conditions.
- Delaying the boundary layer development.
- Thermal dispersion.
- Increasing the order of the fluid molecules.
- Redistribution of the flow.
- Modification of radiative property of the convective medium.
- Increasing the difference between the surface and fluid temperatures.
- Increasing fluid flow rate passively.

- Increasing the thermal conductivity of the solid phase using special nanotechnology fabrications.

Heat transfer improvements resulting from filling either the entire fluidic volume or a portion of it with a porous medium occur through the following mechanisms [22,23]:

- Enhancing effective thermal conductivity of the fluid under static conditions.
- Enhancing effective thermal conductivity of the fluid under dynamic conditions.
- Delaying the boundary layer development.
- Thermal dispersion.
- Increasing the order of the fluid molecules.
- Redistribution of the flow.
- Modification of radiative property of the convective medium.

From the concise summary about mechanisms of enhancing heat transfer described in last section, it can be concluded that these mechanisms can not be achieved without the presence of the enhancing elements. These elements will be called as “heat transfer enhancers”. The following heat transfer enhancers were reported were reported by previous studies:

a. *Heat Transfer Enhancement Using Extended Surfaces (Fins) :* Fins are quite often found in industry, especially in heat exchanger industry as in finned tubes of double-pipe, shell-and-tube and compact heat exchangers [24,25]. As an example, fins are used in air cooled finned tube heat exchangers like car radiators and heat rejection devices. Also, they are used in refrigeration systems and in condensing central heating exchangers. Moreover, fins are also utilized in cooling of large heat flux electronic devices as well as in cooling of gas turbine blades [26]. Fins are also used in thermal storage heat exchanger systems including phase change materials [27,28].

b. *Heat Transfer Enhancement Using Porous Media :* Porous media are used to enhance the rate of heat and mass transfer in energy systems. The values of Nusselt number in presence of porous media are approximately 50% above the values predicted for laminar flows in channels without porous materials [29].

c. *Heat Transfer Enhancement Using Fluids with Large Particles Suspensions :* Huge number of investigations has been carried out in the past in order to seek for developing novel passive methods for enhancing the effective thermal conductivity of the fluid or increasing the convection heat transfer coefficient. One of the methods is introducing into the base liquid high thermally conductive particulate solids such as metals or metal oxides [29].

d. *Heat Transfer Enhancement Using Nanofluids :* Nanofluids are fluids that contain suspensions of nanoparticles of high thermally conductive materials like carbon, metals, and metal oxides into heat transfer fluids to improve the overall thermal conductivity. These nanoparticles are usually of order 100 nm or less [30].

e. *Heat Transfer Enhancement Using Phase-Change Devices :* A heat pipe is an efficient compact device with a simple structure and no moving parts that allows the transfer of a large amount of heat from various engineering systems through a small surface area. It basically consists of a duct closed at both ends whose inside wall is covered with a layer of a porous wicking material saturated with the liquid phase of the working fluid while the vapor phase fills the central core of the duct [29].

f. *Heat Transfer Enhancement Using Flexible Seals :* Single layered (SL) and double layered (DL) microchannels supported by flexible seals are analyzed in the woks of Vafai and Khaled [31]. In their work, they related the deformation of the supporting seals to the average internal pressure by the theory of elasticity They showed that cooling effect due to hydrodynamic expansion increases as Prandtl number decreases.

g. *Heat Transfer Enhancement Using Flexible Complex Seals :* Khaled and Vafai [32] have also demonstrated that significant cooling inside flexible thin films including flexible microchannel heat sinks can be achieved if the supporting seals contain closed cavities which are in contact with the heated surface.

h. *Heat Transfer Enhancement Using Vortex Generators :* Acharya et al. [33] conducted experiments using internally ribbed channel with cylindrical vortex generators placed above the ribs. They studied the effect of the spacing between the vortex generators and the ribs.

i. *Heat Transfer Enhancement Using Protrusions :* The effect of repeated horizontal protrusions on the free-convection heat transfer in a vertical, asymmetrically heated, channel has been experimentally investigated by Tanda [34]. For the ranges of parameters studied, the addition of low-conductivity protrusions leads to a decrease in the average heat transfer coefficient, as compared to that for the smooth surface, in the 0–7% range for the largest channel aspect ratio and in the 18–43% for the smallest channel aspect ratio.

j. *Heat Transfer Enhancement Using Ultra High Thermal :* Conductivity Composite Materials. Composite materials have been used primarily for structural applications. An example of such these materials is the metal matrix composite (MMC) [29].

In the future, as the range of superior heat exchange equipment expands, the task of engineering design will be anything but routine. Proficiency in selecting appropriate heat exchangers will become just as important as the skills required for designing them.

I.2.7. Conclusion

Overall, heat transfer is a critical process in many engineering and scientific applications, playing a vital role in industrial and engineering areas. Through our examination of condensation heat transfer and heat exchangers, we have gained an understanding of the mechanics of these processes, the factors that affect their efficiency, and their advantages and disadvantages in various contexts.

Chapter II: Exploring the ZCINA Plant

II.1. Introduction

The Hassi Messaoud field is one of the largest and most complex oil fields in the world and the largest in Algeria, it is located in the north of the Algerian Sahara [35]. During geological history, this deposit has undergone intense tectonic evolution during its burial until the deposit took its present form. These events can enhance the Petro-physical parameters (natural fracturing, dissolution etc.....) as well as reducing them (reduction of porosity, cementing of grains, creation of small grain matrices, creation of impermeable barriers etc....). This field covers an area of about 2500 km^2. Discovered in 1956 and put into production in 1958, the Hassi Messaoud deposit continues, after more than 50 years, to provide Algeria with the natural resource of crude oil. Significant investments have been made and more will be made in the future to extract the maximum amount of oil and thus increase the final recovery [36]. One of those investments is the ZCINA gas processing complex/unit which is located to the north of the Hassi Messaoud field.

II.2. General description of ZCINA plant

II.2.1. Purpose of the ZCINA plant

LPG ZCINA (new Zone Centre Industrial Naili Abdelhalim) was built upon the decision of Sonatrach to construct a new unit to extract associated gas liquids on the Hassi Messaoud North field.

LPG ZCINA is an associated gas liquids extraction unit designed to receive associated gases from the CINA crude processing unit on the Hassi Messaoud North field and to return depleted gas to CINA and ship the LPG extracted from the feed gas to a new pumping station located at 17 km away (station not supplied). This new unit will be located approximately 5 km north of CINA. Some of the LPG plant feed gas may also come from the LDHP oil separation unit in ZCINA, also located at ZCINA [37].

II.2.2. Presentation of the ZCINA plant

This plant includes :

- Connections to CINA's existing 40" associated gas line, to bring in the feed gas and export the residual gas.
- A feed gas receiving section.
- A feed gas compression unit.

- Three gas processing trains including a gas dehydration section, a liquids recovery section, a separation section recovery section, LPG and condensate separation section, and a hot oil system.
- LPG storage and shipping pump house.
- Condensate storage and pump house.
- Utility systems.
- Flare systems.
- Product shipping lines (LPG, condensate).
- Infrastructure and buildings.

II.2.2.1. Overall description of the process

The facilities are designed to recover associated gas liquids from the CINA crude processing plant and the LDHP oil separation unit.

The gas treatment consists, after receiving the gas from the existing line to the gas re-injection sections located at CIS, of compressing the gas to high pressure, then it is dehydrated and then expanded in a turbo-expander.

The resulting gas is rectified in an absorber and the resulting liquid is stripped in a deethanizer to extract the liquid in the feed gas. A heat exchange train allows the integration of all these operations. A hot oil system provides the additional heat required.

The depleted residual gas is re-compressed in the existing gas line to the gas re-injection sections at the CIS, via the re-compressor directly coupled to the turbo-expander. The extracted liquids are finally separated in a debutanizer to obtain LPG and condensate to the desired specifications [37].

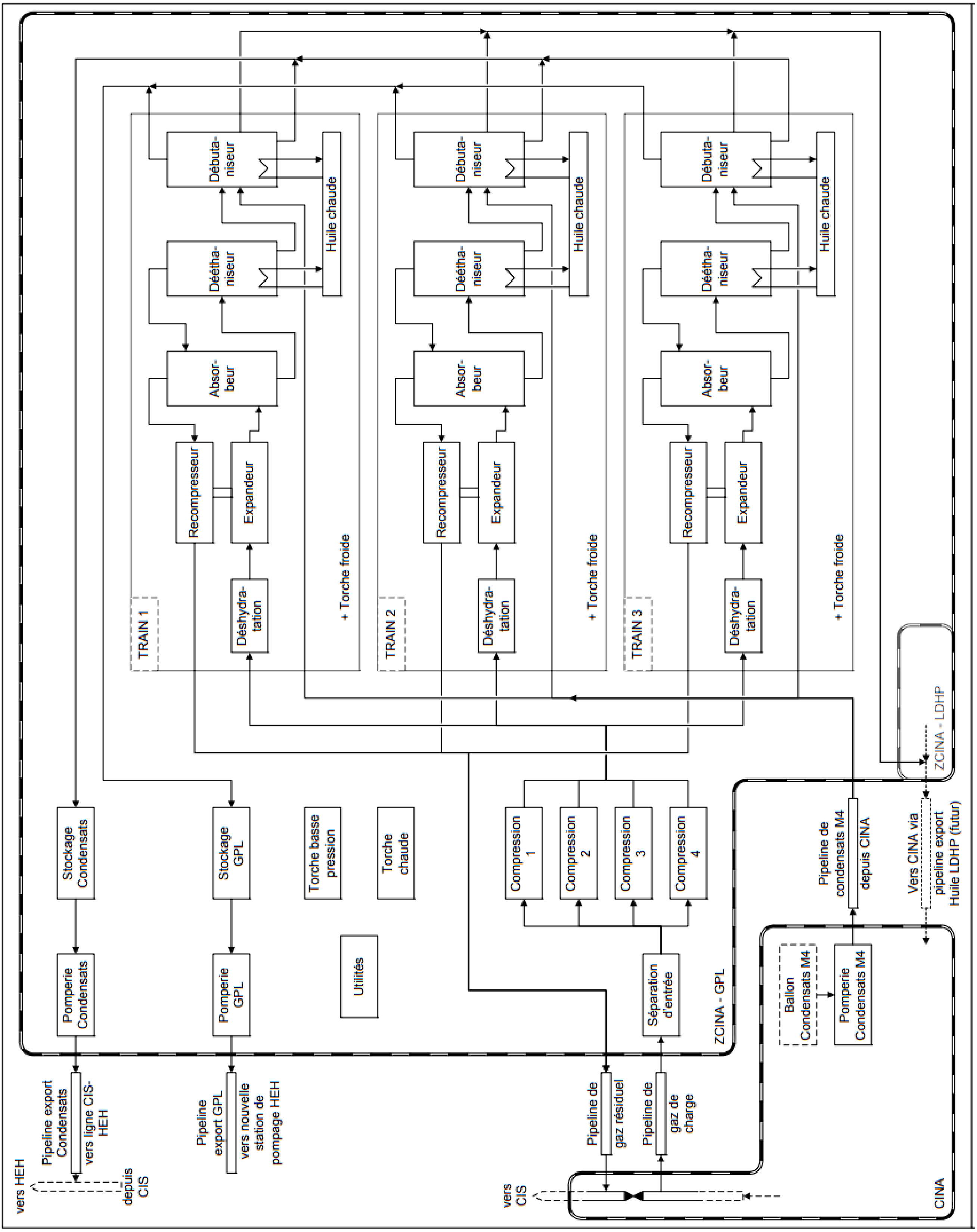


Figure.II.1. Block diagram of the ZCINA LPG plant [37].

II.2.2.2. Units of ZCINA plant

We can encounter two types of units in the plant:

1) **Process units :**

- Gas delivery systems :
  - Charge gas line from CINA (Unit 27).
  - Inlet separation (Unit 20).
- Feed gas compression (Unit 23).
- Dehydration of feed gas (Unit 24).
- Liquid Supply Systems :
  - CINA M4 condensate import & distribution (Unit 37).
- Liquid Treatment Trains (Unit 32) :
  - Cooling section & Deethanization section.
  - Debutanization Section.
- Storage and shipment of liquid products:
  - LPG storage, export, and recycling (Unit 33).
  - LPG export pipeline (Unit 36).
  - Condensate storage, export, and recycling (Unit 35).
  - Condensate export pipeline (Unit 37).
- Gaseous products shipping system :
  - Residual gas export line (Unit 34).

2) **Utility units :**

- Fuel gas system (Unit 45).
- Hot oil system (Unit 41).
- Flare systems (Unit 43).
- Chemical injection system (Unit 42).
- Air instrument / Air service (Unit 63).
- Nitrogen (Unit 64).
- Closed Drains (Unit 57).
- Open drains (Unit 56).
- Oily water treatment (Unit 44).
- Diesel (Unit 62).
- Raw and drinking water (Units 50 & 53).

II.3. Liquid Treatment Trains (Unit 32)

To begin with, the gas received from the CINA crude processing plant enters the inlet separator G01-VL-20-01 which divides the gas and so it is then directed to the compression section. An injection of corrosion inhibitor is provided at the gas outlet of the separator.

The feed gas from the inlet separator is sent to the common vacuum collector of the feed gas compressors G05/G06/G07/G08-KA-23-01. The gas is distributed to the 4 compression trains (the 4th compression train is used as a backup as long as the 4th treatment train is not operational) for the purpose of compressing the gas at high pressure. And then is sent to the treatment trains.

The unit has four identical treatment trains which consist of:

- Dehydration section.
- Gas cooling section (Turbo-expander + recompressor).
- Deethanization section.
- Debutanization section.

The function of the dehydration unit is to reduce the amount of water in the water-saturated feed gas to the specified value of 1ppm vol at the unit outlet. Water is removed from the wet gas to prevent the formation of hydrates in the cold section of the plant that cools the gas and then pass it to the absorber which is a non-reboiling reflux tray column where the majority of the ethane and lighter components are separated at the top of the absorber.

Lastly, the feed is directed to the debutanization section where the gas mixtures are separated in the debutanizer. The LPG is recovered at the top of the column, condensed and collected in a common collector before being sent to the LPG storage and export section [37].

II.3.1. Debutanization Section

The three processing trains are identical. The following description of operation applies to any of the processing trains. The value of X in the equipment numbering corresponds to the number of the number of the relevant processing train (X=1 for train 1, X=2 for train 2, and X=3 for train 3).

The debutanizer G1X-CB-32-01 is a reflux and reboiler distillation column with 43 trays and two feeds. The main feed enters the column at tray #28. The condensate from the M4 separator at CPF CINA serves as the second feed to the debutanizer of each train. This feed occurs at tray no. 4.

The pressure of the debutanizer is maintained at 16 barg by the column head control valve. The top gas is fully condensed in the G1X-GC-32-02 air cooler. The condensed LPG is collected in the reflux flask of the G1X-VL-32-05 debutanizer. A portion of the liquid flow formed is pumped to the head plate of the debutanizer by the G1X-PA-32-03 A/B reflux pump: this constitutes the reflux of the column. The remaining LPG flow is the output of the process train. Under normal conditions, the LPG output of the train is directed to the common LPG manifold "on spec" and then sent to the LPG storage and export section.

Note: In the event that the LPG produced from the reflux tank of the G1X-VL-32-05 debutanizer does not meet specifications, the LPG is manually diverted to the "out of specification" common LPG header and then diverted to the "in specification" common LPG header. and then sent to the LPG storage section in a dedicated sphere.

A rich stream of Isopentane is withdrawn from tray 8 under flow control to meet the LPG and condensate specifications. The produced isopentane is pumped through the G1X-PA-32-04 A/B and then cooled to 60°C through the G1X-GC-32-03 isopentane cooler. The output from each train is then collected on the common isopentane return manifold [37].

The reboiler of the G1X-GA-32-06 is of the "Kettle" type: the liquid collected at the bottom of the column is partially vaporized by hot oil (used as heat transfer fluid). The flow rate of hot oil is automatically adjusted to maintain the temperature of the G1X-CB-32-01 Debutanizer’s hot plate at a given value. During normal operation a temperature of 186 °C is maintained at the bottom of the column to meet the vapor pressure specification of the condensate produced. The vapor portion returns to the bottom plate of the column.

The non-vaporized part in the G1X-GA-32-06 reboiler is the condensate production of the debutanizer. The condensate is sent under pressure to the G1X-GC-32-04 air cooler where it is cooled to 60°C. Under normal condition, the condensate production of the train is directed to the common condensate collector "to specifications" and then sent to the condensate storage and export section.

Note: In case the condensate produced at the bottom of the G1X-CB-32-01 debutanizer does not meet the specifications in terms of vapor pressure, the condensate is automatically diverted to the common "out of specification" condensate collector and then sent to the condensate storage section in a dedicated tray after degasification [37].

II.3.1.1. Main features of the equipment [37]

Table II.1: Main features of the debutanizer G1X-CB-32-01.

Equipment		**G1X-CB-32-01**	
Service		**Debutanizer**	
		Head	**Bottom**
Operating pressure	barg	16	16.4
Operating temperature	°C	73	186
Design pressure	barg	20.5	21
Design temperature (min/max)	°C	-29/120	-5/220
Number of trays	-	43	
Diameter	mm	2200	3200
Height	Mm	35350	

Table II.2: Main features of the debutanizer G1X-CB-32-01.

Equipment		**G1X-GA-32-06**		**G1X-GC-32-02**
Service		**Reboiler of the debutanizer**		**Condenser of the debutanizer**
		Tube	**Calendar**	
Operating pressure	barg	5.4	16.4	16
Operating temperature-inlet	°C	275	186	73.1
Operating temperature-output	°C	220	197	61.5
Design pressure	barg	21	21.5	20.5
Design temperature	°C	-5/290	-5/220	-29/120
Heat exchanged	kW	9800		10390

Table II.3: Main features of the reflux pump of the debutanizer and dispatch of isopentane pumps.

Equipment		**G1X-PA-32-03 A/B**	**G1X-PA-32-04 A/B**
Service		**Reflux pump of the debutanizer**	**Pumps for the dispatch of isopentane**
Operating pressure- vacuum	barg	15.7	17.1
Operating temperature	°C	61	155
Operating Pressure	barg	20.4	33.1
Design Pressure - Vacuum	barg	21.4	21
Design pressure - Exhaust	barg	27	45
Design temperature (min / max)	°C	-32/90	-5/180
Nominal flow rate	m^3/h	290	39
Total manometric height (TMH)	m	105	360
Shaft power	kW	67	36.5

Table II.4: Main features of the isopentane and the condensate air coolers.

Equipment		**G1X-GC-32-03**	**G1X-GC-32-04**
Service		**Air cooler of isopentane**	**Condensate air cooler**
Operating pressure	barg	32.9	16.4
Operating temperature-inlet	°C	155	197
Operating temperature-output	°C	60	60
Design pressure	barg	75	21.5
Design temperature	°C	-5/180	-5/220
Heat exchanged	kW	1400	1080

II.3.1.2. Debutanization Section Diagram

The following diagram provides a visual representation of the debutanization section, highlighting the main steps, equipment, and flow of feed streams, intermediate streams, and final products.

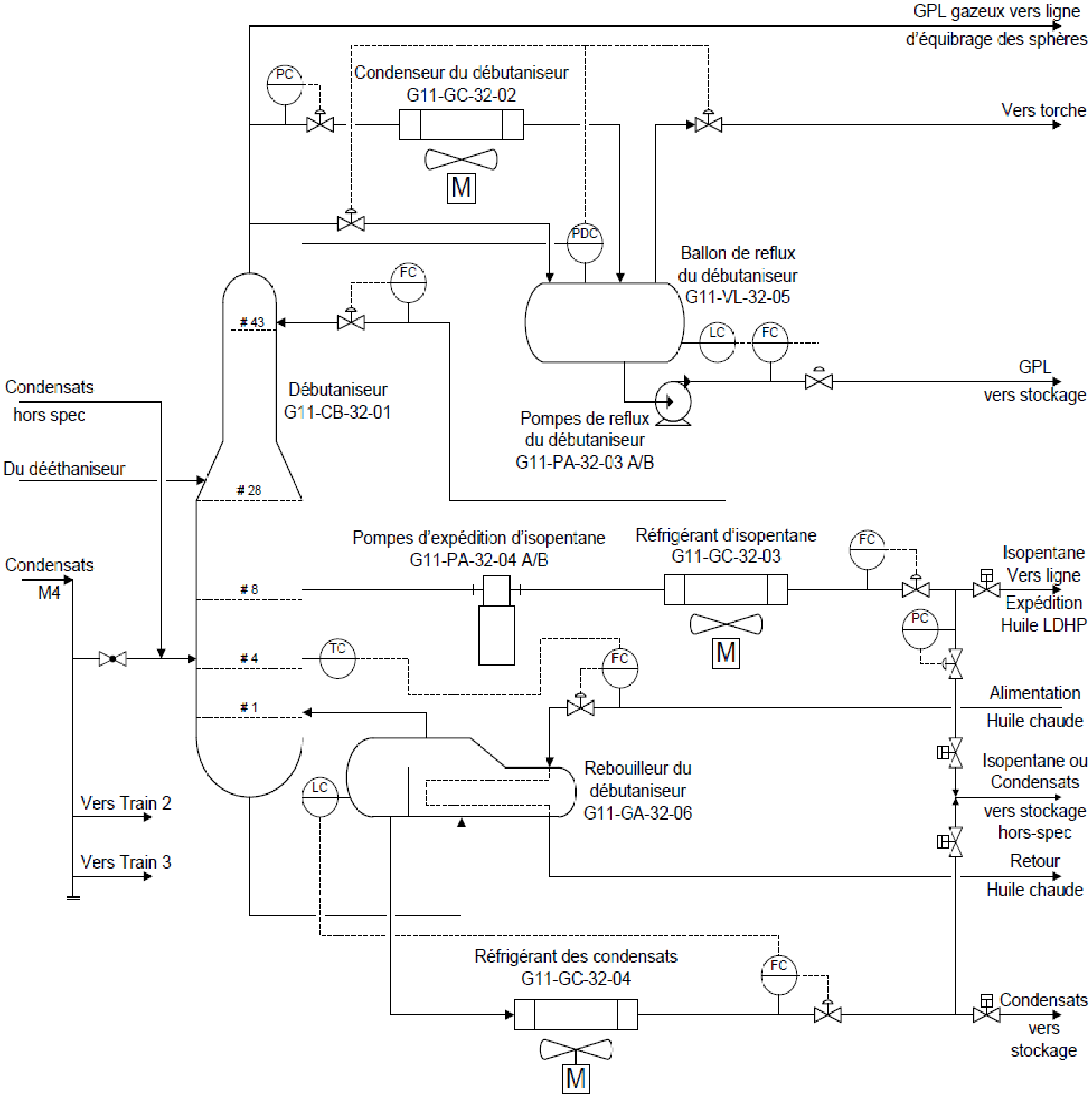


Figure.II.2. Diagram of the debutanization section - Separation of liquids [37].

II.4. Conclusion

The extraction process of the ZCINA plant involves separating the liquids from the associated gas through a series of compression, cooling, and separation processes. The resulting liquids can then be processed and transported to various industries, including petrochemical, plastics, and fuel production.

Overall, ZCINA is an essential facility for extracting valuable liquids from associated gas. These liquids, which include ethane, propane, butane, and natural gasoline, have significant economic value and can be used for a variety of industrial applications.

Part II : Practical framework

Chapter III: Simulation and Analysis of Debutanization Section: Design/Real Case

III.1. Problematic study:

When the temperature of the ambient air entering the forced draft air cooler in the debutanization area increases (case of summer), it can have a negative impact on the quality and liquefaction of the LPG.

LPG is, in fact, a combination of gases that typically liquefies at a moderate temperature and pressure. However, if the temperature of the ambient air entering the air cooler exceeds a certain level, it can increase the temperature of the LPG, making full liquefaction more difficult.

Due to this, a portion of the LPG might stay in its gaseous state, which can cause a rise in pressure within the system. If the pressure exceeds a certain level, the engineers may need to take action such as opening a valve to release the excess LPG (known as production flaring) or reduce the flow of the charge going into the treatment section, resulting in production loss.

Our object is to maintain the total liquefaction of LPG in hot weathers without suffering any loss in productivity.

In order to identify our problem, we proceeded as follows:

- Establish a statistical simulation model to represent the process of separating liquids in the debutanization section, with a specific emphasis on the liquefaction that occurs in the condenser. Our study will incorporate the Ping Robinson thermodynamic model as a fundamental numerical representation. It is important to note that this model specifically applies to a forced-draft air cooler, which can be significantly impacted by any temperature increase in the incoming ambient air. In order to ensure the accuracy and validity of our simulation, we will thoroughly compare our results with the manufacturer's provided operating parameters, and ensure that any recorded relative error falls within an acceptable range.
- We will perform a simulation using the proposed model with the current parameters, and compare the resulting data with the output parameters of the condenser from the same time period. This analysis will allow us to assess the accuracy of our model and validate its effectiveness in predicting real-world outcomes.
- Optimizing condenser performance under high temperatures.
- Conclusion.

III.2. HYSYS Introduction:

Aspen HYSYS is a market-leading process modeling tool for conceptual design, optimization, business planning, asset management, and performance monitoring for oil & gas production, gas processing, petroleum refining, and air separation industries. Aspen HYSYS is a core element of Aspen Tech's aspen ONE® Engineering applications. It has vast importance for chemical engineers to simulate a process [38].

Aspen HYSYS offers a comprehensive thermodynamics foundation for accurate calculation of physical properties, transport properties, and phase behavior for the oil & gas and refining industries. Comprehensive library of unit operation models including distillation, reactors, heat transfer operation, rotating equipments, controllers and logical operations in both the steady state and dynamic environments [39].

III.2.1. Simulation:

Process simulation is a model-based representation of chemical, physical, biological, and other technical processes and unit operations in software Basic prerequisites are a thorough knowledge of chemical and physical properties [39].

Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Simulation is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist [39].

III.2.2. Modes of simulation:

There are two modes of simulation- Steady state mode and Dynamic mode.

III.2.2.1. Steady State Mode:

Initially process simulation was used to simulate steady state processes. Steady state models perform a mass and energy balance of a stationary process (a Process in an equilibrium state) but any changes over time had to be ignored [39].

III.2.2.2. Dynamics Mode:

Dynamic simulation is an extension of steady-state process simulation whereby time-dependence is built into the models via derivative terms i.e., accumulation of mass and energy. The advent of dynamic simulation means that the time-dependent description, prediction and control of real processes in real time have become possible. This includes the description of starting up and shutting down a plant, changes of conditions during a reaction, holdups, thermal changes and more.

Dynamic simulations require increased calculation time and are mathematically more complex than a steady state simulation. It can be seen as a multiply repeated steady state simulation (based on a fixed time step) with constantly changing parameters [39].

III.3. Simulation Study:

III.3.1. Design Case Simulation:

In this section, we will use HYSYS V11 to simulate the operational parameters of the air cooler (debutanizer overhead condenser). The results obtained will be reported and will be compared with the data provided by the design for accuracy.

Note: As mentioned before, the three processing trains are identical, so the following operation applies to any of the processing trains. The design case was carried out under the ambient air inlet temperature 25 °C.

III.3.1.1. Steps for Air Cooler Simulation:

The following compositions are represented in the feedstock entering the debutanization section:

Table III.1: Molar compositions of the feed entering the debutanizer (Appendix 1).

Components	Molar Fractions
Methane	0 %
Ethane	2,6 %
Propane	62,45 %
i-Butane	6,31 %
n-Butane	18,32 %
i-Pentane	3,38 %
n-Pentane	4,45 %
n-Hexane	1,96 %
n-Heptane	0,53 %
n-Octane	0 %

This feed will be treated and separated in the debutanizer before being introduced into the air cooler G11-GC-32-02 with the parameters of: temperature, pressure, molar flow and molar compositions that are presented in the following tables:

Note: The parameters listed in the tables provided (design/real case) can be verified in Appendix 2.

Table III.2: Characteristic data of the supply load of the air cooler.

Inlet		
Temperature	72.64	°C
Pressure	1881	kPa
Molar Flow	2784	kgmole/h

Table III.3: Molar composition of the air cooler feed.

Components	**Molar Fractions**
Methane	0 %
Ethane	2,9 %
Propane	69,56 %
i-Butane	7,03 %
n-Butane	20,38 %
i-Pentane	0,12 %
n-Pentane	0,02 %
n-Hexane	0 %
n-Heptane	0 %
n-Octane	0 %

The air-cooling system operates with pressure and flow parameters presented in the following table:

Table III.4: Air cooler parameters.

AC- G11-GC-32-02		
Feed Pressure	1881	kPa
Product Pressure	1839	kPa
Molar Flow	2784	kgmole/h

- Number of bays : 4.
- Number of fans: 8 (2 per bay).
- Number of bundles: 8 (2 per bay).
- Number of tubes: 273 (per bundle) (Appendix 3).

The outlet parameters of the air cooler G11-GC-32-02: the temperature, pressure and molar flow are presented in the following table:

Table III.5: Characteristic data of the air cooler outlet load.

Outlet		
Temperature	61.50	°C
Pressure	1839	kPa
Molar Flow	2784	kgmole/h

The figure presented below provides a visual representation of the inlet and outlet parameters of the air cooler.

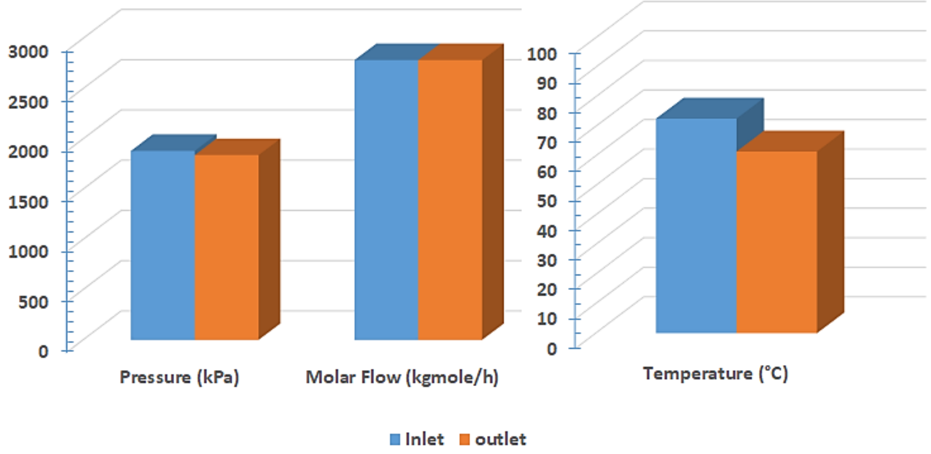


Figure III.1. Inlet vs. outlet comparison of air cooler performance (design case).

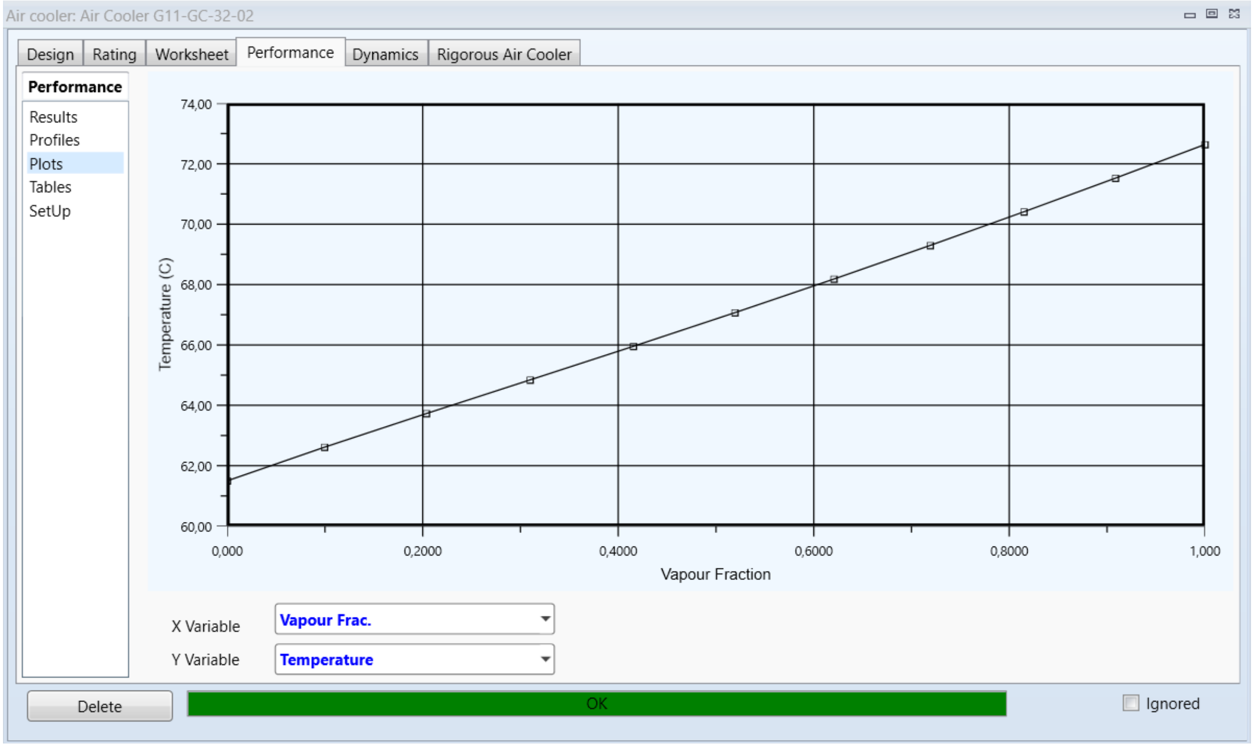
In order to obtain our final product which is LPG, the air cooler is equipped with a reflux flask allowing the separation of the liquid and gaseous phases, without leaving any trace of vapor.

The pressure, temperature and molar flow parameters of the latter are shown below:

Table III.6: Parameters of the phases.

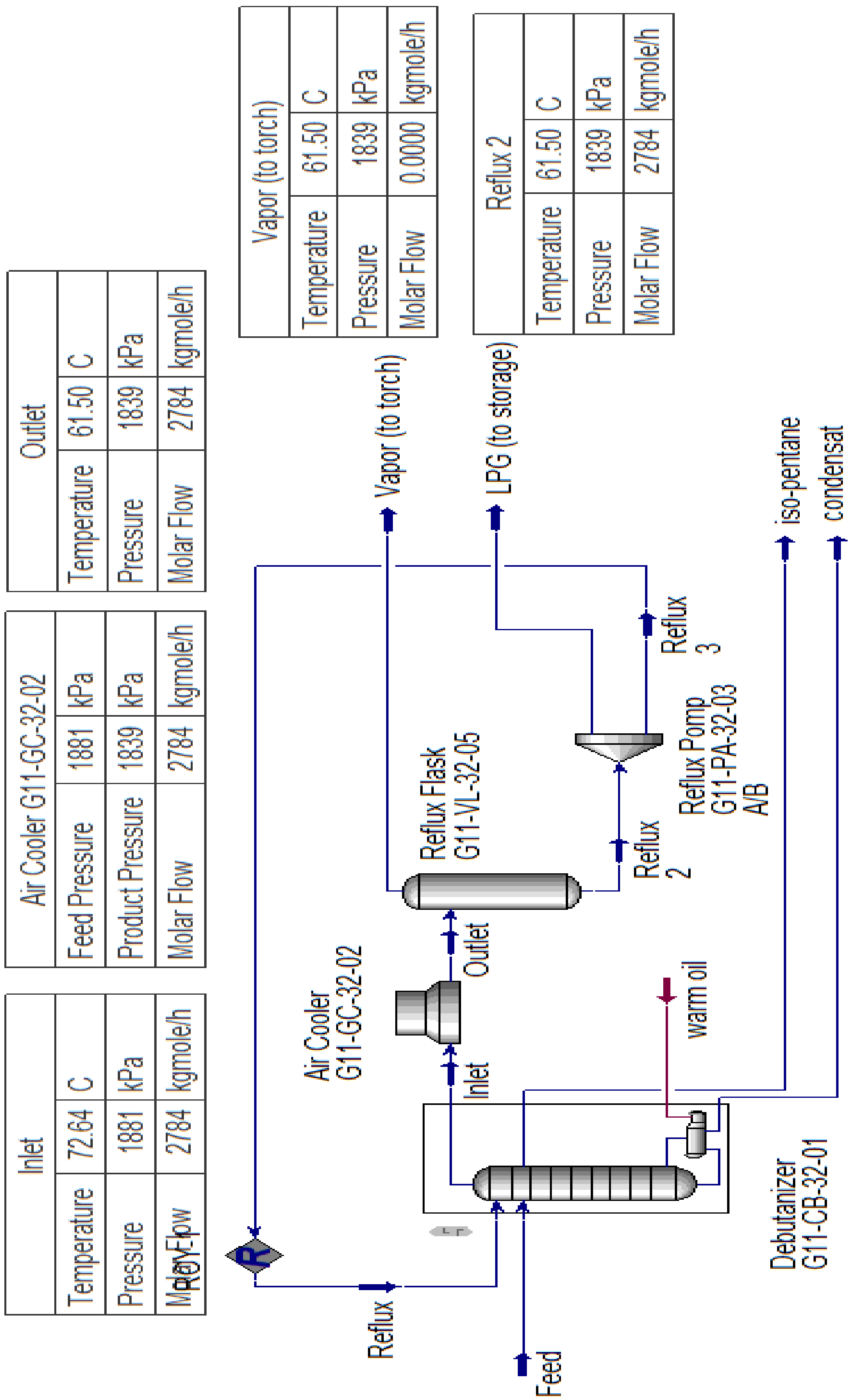
	Liquid Outlet (LPG)	Steam Outlet
Temperature °C	61.5	61.5
Pressure kPa	1839	1839
Molar Flow kgmole/h	2784 (100%)	0

The figure below clearly illustrates that the vapor phase has completely dissipated, and the LPG is entirely liquefied at a temperature of 61.5°C.



X Variable: Vapour Frac.
Y Variable: Temperature

Figure III.2. Phase transition of LPG (design case).



Inlet		
Temperature	72.64	C
Pressure	1881	kPa
Molar Flow	2784	kgmole/h

Air Cooler G11-GC-32-02		
Feed Pressure	1881	kPa
Product Pressure	1839	kPa
Molar Flow	2784	kgmole/h

Outlet		
Temperature	61.50	C
Pressure	1839	kPa
Molar Flow	2784	kgmole/h

Vapor (to torch)		
Temperature	61.50	C
Pressure	1839	kPa
Molar Flow	0.0000	kgmole/h

Reflux 2		
Temperature	61.50	C
Pressure	1839	kPa
Molar Flow	2784	kgmole/h

Figure III.3. Design case simulation of the cooling section for an ambient air temperature of 25°C.

III.3.2. Real Case Simulation:

This simulation is meant to be an accurate representation of a summer day where the ambient air temperature reaches up to 60 degrees Celsius.

The ambient air entering the Air-cooler is set at approximately 55°C. for the same feed fractions, the following results are obtained:

Table III.7: Characteristic data of the Inlet feedstock.

Inlet		
Temperature	77.81	°C
Pressure	1881	kPa
Molar Flow	2156	kgmole/h

Table III.8: Molar composition of the air cooler feed.

Components	Molar Fractions
Methane	0 %
Ethane	2,4 %
Propane	65,9 %
i-Butane	7,32 %
n-Butane	21,85%
i-Pentane	1,36 %
n-Pentane	0,9 %
n-Hexane	0 %
n-Heptane	0 %
n-Octane	0 %

Table III.9: Air cooler parameters.

AC- G11-GC-32-02		
Feed Pressure	1881	kPa
Product Pressure	1781	kPa
Molar Flow	2156	kgmole/h

Table III.10: Characteristic data of the Outlet feedstock.

Outlet		
Temperature	66.31	C
Pressure	1781	kPa
Molar Flow	2156	kgmole/h

To visualize the air cooler inlet and outlet parameters, refer to the figure below.

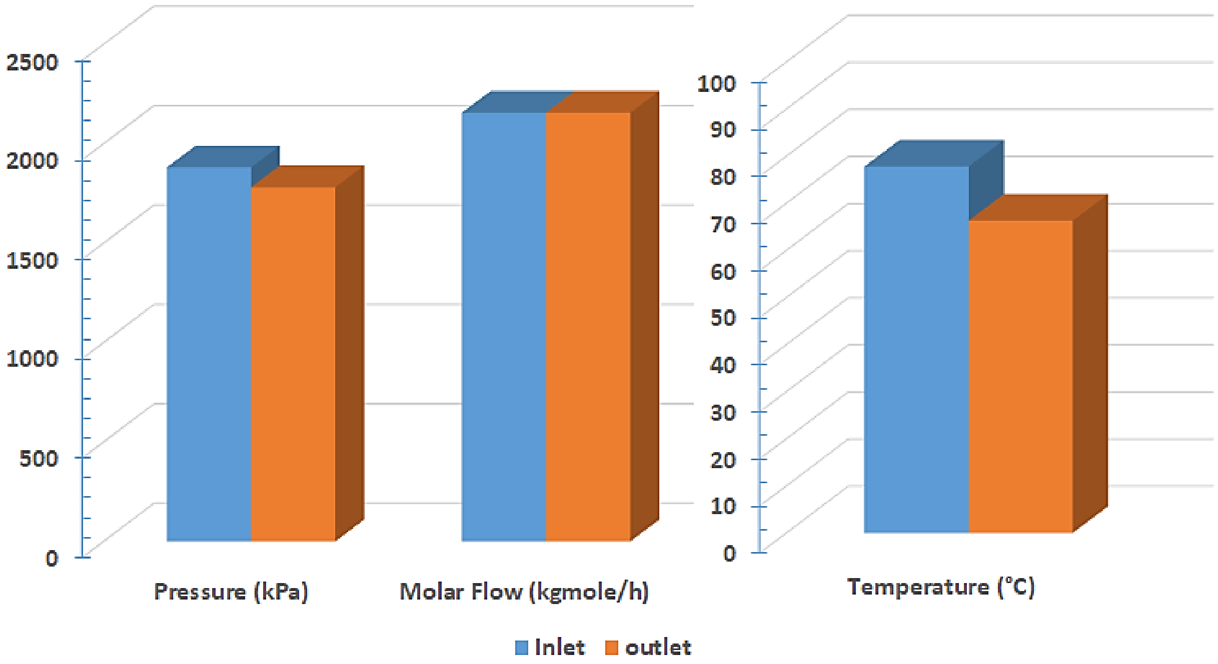
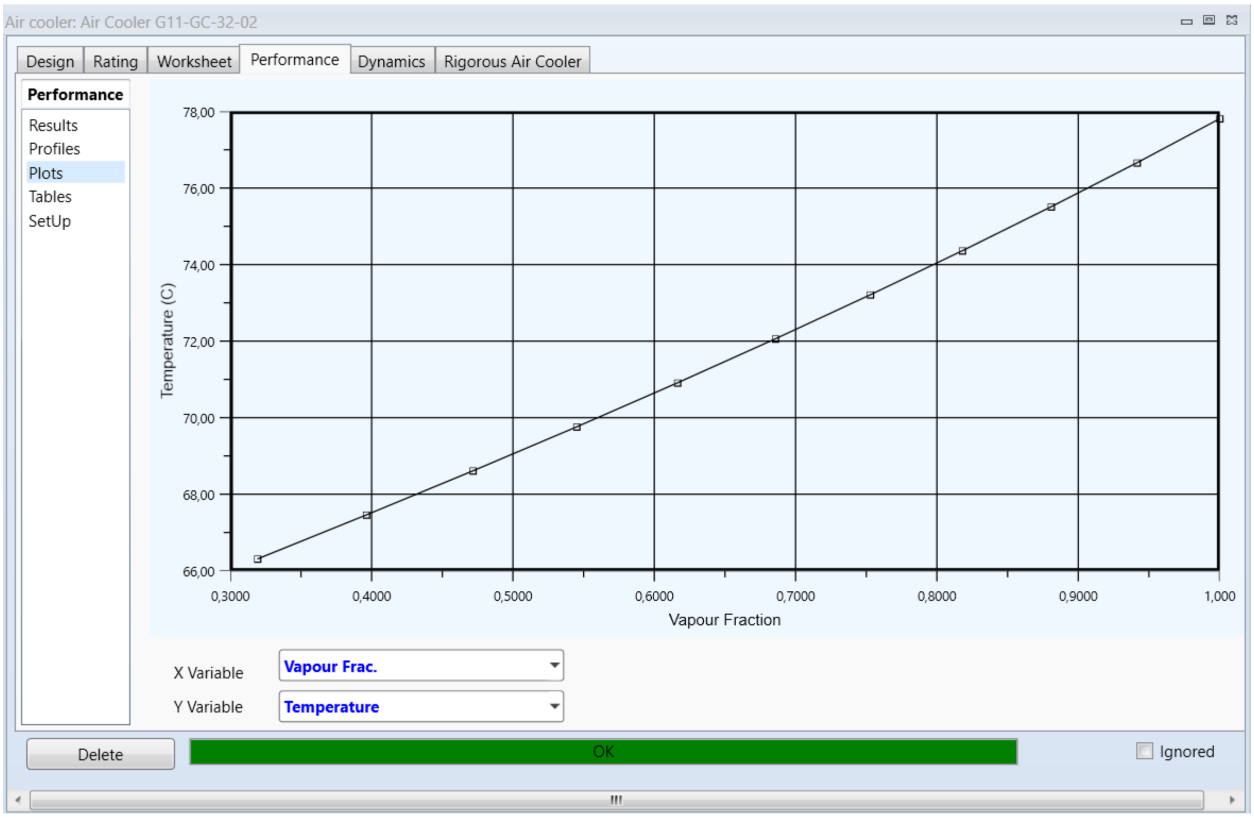


Figure III.4. Inlet vs. outlet comparison of air cooler performance (real case).

The evidence in the table and the figure below confirms our initial worries, showing that the LPG did not fully liquefy when exposed to high ambient air temperature. Instead, a vapor phase is clearly present, indicating partial liquefaction.

Table III.11: Parameters of the phases.

	Liquid Outlet (LPG)	vapor Outlet
Temperature C	66.31	66.31
Pressure kPa	1781	1781
Molar Flow kgmole/h	1468 (68,08%)	688.1 (31,92%)



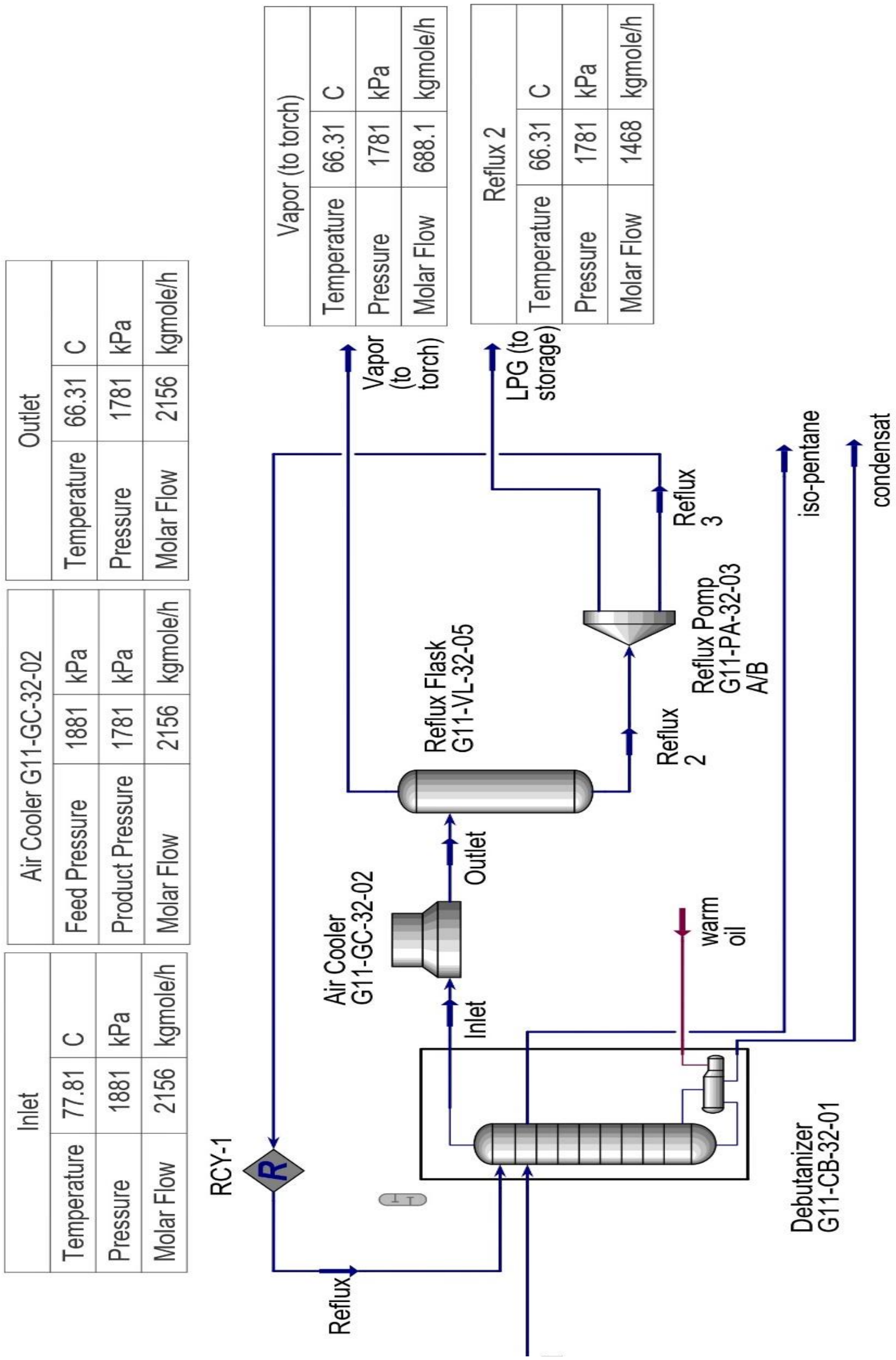
Air cooler: Air Cooler G11-GC-32-02

X Variable: Vapour Frac.

Y Variable: Temperature

Figure III.5. Phase transition of LPG (real case).

The real case results corroborate our concerns, revealing the presence of a vapor phase and incomplete liquefaction of LPG under the stated conditions.



Inlet		
Temperature	77.81	C
Pressure	1881	kPa
Molar Flow	2156	kgmole/h

Air Cooler G11-GC-32-02		
Feed Pressure	1881	kPa
Product Pressure	1781	kPa
Molar Flow	2156	kgmole/h

Outlet		
Temperature	66.31	C
Pressure	1781	kPa
Molar Flow	2156	kgmole/h

Vapor (to torch)		
Temperature	66.31	C
Pressure	1781	kPa
Molar Flow	688.1	kgmole/h

Reflux 2		
Temperature	66.31	C
Pressure	1781	kPa
Molar Flow	1468	kgmole/h

Figure III.6. Real case simulation of the cooling section for an ambient air temperature of 55°C.

A comparison between the parameters of product temperature, vapor phase appearance, and molar flow of the stored LPG in the design case and actual case scenarios is shown in the figures below. They visually illustrate the differences observed between the expected and actual results, aiding in analysis and further investigation.

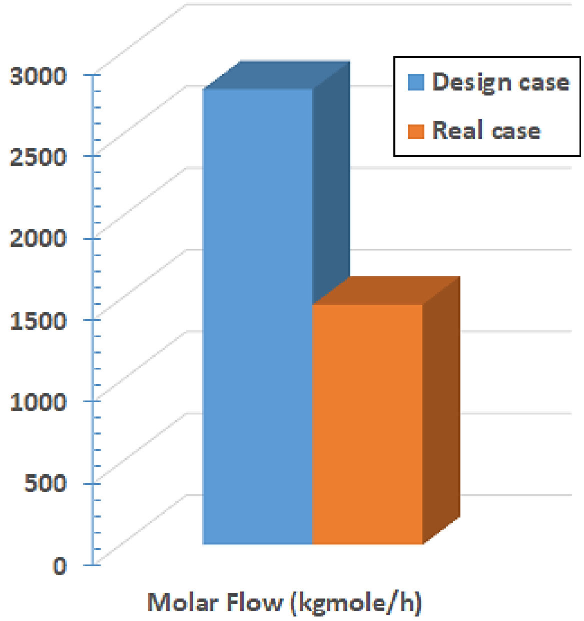


Figure III.7. Design case vs real case Molar Flow of stored GPL

III.4. Results discussion :

- When the ambient air temperature is higher than necessary (55°C in our case), the cooling efficiency of the air cooler can be affected. This is because the temperature difference between the LPG vapor and the ambient air becomes smaller, and as a result, the rate of heat transfer decreases. Which can prevent the complete liquefaction of LPG. As a result, a vapor phase may appear, which can't be liquefied, and this may require the plant to either reduce the load or send the vapor to the flare system for disposal. This, in turn, can impact the overall production capacity of the plant.
- When the LPG is not fully condensed into a liquid form. it emerges from the Air cooler with a relatively high temperature. This causes the temperature at the head of the debutanizer to increase (from 72 to 77°C), since the column is now operating with a lower temperature difference between the overhead vapor and the reflux liquid flowing down the column.
- The increase of temperature at the head of the column affects the molar fraction of the composition to the extent that lighter components, such as n-butane, to vaporize and

enter the overhead stream, even though they would typically be separated and removed as a liquid. As a result, the molar fractions of the feed will change, with a higher concentration of butane in the overhead product.

- We can also notice that the difference in pressure between the inlet and outlet of the air cooler has remarkably elevated since the temperature of the ambient air increases, it can cause an increase in the volume of air, leading to an increase in the pressure drop across the heat exchanger. Additionally, a higher ambient air temperature can reduce the cooling efficiency of the heat exchanger, leading to a higher temperature of the fluid exiting the heat exchanger and potentially increasing the pressure loss.
- Effectively, the molar flow rate is influenced by rise of the pressure drop or (Process stream DeltaP) in a way that the latter indicates an increase in flow resistance, which makes it more difficult for the fluid to flow through the conduit. This increased resistance will tend to reduce the overall flow rate through the conduit, including the molar flow rate and vice versa.
- In summary, changes in the ambient air conditions can reduce the performance of the air cooler, leading to inadequate liquefaction of LPG and the production of excess vapor that is not required. As a result, the LPG output may contain a significant fraction of vapor (up to 30% of the outlet feedstock) that cannot be effectively liquefied due to the reduced cooling capacity of the air cooler.

Chapter IV: Overcoming Temperature Constraints: Innovative Approaches to Improve Air Cooler Efficiency

IV.1. Introduction

Air-cooled heat exchangers are commonly employed in many industrial processes to transfer heat from a hot fluid to a cooler fluid. An air-cooled heat exchanger's ability to work, however, can be compromised in high-temperature environments due to factors such as reduced heat transfer efficiency, material failure, and higher thermal stress. Therefore, it's crucial to develop solutions that help to maintain the functioning of the heat exchanger under these circumstances.

In this discussion, we will explore some potential solutions that could be used to keep an air-cooled heat exchanger operating under high temperature conditions, including increasing airflow, increasing heat transfer surface area, and using alternative cooling techniques.

Our objective is to enhance cooling efficiency and mitigate the adverse effects of high ambient temperatures on the debutanization process by finding an adaptable solution.

IV.2. Proposed solutions

IV.2.1. Addition of extra air coolers

The simplest approach is to include additional air coolers to the unit, with an optimization of some parameters such as, the speed, the exchange surface area, and the number of passes of fluid in the headers (tubes).

More air coolers improve the system's heat transfer surface area, allowing for further efficient heat dissipation. A higher heat transfer rate is possible due to improved convective heat transfer, which is made possible by the additional coolers' increased airflow across the heat exchanger.

Maintaining the functionality of the heat exchanger requires optimizing the speed of the air coolers. The fan speed should be regulated to provide adequate cooling while consuming the least amount of energy possible. To guarantee optimal performance, a balance between cooling effectiveness and energy consumption is essential.

When installing extra air coolers, the exchange surface area is another crucial factor to take into account. Increasing the exchange surface area enhances heat dissipation by extending the surface area available for heat transmission. Efficiency of heat transfer is also influenced by the volume of fluid that flows through the headers (tubes). A greater contact duration between the fluid and the heat transfer surface will result in enhanced heat transfer performance when the number of passes is increased [40].

In fact, this option may seem straightforward and doable but it has some negative aspects such as:

- Both financially and energetically demanding.
- Daily maintenance.
- Still depends on the hot ambient air which is an uncontrollable factor.
- Requires more space.

IV.2.2. Including supplementary fans / modifying the fans geometry

By maintaining the same number of air coolers, we can boost the performance of the latter through adjusting the number of the fans and their performance which can:

- **Increase air flow rate**: By increasing the number or size of the fans, you can increase the air flow rate through the heat exchanger. This means that more air passes over the fins, allowing for greater heat transfer.
- **Increase surface area**: By changing the shape or size of the fins, you can increase the surface area available for heat transfer. This can be achieved by using fins with more surface area per unit volume, or by increasing the number of fins in the heat exchanger.
- **Improve heat transfer coefficient**: By changing the shape or size of the fins, the heat transfer coefficient can be improved as well. This is the measure of how easily heat is transferred between the fins and the air. By increasing the heat transfer coefficient, the overall performance of the heat exchanger can be improved.
- **Reduce pressure drop**: When air flows through a heat exchanger, there is some resistance to the flow, which creates a pressure drop. By changing the geometry of the fins or fans, you can reduce the pressure drop, which means that more air can flow through the heat exchanger at a given pressure. This can improve the efficiency of the system.

In addition to the cost and the maintenance needs of this resolve. We may also encounter difficulties such as:

- **Limited impact**: Depending on the specific application and environmental conditions, the changes may only have a limited impact on the overall performance of the system.
- **Compatibility issues**: If the changes are not compatible with other components of the system, such as the fans or pumps, it may result in additional modifications or replacements, which can add to the cost and complexity of the project.

IV.2.3. The use/employment of nitrogen

Among the factory's procedures is the production of nitrogen which can be used as alternative to increase the cooling performance of air coolers by supplementing the ambient air with nitrogen gas. This can be done in a few different ways:

- Injecting nitrogen into the ambient air stream is a frequent way to improve air cooler cooling performance. Since nitrogen has a higher heat transfer coefficient than air, it can absorb and transfer heat more efficiently. This procedure can be carried out by employing a specialized injection system that injects nitrogen into the ambient air stream before it enters the Cooling Air Cooled Heat Exchanger (ACHE).
- Creating a barrier between the ambient air and the ACHE using a nitrogen blanket, as a result, the amount of ambient air that comes into contact with the ACHE is reduced which can lower the temperature of air.
- By using a cooling tower filled with a nitrogen-rich atmosphere. Using water and air, a cooling tower is a heat rejection mechanism that dissipates heat from a structure or industry into the atmosphere. In this case, the ambient air can be cooled before it enters the ACHE by filling a cooling tower with a nitrogen-rich atmosphere. This can be achieved by circulating the ambient air through the cooling tower where it comes into contact with the nitrogen-rich atmosphere.

While the use of nitrogen to boost the cooling performance of the air may seem beneficial in certain applications, there are also potential negative sides to consider:

- The nitrogen injection systems and nitrogen-rich atmospheres are costly significant
- The requirement of additional maintenance and monitoring for the nitrogen supply and the functioning of injection system.
- Potential risk of asphyxiation (Appendix 4) if proper safety measures are not followed

IV.2.4. Wet-Surface Air Coolers

Unlike traditional air-cooled heat exchangers, the tube bundles in a wet-surface air cooler (WSAC) are sprayed with water and use evaporative cooling to reject the heat from the process medium. This results in superior cooling and a guaranteed liquefaction of the LPG [41].

Whereas the WSAC can provide effective cooling but there are also several disadvantages that should be considered, including:

- **Corrosion**: WSACs are typically made of materials that are vulnerable to corrosion, such as carbon steel. The exposure to water and air can accelerate the corrosion process, leading to a decrease in the performance and lifespan of the equipment.

- **Water consumption**: WSACs require a significant amount of water for their operation, which can be a concern in areas with limited water resources or where water is expensive.
- **Energy consumption**: WSACs require energy to pump water and air through the system, which can increase overall energy consumption and operating costs.

IV.3. Optimization Approaches

After conducting our practical internships and conducting a thorough evaluation and comparison of available alternatives, it has become clear that integrating additional fans is the most optimal approach. This choice brings significant advantages, especially in terms of cost-effectiveness compared to installing entirely new systems. Additionally, opting for additional fans requires less space, which is crucial considering the limited space available in the installation where the internship took place. This solution greatly facilitates the process of arranging and maintaining the remodeling project. By implementing this solution, we can strike a balance between cost-efficiency, space utilization, and overall ease of management.

IV.3.1. The purpose of adding extra fans

The addition of extra fans to the air cooler in the debutanization section can have a significant influence on the cooling effectiveness and overall performance. Here are some ways in which the addition of extra fans can impact the section:

- Enhanced Cooling Capacity: By installing more fans, the section's airflow and cooling capacity are both improved. This makes it possible to dissipate heat more effectively, lowering temperatures and preserving ideal working conditions.
- Improved Heat Transfer: The additional fans' greater airflow enables better heat transfer between the process fluid and the cooling surfaces. Better overall performance is the outcome, as cooling proceeds more quickly and effectively.
- Temperature Control: The section's temperature may rise due to hot ambient air, which could have an impact on the stability of the process and the quality of the final product. The addition of more fans aids in reducing the heat load, enabling accurate temperature control and upholding the preferred working conditions.
- Reduced Heat Exchanger Fouling: Heat exchangers are vulnerable to fouling in high-temperature settings because of the buildup of deposits and pollutants. The additional fans' greater airflow reduces fouling by improving circulation and prevents particle matter from accumulating on the heat exchange surfaces. As a result, heat exchanger performance is enhanced and routine cleaning and maintenance requirements are diminished.
- Minimized Hotspots: High temperatures can create localized hotspots inside the air cooler unit, resulting in uneven cooling and perhaps reducing the cooling process' effectiveness. By adding

more fans, the airflow is distributed more evenly, which helps to prevent hotspots and ensures uniform cooling throughout the entire unit.

- Improved Overall Efficiency: greater section efficiency is a result of the additional fans' increased cooling capacity and greater heat transfer efficiency. This could result in higher production rates, lower energy use, and better resource usage.
- Operational Flexibility: Additional fans provide the air cooler unit more flexibility in how it operates. Depending on the surrounding conditions and the need for cooling, it enables modifications to fan speed or the activation/deactivation of fans. This adaptability guarantees effective cooling in a variety of climatic conditions, improving the section's performance.
- Redundancy and Reliability: The cooling system becomes more redundant with the addition of additional fans. The other fans can continue to run in the case of a fan failure or maintenance need, delivering continual cooling and reducing downtime. This improves the section's availability and dependability.

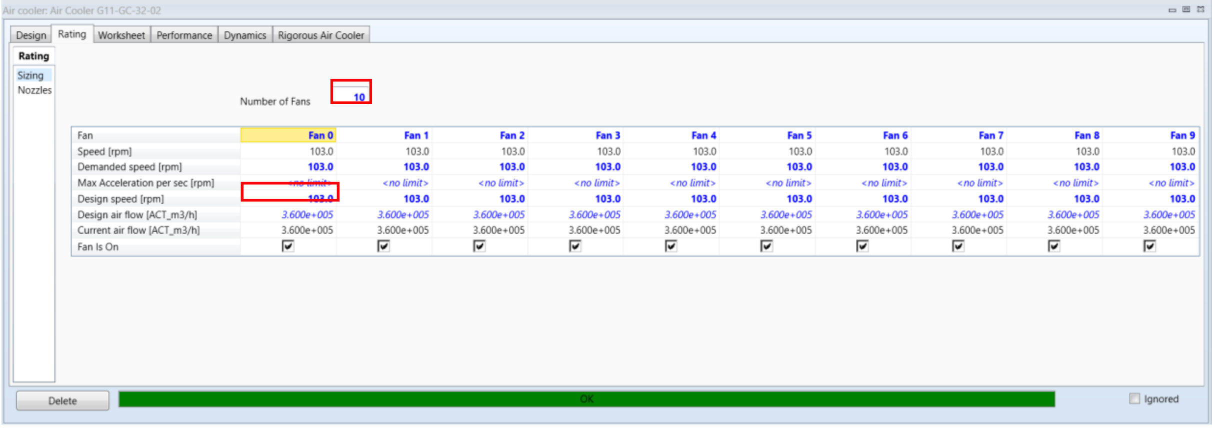
Overall, the cooling capacity and efficiency of the system are considerably increased by adding extra fans to the air cooler when the temperature is high. Improved temperature management, more efficient heat dissipation, and dependable cooling performance are made possible by the increased airflow and improved heat transfer capabilities, which ultimately optimizes the overall cooling process.

IV.3.2. Integration of Additional Fans in HYSYS

We have preserved the section feed compositions and the air cooler inlet air temperature (55°C) unaltered in order to observe the effects of adding an additional fan to the air cooler unit in our simulation. The goal was to examine how this adjustment changed the product's temperature as well as the vapor phase's appearance.

- ➢ To achieve this, we integrated the extra fans to the air cooler unit already in place within the simulation framework. The original case had eight fans, and we added two more, bringing the total to ten. In order to make sure the air cooler unit was properly connected to the necessary process streams, its placement within the process flow diagram was established.
- ➢ The simulation parameters were then changed to include the additional fan's specifications. The fan speed was one of these variables (reducing the initial speed 173.2 to 103 rpm).

After incorporating the modifications in the speed parameter to accommodate the additional fans, the resultant speed can be described as follows:



Number of Fans 10

Fan	Fan 0	Fan 1	Fan 2	Fan 3	Fan 4	Fan 5	Fan 6	Fan 7	Fan 8	Fan 9
Speed [rpm]	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0
Demanded speed [rpm]	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0
Max Acceleration per sec [rpm]	<no limit>	<no limit>	<no limit>	<no limit>	<no limit>	<no limit>	<no limit>	<no limit>	<no limit>	<no limit>
Design speed [rpm]	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0	103.0
Design air flow [ACT_m3/h]	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005
Current air flow [ACT_m3/h]	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005	3.600e+005
Fan Is On	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

Figure IV.1. Applied modifications for the air-cooled heat exchanger.

Running the simulation with the added fan allowed us to monitor the subsequent alterations in the airflow volume, which directly impacted the product temperature and the appearance of the vapor phase.

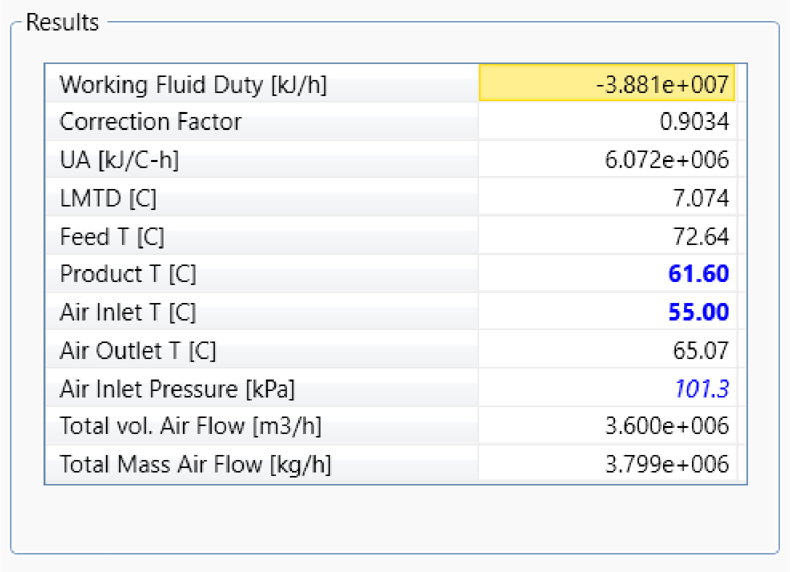
Table IV.1: Air flow amount in each case.

Air cooler	Solution case	Design case	Real case
Total vol Air Flow [m^3/h]	3.600e+006	2.880e+006	2.880e+006
Total Mass Air Flow [kg/h]	3.799e+006	3.332e+006	3.053e+006

Real case: we perceive that the total mass air flow decreased, this can be attributed to the rise of ambient air temperature since the air density decreases with the latter, the total mass airflow decreases for a constant volume airflow rate.

Solution case: it is observed that after adding extra fans to the system, both the total volume and mass air flow increased relatively, and this is due to:

- The additional fans contribute to a higher total volume of air passing through the system thus an increased mass airflow.
- The balance between adding extra fans and adjusting speed, for when the initial speed is way too high resulting in excessive airflow rate, decreasing the speed is necessary to bring the airflow within an optimal range based on the required conditions.



Results

Working Fluid Duty [kJ/h]	-3.881e+007
Correction Factor	0.9034
UA [kJ/C-h]	6.072e+006
LMTD [C]	7.074
Feed T [C]	72.64
Product T [C]	**61.60**
Air Inlet T [C]	**55.00**
Air Outlet T [C]	65.07
Air Inlet Pressure [kPa]	*101.3*
Total vol. Air Flow [m3/h]	3.600e+006
Total Mass Air Flow [kg/h]	3.799e+006

Figure IV.2. Results of executing the process with additional fans in the air-cooled heat exchanger.

By introducing the additional fan, we were able to achieve the desired product temperature when the inlet air temperature was set at 55°C, thus meeting our objective.

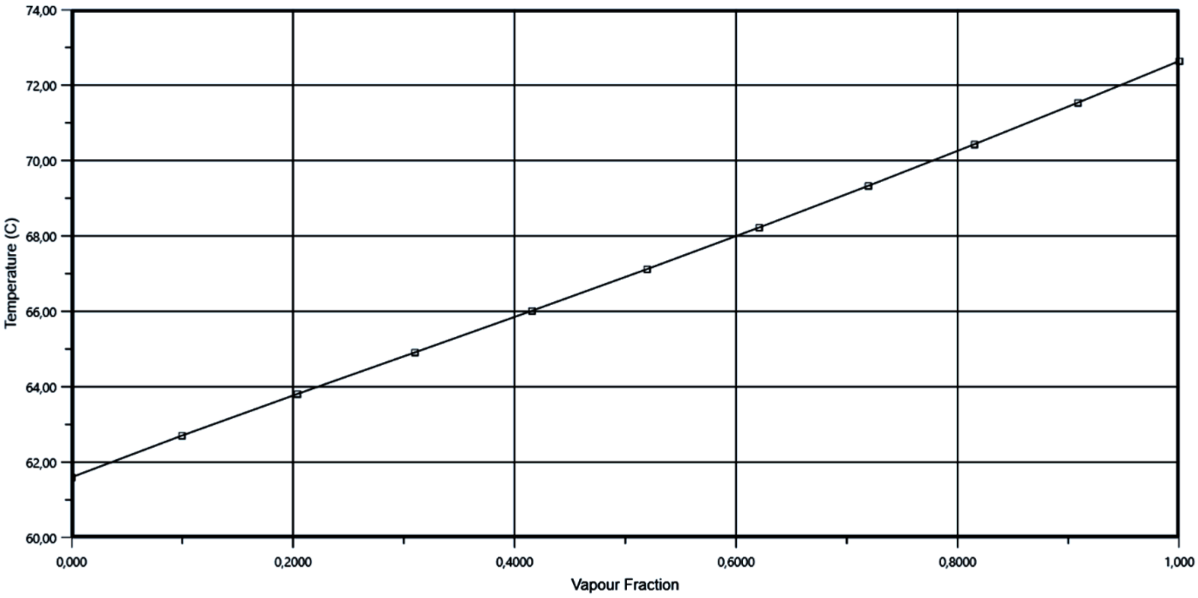


Figure IV.3. Temperature-Vapor Fraction diagram.

The figure clearly illustrates that the successful attainment of the desired temperature led to the complete liquefaction of the vapor phase.

To evaluate the impact of the modification, we conducted a comparative analysis between the outcomes of the simulation with and without the additional fan (actual case) and the design case simulated at a 25°C inlet air temperature. Our analysis was particularly concerned with identifying any temperature variations, modifications to the molar flow of the liquid/vapor phases, or general improvements in the system's performance.

Table IV.2: Different outcomes of each case of the air-cooled heat exchanger outlet.

		AC- G11-GC-32-02 Outlet		
		Solution case	Real case	Design case
Temperature C		61.6	66.31	61.5
Pressure kPa		1843	1781	1893
Molar Flow kgmole/h	Liquid phase	2784 (100%)	1468 (68,08%)	2784 (100%)
	Vapor phase	0	688.1 (31,92%)	0

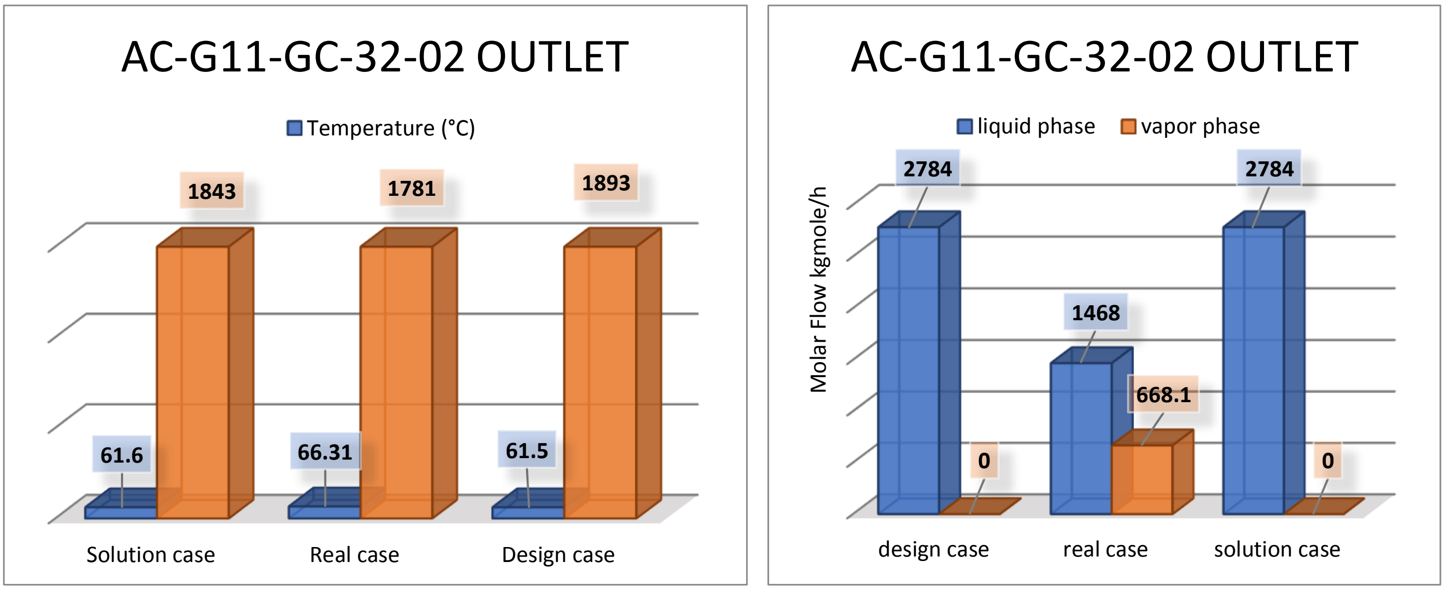


Figure IV.4. Different outcomes of each case of the air-cooled heat exchanger outlet.

The comparison of the results in the table shows that the case with the extra fans has obvious similarities to the design case, considering the fact that the inlet air temperature was kept at 55°C. Despite this adjustment, the outcomes in terms of temperature, molar flow, and the appearance of the vapor phase closely align with the design case. This shows that the additional fans' integration effectively compensates the increased inlet air temperature, maintaining system performance at a level consistent with the design expectations.

Derived from the “Temperature-Vapor Fraction diagram”, it can be stated that a temperature below approximately 61.6°C is required to prevent any vapor from forming. And this objective can be attained by incorporating fans and adjusting speed, which is shown/proven in the solution case.

The inverse correlation between temperature and pressure can be clarified with the generation of vapor fraction. As the temperature increases, gas molecules move faster and collide with container walls more frequently and with greater force, causing a higher pressure. However, faster-moving molecules also have more space between them, which results in a lower gas density and therefore a decrease in pressure.

In summary, results reveal that the additional fans effectively reduce the negative effects of the high inlet air temperature, allowing the case with added fans to closely resemble the performance observed in the design case.

IV.4. Conclusion

To Summarize, the debutanization section of an LPG plant is confronted with a multitude of challenges when it comes to preserving optimal operating conditions in the presence of hot ambient air. Under these circumstances, the forced draft air cooler, which plays a crucial role in the dissipation of heat, often grapples with the limitations of its cooling capacity. This limitation can lead to suboptimal heat transfer rates, higher temperatures within the system, and potentially jeopardize the quality and efficiency of the overall process. Therefore, it becomes essential to explore effective strategies that can enhance the cooling efficiency of the forced draft air cooler in order to mitigate the adverse effects of high ambient temperatures and uphold the desired operating conditions for the debutanization process.

When faced with this scenario/situation, the addition of more fans emerges as a promising solution to enhance cooling effectiveness, sustain optimal operating temperatures, and meet the required product specifications, thereby overcoming the limitations associated with hot ambient air conditions.

General Conclusion

General Conclusion

In conclusion, this study investigated the effects of high ambient air temperature on the air-cooling performance and liquefaction of LPG in the debutanization section of the ZCINA complex's LPG treatment train. Through the utilization of simulation-based analysis using HYSYS software, several important findings were obtained.

Firstly, the efficiency of the air cooler was determined, providing insights into its performance under standard operating conditions. This information can help optimize the cooling system and improve overall efficiency.

Secondly, simulation procedures were developed to simulate the design conditions, enabling a better understanding of the system's behavior and providing a basis for comparison with the actual operational conditions.

Furthermore, the impact of ambient air temperature on LPG liquefaction was identified through real case simulations. This analysis revealed the challenges posed by high ambient air temperature and its negative effects on the liquefaction process.

Lastly, operational adjustments were proposed to enhance the liquefaction process under such conditions. The adjustments involve the addition of extra fans to the air cooler unit. This addition aims to enhance the cooling process, facilitating more efficient liquefaction and maximizing the production of liquefied petroleum gas in hot desert environments.

Overall, this study contributes to a better understanding of the factors affecting air cooling performance and LPG liquefaction in high-temperature environments. The findings and proposed operational adjustments can assist in the optimization of LPG treatment processes, ensuring reliable and efficient production even under challenging ambient air temperature conditions. Therefore, we strongly recommend conducting more comprehensive studies to further investigate the effectiveness of all the proposed solutions. By conducting these detailed studies, we can ensure that the recommended adjustments are thoroughly tested and validated before implementation

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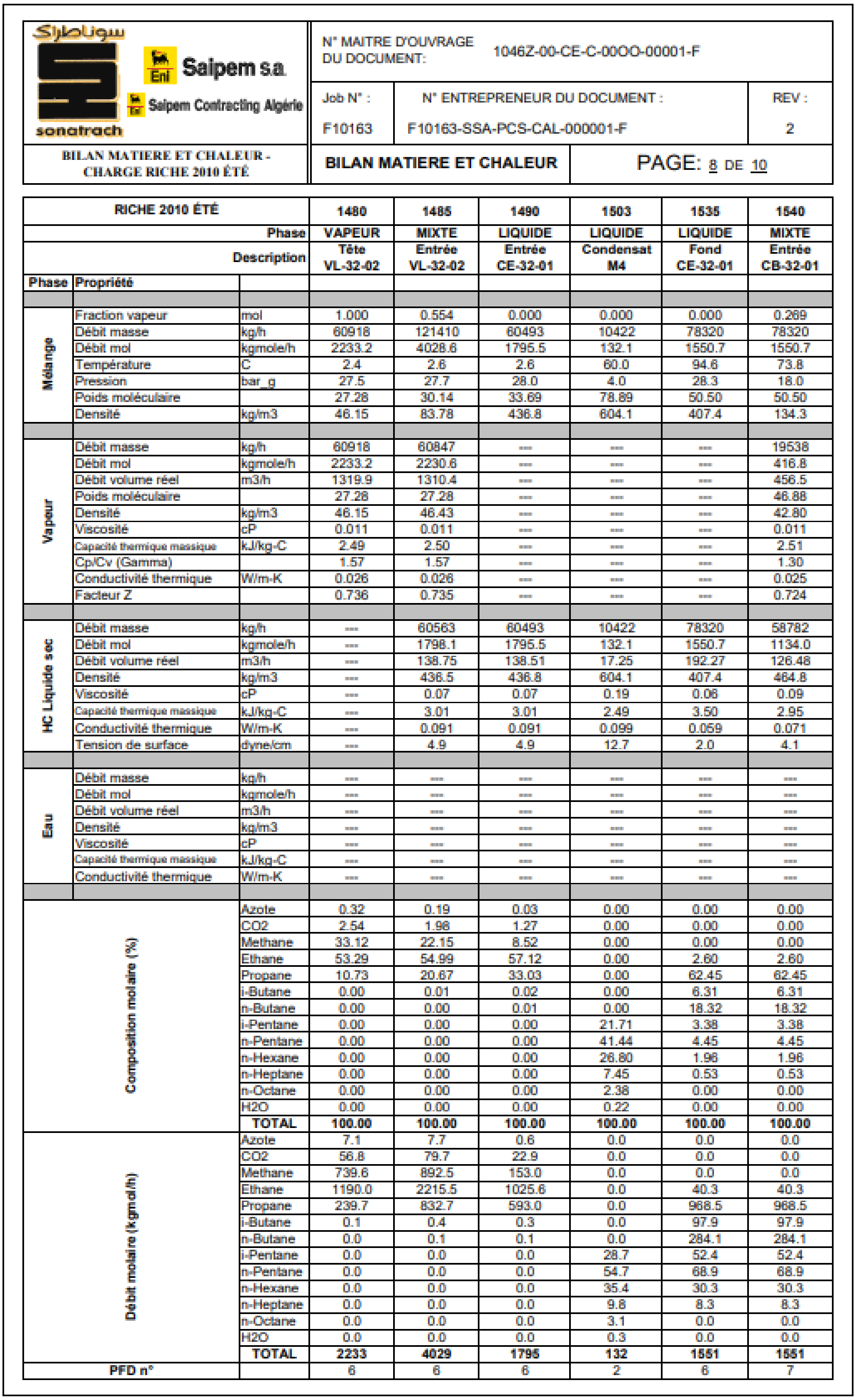
Appendix

Appendix 1: Material and heat balance - rich load 2010 summer.



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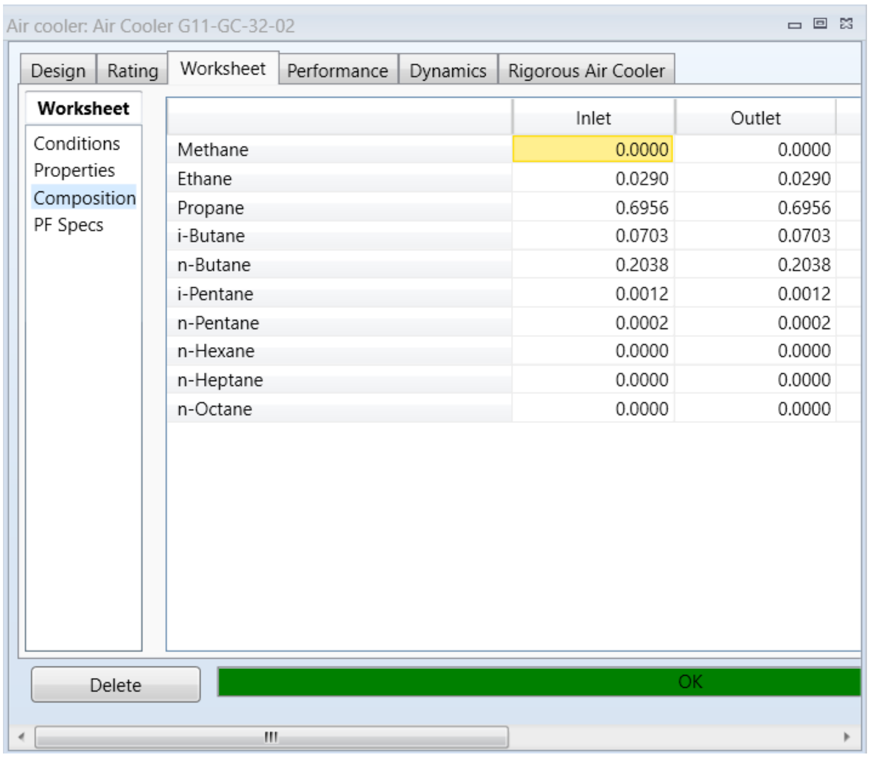
N° MAITRE D'OUVRAGE DU DOCUMENT:	1046Z-00-CE-C-00OO-00001-F	
Job N° : F10163	N° ENTREPRENEUR DU DOCUMENT : F10163-SSA-PCS-CAL-000001-F	REV : 2
BILAN MATIERE ET CHALEUR - CHARGE RICHE 2010 ÉTÉ	BILAN MATIERE ET CHALEUR	PAGE: 8 DE 10

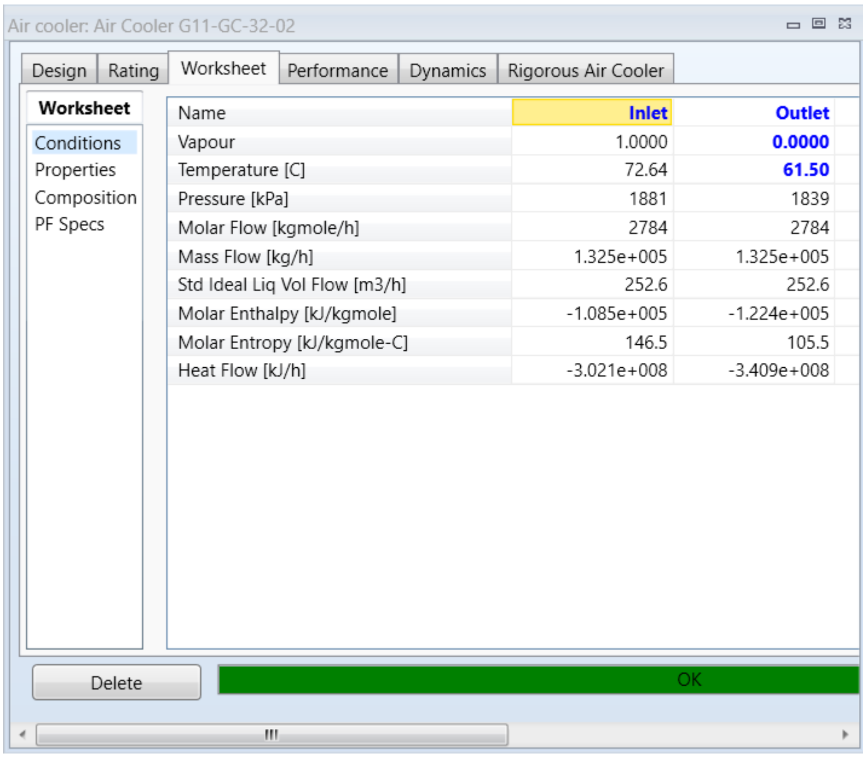
RICHE 2010 ÉTÉ			1480	1485	1490	1503	1535	1540
		Phase	VAPEUR	MIXTE	LIQUIDE	LIQUIDE	LIQUIDE	MIXTE
		Description	Tête VL-32-02	Entrée VL-32-02	Entrée CE-32-01	Condensat M4	Fond CE-32-01	Entrée CB-32-01
Phase	Propriété							
Mélange	Fraction vapeur	mol	1.000	0.554	0.000	0.000	0.000	0.269
	Débit masse	kg/h	60918	121410	60493	10422	78320	78320
	Débit mol	kgmole/h	2233.2	4028.6	1795.5	132.1	1550.7	1550.7
	Température	C	2.4	2.6	2.6	60.0	94.6	73.8
	Pression	bar_g	27.5	27.7	28.0	4.0	28.3	18.0
	Poids moléculaire		27.28	30.14	33.69	78.89	50.50	50.50
	Densité	kg/m3	46.15	83.78	436.8	604.1	407.4	134.3
Vapeur	Débit masse	kg/h	60918	60847	---	---	---	19538
	Débit mol	kgmole/h	2233.2	2230.6	---	---	---	416.8
	Débit volume réel	m3/h	1319.9	1310.4	---	---	---	456.5
	Poids moléculaire		27.28	27.28	---	---	---	46.88
	Densité	kg/m3	46.15	46.43	---	---	---	42.80
	Viscosité	cP	0.011	0.011	---	---	---	0.011
	Capacité thermique massique	kJ/kg-C	2.49	2.50	---	---	---	2.51
	Cp/Cv (Gamma)		1.57	1.57	---	---	---	1.30
	Conductivité thermique	W/m-K	0.026	0.026	---	---	---	0.025
	Facteur Z		0.736	0.735	---	---	---	0.724
HC Liquide sec	Débit masse	kg/h	---	60563	60493	10422	78320	58782
	Débit mol	kgmole/h	---	1798.1	1795.5	132.1	1550.7	1134.0
	Débit volume réel	m3/h	---	138.75	138.51	17.25	192.27	126.48
	Densité	kg/m3	---	436.5	436.8	604.1	407.4	464.8
	Viscosité	cP	---	0.07	0.07	0.19	0.06	0.09
	Capacité thermique massique	kJ/kg-C	---	3.01	3.01	2.49	3.50	2.95
	Conductivité thermique	W/m-K	---	0.091	0.091	0.099	0.059	0.071
	Tension de surface	dyne/cm	---	4.9	4.9	12.7	2.0	4.1
Eau	Débit masse	kg/h	---	---	---	---	---	---
	Débit mol	kgmole/h	---	---	---	---	---	---
	Débit volume réel	m3/h	---	---	---	---	---	---
	Densité	kg/m3	---	---	---	---	---	---
	Viscosité	cP	---	---	---	---	---	---
	Capacité thermique massique	kJ/kg-C	---	---	---	---	---	---
	Conductivité thermique	W/m-K	---	---	---	---	---	---
Composition molaire (%)		Azote	0.32	0.19	0.03	0.00	0.00	0.00
		CO2	2.54	1.98	1.27	0.00	0.00	0.00
		Methane	33.12	22.15	8.52	0.00	0.00	0.00
		Ethane	53.29	54.99	57.12	0.00	2.60	2.60
		Propane	10.73	20.67	33.03	0.00	62.45	62.45
		i-Butane	0.00	0.01	0.02	0.00	6.31	6.31
		n-Butane	0.00	0.00	0.01	0.00	18.32	18.32
		i-Pentane	0.00	0.00	0.00	21.71	3.38	3.38
		n-Pentane	0.00	0.00	0.00	41.44	4.45	4.45
		n-Hexane	0.00	0.00	0.00	26.80	1.96	1.96
		n-Heptane	0.00	0.00	0.00	7.45	0.53	0.53
		n-Octane	0.00	0.00	0.00	2.38	0.00	0.00
		H2O	0.00	0.00	0.00	0.22	0.00	0.00
		TOTAL	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Débit molaire (kgmol/h)		Azote	7.1	7.7	0.6	0.0	0.0	0.0
		CO2	56.8	79.7	22.9	0.0	0.0	0.0
		Methane	739.6	892.5	153.0	0.0	0.0	0.0
		Ethane	1190.0	2215.5	1025.6	0.0	40.3	40.3
		Propane	239.7	832.7	593.0	0.0	968.5	968.5
		i-Butane	0.1	0.4	0.3	0.0	97.9	97.9
		n-Butane	0.0	0.1	0.1	0.0	284.1	284.1
		i-Pentane	0.0	0.0	0.0	28.7	52.4	52.4
		n-Pentane	0.0	0.0	0.0	54.7	68.9	68.9
		n-Hexane	0.0	0.0	0.0	35.4	30.3	30.3
		n-Heptane	0.0	0.0	0.0	9.8	8.3	8.3
		n-Octane	0.0	0.0	0.0	3.1	0.0	0.0
		H2O	0.0	0.0	0.0	0.3	0.0	0.0
		TOTAL	**2233**	**4029**	**1795**	**132**	**1551**	**1551**
PFD n°			6	6	6	2	6	7

Appendix 2: The HYSYS results for both the design and real case scenarios.



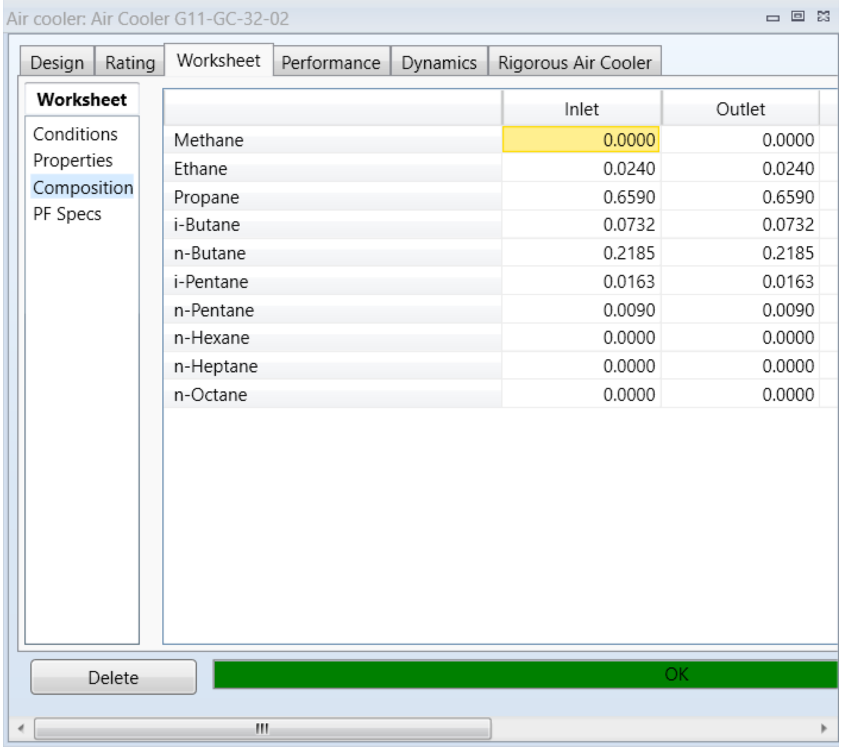
	Inlet	Outlet
Methane	0.0000	0.0000
Ethane	0.0290	0.0290
Propane	0.6956	0.6956
i-Butane	0.0703	0.0703
n-Butane	0.2038	0.2038
i-Pentane	0.0012	0.0012
n-Pentane	0.0002	0.0002
n-Hexane	0.0000	0.0000
n-Heptane	0.0000	0.0000
n-Octane	0.0000	0.0000

Figure Inlet and outlet compositions of the air cooler (design case).



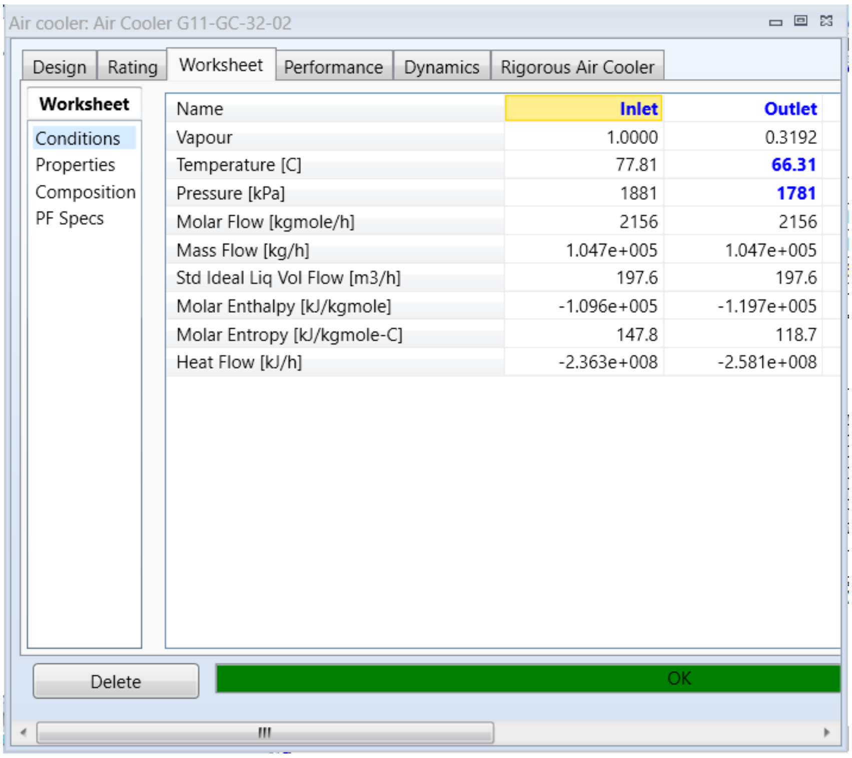
Name	Inlet	Outlet
Vapour	1.0000	0.0000
Temperature [C]	72.64	61.50
Pressure [kPa]	1881	1839
Molar Flow [kgmole/h]	2784	2784
Mass Flow [kg/h]	1.325e+005	1.325e+005
Std Ideal Liq Vol Flow [m3/h]	252.6	252.6
Molar Enthalpy [kJ/kgmole]	-1.085e+005	-1.224e+005
Molar Entropy [kJ/kgmole-C]	146.5	105.5
Heat Flow [kJ/h]	-3.021e+008	-3.409e+008

Figure Inlet and outlet conditions of the air cooler (design case).



	Inlet	Outlet
Methane	0.0000	0.0000
Ethane	0.0240	0.0240
Propane	0.6590	0.6590
i-Butane	0.0732	0.0732
n-Butane	0.2185	0.2185
i-Pentane	0.0163	0.0163
n-Pentane	0.0090	0.0090
n-Hexane	0.0000	0.0000
n-Heptane	0.0000	0.0000
n-Octane	0.0000	0.0000

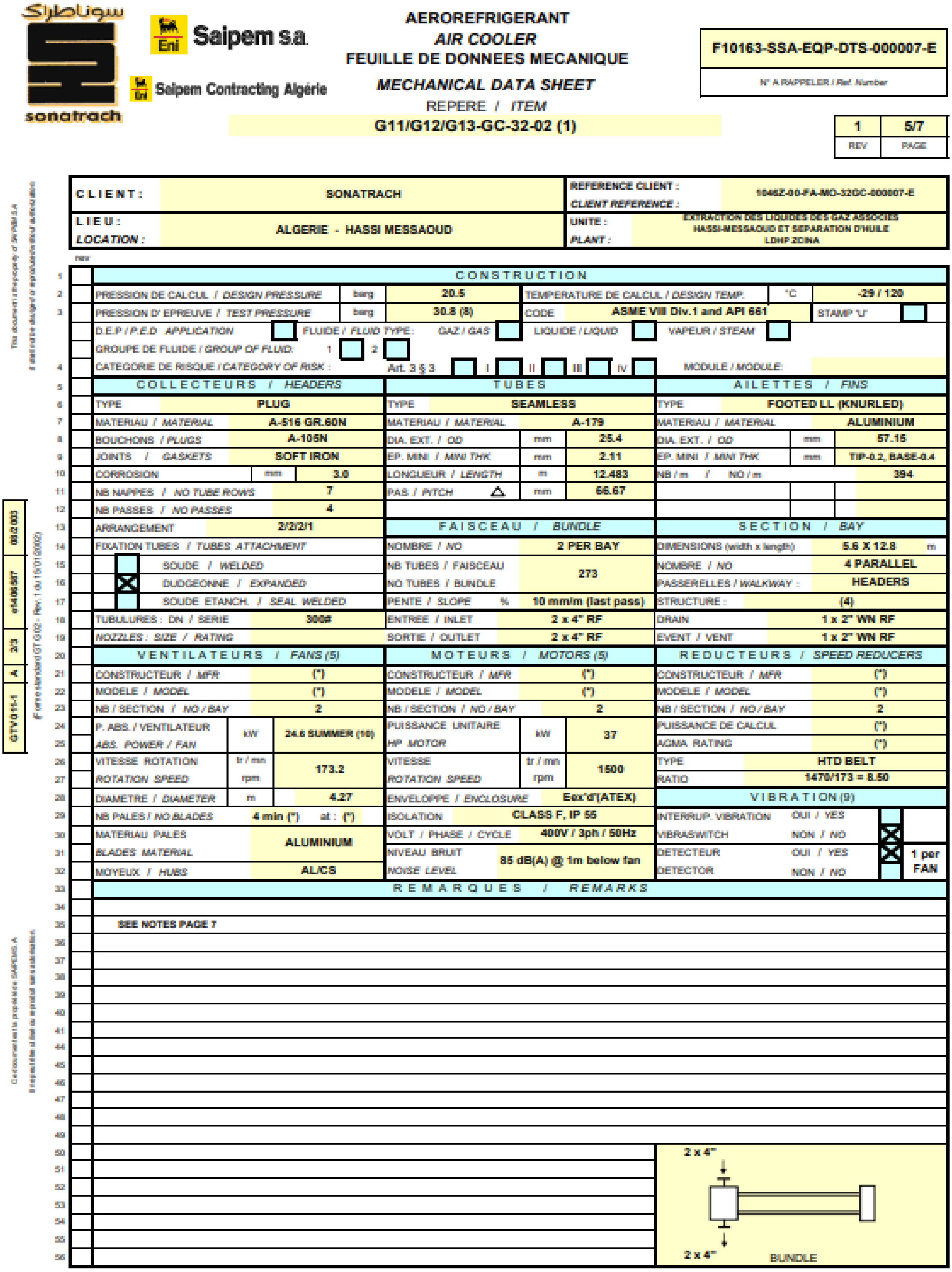
Figure Inlet and outlet compositions of the air cooler (real case).



Name	Inlet	Outlet
Vapour	1.0000	0.3192
Temperature [C]	77.81	66.31
Pressure [kPa]	1881	1781
Molar Flow [kgmole/h]	2156	2156
Mass Flow [kg/h]	1.047e+005	1.047e+005
Std Ideal Liq Vol Flow [m3/h]	197.6	197.6
Molar Enthalpy [kJ/kgmole]	-1.096e+005	-1.197e+005
Molar Entropy [kJ/kgmole-C]	147.8	118.7
Heat Flow [kJ/h]	-2.363e+008	-2.581e+008

Figure Inlet and outlet conditions of the air cooler (real case).

Appendix 3: Mechanical data sheet - debutanizer overhead condenser.



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AEROREFRIGERANT
AIR COOLER
FEUILLE DE DONNEES MECANIQUE
MECHANICAL DATA SHEET
REPERE / *ITEM*
G11/G12/G13-GC-32-02 (1)

F10163-SSA-EQP-DTS-000007-E
N° A RAPPELER / *Ref. Number*

1	5/7
REV	PAGE

CLIENT :	SONATRACH	REFERENCE CLIENT : *CLIENT REFERENCE :*	1046Z-00-FA-MO-32GC-000007-E
LIEU : *LOCATION :*	ALGERIE - HASSI MESSAOUD	UNITE : *PLANT :*	EXTRACTION DES LIQUIDES DES GAZ ASSOCIES HASSI-MESSAOUD ET SEPARATION D'HUILE LDHP ZCINA

rev

CONSTRUCTION

PRESSION DE CALCUL / *DESIGN PRESSURE*	barg	20.5	TEMPERATURE DE CALCUL / *DESIGN TEMP.*	°C	-29 / 120
PRESSION D' EPREUVE / *TEST PRESSURE*	barg	30.8 (8)	CODE	ASME VIII Div.1 and API 661	STAMP 'U' ☐

D.E.P / *P.E.D APPLICATION* ☐ FLUIDE / *FLUID TYPE:* GAZ / *GAS* ☐ LIQUIDE / *LIQUID* ☐ VAPEUR / *STEAM* ☐

GROUPE DE FLUIDE / *GROUP OF FLUID:* 1 ☐ 2 ☐

CATEGORIE DE RISQUE / *CATEGORY OF RISK :* Art. 3 § 3 ☐ I ☐ II ☐ III ☐ IV ☐ MODULE / *MODULE:*

COLLECTEURS / *HEADERS*

TYPE		PLUG
MATERIAU / *MATERIAL*		A-516 GR.60N
BOUCHONS / *PLUGS*		A-105N
JOINTS / *GASKETS*		SOFT IRON
CORROSION	mm	3.0
NB NAPPES / *NO TUBE ROWS*		7
NB PASSES / *NO PASSES*		4
ARRANGEMENT		2/2/2/1
FIXATION TUBES / *TUBES ATTACHMENT*		
☐ SOUDE / *WELDED*		
☒ DUDGEONNE / *EXPANDED*		
☐ SOUDE ETANCH. / *SEAL WELDED*		
TUBULURES : DN / SERIE *NOZZLES : SIZE / RATING*		300#

TUBES

TYPE		SEAMLESS
MATERIAU / *MATERIAL*		A-179
DIA. EXT. / *OD*	mm	25.4
EP. MINI / *MINI THK*	mm	2.11
LONGUEUR / *LENGTH*	m	12.483
PAS / *PITCH* △	mm	66.67

FAISCEAU / *BUNDLE*

NOMBRE / *NO*		2 PER BAY
NB TUBES / FAISCEAU NO TUBES / BUNDLE		273
PENTE / *SLOPE*	%	10 mm/m (last pass)
ENTREE / *INLET*		2 x 4" RF
SORTIE / *OUTLET*		2 x 4" RF

AILETTES / *FINS*

TYPE		FOOTED LL (KNURLED)
MATERIAU / *MATERIAL*		ALUMINIUM
DIA. EXT. / *OD*	mm	57.15
EP. MINI / *MINI THK*	mm	TIP-0.2, BASE-0.4
NB / m / NO / m		394

SECTION / *BAY*

DIMENSIONS (width x length)	m	5.6 X 12.8
NOMBRE / *NO*		4 PARALLEL
PASSERELLES / *WALKWAY* :		HEADERS
STRUCTURE :		(4)
DRAIN		1 x 2" WN RF
EVENT / *VENT*		1 x 2" WN RF

VENTILATEURS / *FANS (5)*

CONSTRUCTEUR / *MFR*		(*)
MODELE / *MODEL*		(*)
NB / SECTION / *NO / BAY*		2
P. ABS. / VENTILATEUR *ABS. POWER / FAN*	kW	24.6 SUMMER (10)
VITESSE ROTATION *ROTATION SPEED*	tr / mn rpm	173.2
DIAMETRE / *DIAMETER*	m	4.27
NB PALES / *NO BLADES*		4 min (*) at : (*)
MATERIAU PALES *BLADES MATERIAL*		ALUMINIUM
MOYEUX / *HUBS*		AL/CS

MOTEURS / *MOTORS (5)*

CONSTRUCTEUR / *MFR*		(*)
MODELE / *MODEL*		(*)
NB / SECTION / *NO / BAY*		2
PUISSANCE UNITAIRE *HP MOTOR*	kW	37
VITESSE *ROTATION SPEED*	tr / mn rpm	1500
ENVELOPPE / *ENCLOSURE*		Eex'd'(ATEX)
ISOLATION		CLASS F, IP 55
VOLT / PHASE / CYCLE		400V / 3ph / 50Hz
NIVEAU BRUIT *NOISE LEVEL*		85 dB(A) @ 1m below fan

REDUCTEURS / *SPEED REDUCERS*

CONSTRUCTEUR / *MFR*	(*)
MODELE / *MODEL*	(*)
NB / SECTION / *NO / BAY*	2
PUISSANCE DE CALCUL	(*)
AGMA RATING	(*)
TYPE	HTD BELT
RATIO	1470/173 = 8.50

VIBRATION (9)

INTERRUP. VIBRATION	OUI / YES	☐	
VIBRASWITCH	NON / NO	☒	
DETECTEUR	OUI / YES	☒	1 per FAN
DETECTOR	NON / NO	☐	

REMARQUES / *REMARKS*

SEE NOTES PAGE 7

2 x 4"

2 x 4"

BUNDLE

Appendix 4:

Asphyxiation: the state or process of being deprived of oxygen, which can result in unconsciousness or death; suffocation.