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-TOPIC-

MERCURY REMOVEL UNIT IN GAS PROCESSING FACILITIES AT R'HOURD-ENNOUS

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motivation throughout this journey.

Gabani Youcef

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List of abbreviations

CO2 : Carbon dioxide.

H2O: Water.

S: Sulphur

Al : Aluminium

Ppmv : Volume fraction = 1 ul/l

AC : Activated carbon

MRU : Mercury removal unit

SH-RN : Sonatrach Rhourde Nouss

CPF : Central production facility

Jt valve : Joule-Thomson valve

HP : High pressure

BP: Low pressure

MP : Medium pressure

Hg : Mercury

ExHg: Extractor of mercury

PID : Piping and instrumentation diagram

الملخص

الهدف من هذا المشروع الدراسي ، هو دراسة الجدوى التقنية لاستخدام طريقة الامتزاز لإزالة الزئبق من تيارات الغاز. حيث يركز على تحسين كفاءة وحدة إزالة الزئبق ، عن طريق تحليل شامل لمخططات التدفق (PFDs) و تنظيم المعدات والأجزاء الرئيسية.

من خلال دراسة التمثيلات البيانية وتحليل نتائج البيانات ، يهدف البحث إلى تحديد المعاملات التشغيلية الرئيسية التي يمكن تحسينها لزيادة كفاءة الإزالة الكلية للزئبق. بالإضافة إلى ذلك، سيتم تناول الجوانب الاقتصادية لتنفيذ هذه العملية. سيقدم هذا البحث معلومات قيمة لتطوير وتحسين الاستراتيجيات الغير مكلفة والغير مضرة بالبيئة من أجل إزالة الزئبق من منشآت إنتاج الغاز .

هذه الدراسة قدمت نتائج فعالة في ازالة الزئبق من تيار الغاز الطبيعي في حقل رهود النص ، حيث انخفض تركيز الزئبق في الغاز عند استعمال طريقة الامتزاز من تركيز 80 ug/sm^3 الى تركيز 0.2 ug/sm^3 وهذه نتيجة مقبولة حسب المعايير الدولية.

الكلمات المفتاحية :، : PFD ، الامتزاز، المادة الممتزة، وحدة إزالة الزئبق (MRU) ، مجمع الفلتر، فلتر الغبار (descender)

Résumé

Cette thèse examine la faisabilité technique et économique de l'utilisation d'une méthode d'adsorption pour l'élimination du mercure des flux de gaz. L'accent est mis sur l'optimisation de l'efficacité de l'unité d'élimination du mercure MRU , grâce à une analyse complète des schémas de flux de procédé (PFDs), de la disposition de l'équipement et des composants clés.

À travers l’étude des représentations graphiques et l’analyse des données, la thèse vise à identifier les paramètres opérationnels clés pouvant être optimisés pour améliorer l'efficacité globale de l'unité MRU. De plus, les considérations économiques liées à la mise en œuvre de cette méthode . Cette recherche apportera des informations précieuses pour le développement et l'optimisation de stratégies rentables et respectueuses de l'environnement pour l'élimination du mercure des installations de production du gaz.

Cette étude a fourni des résultats efficaces dans l’élimination du mercure du flux de gaz naturel dans le chantier Rhourde-Nouss , tels que la concentration de mercure dans le gaz a diminué lors e l’utilisation de l’adsorption de 80 ug/sm^3 au 0.2 ug/sm^3 , ce qui consiste un résultat acceptable des normes internationales.

Mots-clés : PFD, Adsorption, Adsorbant, Unité d'élimination du mercure MRU), Filtre coalesceur, Filtre à poussière (Descender)

Abstract

This dissertation investigates the technical and economic feasibility of employing an adsorption method for mercury removal from gas streams. The focus lies on optimizing the efficiency of the Mercury Removal Unit (MRU) through a comprehensive analysis of process flow diagrams (PFDs), equipment layout, and key components.

Through graphical representations and data analysis, the dissertation aims to identify key operational parameters that can be optimized to enhance the overall removal efficiency of the MRU. Additionally, the economic considerations of implementing this method. This research will contribute valuable insights to the development and optimization of cost-effective and environmentally strategies for mercury removal from gas production facilities.

This study has provided effective results in removing mercury from natural gas stream in the Rhourde – Nouss field , where the concentration of mercury in gas decreased from 80 ug/sm^3 to 0.2 ug/sm^3, which is an acceptable result of international standards.

Keywords: PFD, Adsorption, Adsorbent, Mercury Removal Unit (MRU), Filter Coalescer, Dust Filter (Descender)

General introduciton

Natural gas is a mixture of materials rich in methane and other materials with low percentages of hydrocarbons, nitrogen, water, sulfur compounds and some impurities such as H2S and CO2, which cause many problems during processing operations that do not meet international gas standards, and it also contains quantities of mercury, which is one of the most difficult problems faced by workers in Rhourd Nouss field during gas processing operations, as it is the main reason for the corrosion of aluminum heat exchangers, which are essential components of gas processing plants that affect gas productivity.

During the processing of natural gas, some of the mercury can escape into the atmosphere through various streams, including the outlets of the glycol dehydrators. This released mercury can contaminate the surrounding environment and pose health risks to nearby communities if not properly captured and disposed of.

Mercury present in natural gas can pose a significant risk to human health. It is essential to take steps to minimize exposure to mercury and protect vulnerable populations.

Therefore, it is necessary to remove mercury from the gas stream before further processing or transportation. The presence of mercury requires additional processing steps, which can add complexity and cost. These mercury removal processes can also slow down the overall production rate.

The goal of our work is to eliminate mercury from the gas stream before further processing or transportation under current conditions, by comparing the treatment efficiency with respect to the production rate and quality.

The specific objectives of our work are to:

- Evaluate the performance of the new method in terms of its ability to remove mercury from natural gas and its impact on the production rate and quality of the gas.
- Optimize the new method for maximum efficiency and cost-effectiveness.

The dissertation is divided into four chapters. After a general introduction , we present the first chapter that include an overview of natural gas, different types of natural gas , mercury presence in the petroleum industry , it’s properties and the environmental aspects of it . The second chapter contains technologies of mercury removal from natural gas and condensate such as adsorption, absorption and condensation. The third chapter describes the field of Rhourde-Nouss where the operation of mercury removal is conducted, and the final chapter contains a detailed description of mercury removal unit and the measurements needed to evaluate the success of this operation. Finally , a general conclusion about the results of the project with improvements and optimization of its efficiency in the future.

Chapter 1:

Overview of natural gas and mercury presence

I. Chapter I: Overview of natural gas and mercury presence

I.1. Introduction

While natural gas is a valuable fuel source, a surprising hitch-hiker can sometimes be found alongside it: mercury. This toxic element occurs naturally in trace amounts within some natural gas reservoirs. Although these levels are typically very low, even small quantities can pose problems. Mercury can damage equipment in processing plants and contaminate pipelines over time. Due to this, the natural gas industry employs specialized methods to remove mercury before it reaches consumers. Understanding the presence of mercury and its removal process is crucial for ensuring safe and efficient natural gas production **[1]** .

I.2. Definition of natural gas

Natural gas is a primary energy source that is well distributed throughout the world, clean, and increasingly used. Natural gas is a fossil fuel like coal, anthracite, or lignite. It is a mixture whose main constituent is 75% to 95% methane (CH_4) **[2]** .

This energy has many qualities of relative abundance, flexibility of use, ecological qualities, and competitive prices. The implementation of this energy relies on the technical mastery of the entire gas chain, which goes from extraction to users, through processing, storage, transportation, and distribution.

I.3. Origine des constituants du gaz naturel

There are many different theories about the origins of natural gas. The theory is that natural gas and oil are formed when matter or debris (like plant or animal remains) are compressed underground, at very high pressure for a very long time. Millions of years ago, the remains of plants and animals decomposed and built up in thick layers.

Over time, as sediment, mud, and other debris piled up on top of the organic matter, metamorphism occurred and the sediment, mud, and other debris were changed into rock, putting pressure on the organic matter.

The increasing pressure compressed the organic matter and, combined with other underground effects, broke down the individual constituents into gas and oil.

Thus, the events that are thought to have taken place in the formation of natural gas and oil are:

- **400 to 300 million years ago:** Tiny marine plants and animals died and were buried at the bottom of the ocean; over time, they were covered by layers of silt and sand.
- **300 to 100 million years ago:** The organic debris began to change through simple chemical reactions.
- **100 to 50 million years ago:** The organic debris was buried deeper and deeper; the pressure increased and (possibly) the temperature increased (but, as previously stated, the level of the temperature is largely unknown and, at best, very speculative).
- **50 to 1 million years ago:** The organic debris reacted, under the conditions prevailing underground, to produce methane and other hydrocarbon products that eventually became natural gas, which migrated to reservoirs where it was trapped and awaiting discovery **[2]** .

I.3.1. Hydrocarbon constituents

Hydrocarbons are molecules composed solely of carbon (C) and hydrogen (H) atoms. Here are some examples of hydrocarbons:

- **Methane (CH_4)**: The main constituent of natural gas and liquefied natural gas (LNG).
- **Ethane (C_2H_6)**: Present in natural gas, but in a smaller proportion than methane.
- **Propane (C_3H_8)**: The main component of liquefied petroleum gas (LPG).
- **Butane (C_4H_{10})**: Obtained by distillation of LPG and often sold in gas canisters for domestic use.
- **Pentane (C_5H_{12})**: Used as a solvent in organic chemistry.
- **Hexane (C_6H_{14}), Heptane (C_7H_{16}), Octane (C_8H_{18})**: These compounds are used as fuels in internal combustion engines of vehicles.
- **Nonane (C_9H_{20}) and Decane ($C_{10}H_{22}$)**, etc.

Table I.1: Molecule formula & name according to the number of Carbons [1] .

Number of Carbon Atoms	Molecule Name	Formula
1	Methane	CH_4
2	Ethane	C_2H_6
3	Propane	C_3H_8
4	Butane	C_4H_{10}
5	Pentane	C_5H_{12}
6	Hexane	C_6H_{14}
7	Heptane	C_7H_{16}
8	Octane	C_8H_{18}
9	Nonane	C_9H_{20}
10	Decane	$C_{10}H_{22}$

Hydrocarbons are classified into two categories:

- **Saturated hydrocarbons (or "alkanes")**: All bonds between carbon and hydrogen atoms are single bonds **[4]** .
- **Unsaturated hydrocarbons**: They contain at least one double ("alkenes") or triple ("alkynes") bond. These bonds are called "unsaturations" and make these compounds richer in electrons **[4]** .

In addition to acyclic hydrocarbons (without a cyclic structure), there are also **cyclic hydrocarbons (or "aromatics")**, such as benzene, naphthalene, and anthracene. Benzene, for example, is a cycle formed by six carbon atoms.

Here is a table summarizing the key differences between saturated and unsaturated hydrocarbons:

Table I.2 : Difference between Saturated end Unsaturated Hydrocarbons **[1]** .

Feature	Saturated Hydrocarbons	Unsaturated Hydrocarbons
Bonds between carbon atoms	Single bonds only	At least one double or triple bond
Chemical formula	CnH2n+2	CnH2n
Physical state	Generally gases, liquids, or solids at room temperature	Generally liquids or solids at room temperature
Reactivity	Less reactive	More reactive
Examples	Methane, ethane, propane, butane, pentane	Ethene, propene, butyne, benzene, naphthalene

I.3.2. Non-hydrocarbon constituents

Non-hydrocarbon constituents are molecules that include elements other than carbon (C) and hydrogen (H). These elements can introduce different properties and functionalities to the molecule compared to hydrocarbons. Here are some examples of non-hydrocarbon constituents:

- **Oxygen (O_2)**: Found in compounds such as alcohols, ketones, and carboxylic acids. Oxygen atoms can form polar bonds, making these compounds more water-soluble and reactive [5] .
- **Nitrogen (N_2)**: Found in amines and nitrites. Nitrogen atoms can form various bonds, including double and triple bonds, and can also exhibit different oxidation states [5] .
- **Chlorine (Cl_2)**: Found in organic chlorides. Chlorine atoms can make the molecule more reactive and can also introduce halogen bonding interactions [5] .
- **Sulfur (S)**: Found in thiols and sulfides. Sulfur atoms can form various bonds, including double bonds, and can also exhibit different oxidation states [5] .
- **Phosphorus (P_4)**: Found in phosphates and phosphines. Phosphorus atoms can form various bonds, including double and triple bonds, and can also exhibit different oxidation states [5] .

Table I.3 : Non Hydrocarbons elements and their chemical properties **[2]** .

Element	Examples of Compounds	Chemical Properties
Oxygen (O_2)	Alcohols, ketones, carboxylic acids	Polar bonds, water-soluble, reactive
Nitrogen (N_2)	Amines, nitriles	Various bonds, double and triple bonds, different oxidation states
Chlorine (Cl_2)	Organic chlorides	Increased reactivity, halogen bonding interactions
Sulfur (S)	Thiols, sulfides	Various bonds, double bonds, different oxidation states
Phosphor	Phosphates, phosphines	Various bonds, double and triple bonds, different oxidation states

I.4. Gaz conventionnels et Gaz non conventionnels

Natural gas is a naturally occurring fuel, mainly composed of methane (CH_4), but also ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), nitrogen (N_2) and carbon dioxide (CO_2). There are two types of natural gas: conventional and unconventional, here are the differences between them:

I.4.1. Conventional gas

- Forms in what is known as "parent rock", which is sedimentary rock rich in organic matter.
- Naturally trapped under pressure beneath impermeable cover.
- Can be associated (mixed with oil) or non-associated (found in the presence of oil but not mixed with this resource).
- Conventional non-associated gas is the main source of supply for the natural gas network in France and around the world.

I.4.2. Non-conventional gas:

Mainly composed of methane, but requires costly and complex exploitation techniques.

Examples of unconventional gas:

- **Shale gas**: found in a highly permeable bedrock.
- **Coal gas**: trapped in the coal.
- **Compact gas:** found in certain underground reservoirs.
- **Methane hydrates**: trapped at low temperature and high pressure, mainly under the oceans in Alaska and Russia.

I.5. Different types of natural gas:

I.5.1. Associated gas:

Associated gas is found in the reservoir layer with an oil deposit , It may exist as dissolved gas in oil or as cap gas located above the oil reservoir.

Associated gas is a type of natural gas that is found in association with oil deposits. It is typically found in the same reservoir as the oil, and it is produced along with the oil during the production process **[6]** .

I.5.2. Dry gas

Dry gas is a natural gas that does not form a liquid phase under production conditions, It is concentrated in methane and contains few hydrocarbons heavier than ethane. Dry gas is a type of natural gas that is composed primarily of methane. It is typically found in association with oil deposits, but it can also be found in non-associated gas reservoirs **[6]**.

I.5.3. Condensate gas:

During the production phase of this gas, a condensate phase is formed in the heavy components of the reservoir.

Condensate gas is a type of natural gas that contains a significant amount of heavier hydrocarbons, such as pentane and hexane. These hydrocarbons are liquid at reservoir conditions, but they condense to a liquid phase when the gas is produced **[6]**.

I.5.4. Wet gas

Forms a liquid phase during production at surface conditions, without retrograde condensation in the reservoir. Wet gas is a type of natural gas that contains a significant amount of heavier hydrocarbons, such as propane and butane. These hydrocarbons are gaseous at reservoir conditions, but they condense to a liquid phase when the gas is produced **[6].**

I.6. Overview on Mercury

Mercury (Hg) is a trace element that can be found in natural gas streams, existing in both the gas phase and the liquid phase.

The concentration of mercury varies significantly across different gas production fields. It can range from a few nanograms per cubic meter (ng/m³) to several hundred micrograms per cubic meter (µg/m³).

I.6.1. The properties of mercury

Mercury is a fascinating element with unique properties:

1. **Room temperature condition:** Mercury is the only metal that is liquid at room temperature. It has a silvery appearance and slowly tarnishes in damp air.[3]
2. **Density** is approximately 13.5 g/cm³. [7]
3. **Conductivity :** Compared with other metals, mercury is a poor conductor of heat, but a reasonable electrical conductor**.[7]**
4. **Alloys:** Mercury forms amalgams with copper, tin and zinc. These amalgams are liquid alloys **[7]** .
5. **Physical properties:**
   a. **Melting point**: −38,8 °C (234,3 K)
   b. **Boiling point**: 356,6 °C (629,8 K)
   c. **Condition at 20 °C**: Liquide
   d. **Electronic configuration**: [Xe] $4f^{14}\ 5d^{10}\ 6s^{2}$
   e. **Relative Atomic Mass**: 200,592
   f. **Atomic number**: 80

6. **Chemical properties:**
   a. **Relatively low chemical reactivity:** Mercury is a relatively unreactive metal, which explains its resistance to corrosion and oxidation in dry air **[7]**.

b. **Alloy formation:** Mercury can form alloys with many other metals, such as gold, silver and aluminium **[7]**.

c. **Toxicity:** Mercury is highly toxic to humans and animals. Exposure to mercury can cause damage to the nervous system, kidneys, lungs and reproductive system **[7]**.

d. **Chemical compounds:** Mercury can form various chemical compounds, including chlorides (HgCl2), sulphides (HgS) and oxides (HgO) **[7]** .

I.6.2. Environmental aspects

The presence of mercury in Mercury Removal Units (MRUs) raises several important environmental concerns:

I.6.2.1. Air pollution:

- **Mercury emissions:** MRUs can release mercury gas into the atmosphere, contributing to air pollution and public health problems. Inhaling mercury can cause neurological, respiratory, and kidney damage **[7]** .

- **Dry and wet deposition:** Gaseous mercury falls back onto land and water bodies as dry and wet deposition, contaminating soil, sediment, and the food chain. This can lead to harmful effects on ecosystems and human health **[7]** .

I.6.2.2. Soil and water contamination:

- **Leaks and spills:** Accidental leaks or spills of mercury from MRUs can contaminate soil and groundwater. Mercury is a persistent and bio accumulative pollutant, meaning it can accumulate in living organisms over time and cause significant harm **[7]** .
- **Treatment residuals:** Processing mercury in MRUs generates hazardous waste that requires safe and responsible disposal. Improper waste management can lead to further contamination of soil and water **[7]** .

I.6.2.3. Impact on human health:

- **Occupational exposure:** Workers at MRUs are at increased risk of mercury poisoning, which can lead to serious health problems **[7]** .

- **Indirect exposure:** Populations living near MRUs can be exposed to mercury through contaminated air, water, and soil. This can lead to health problems, particularly for pregnant women, children, and people with weakened immune systems **[7]** .

I.6.3. Global mercury cycle

The global mercury cycle is a complex process that involves the movement of mercury between the atmosphere, land, water, and living organisms. Mercury is a naturally occurring element found in the Earth's crust, but human activities have increased its prominence in the environment. Here are the key stages of the global mercury cycle:

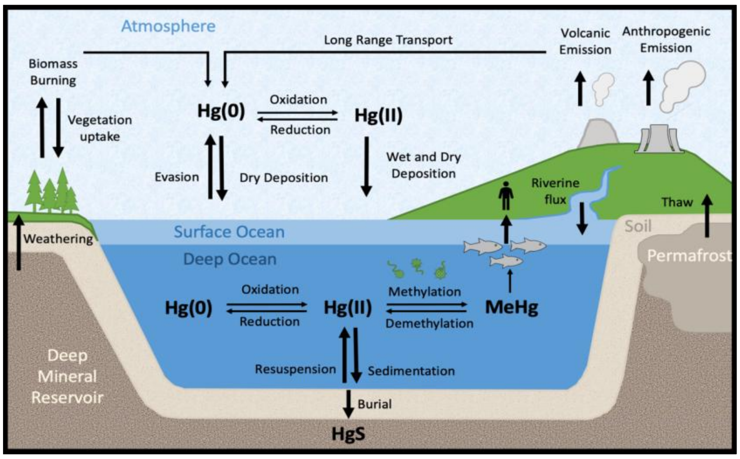


Figure I.1 : stages of the global mercury cycle [8]

1. **Natural and Anthropogenic Emissions:** Mercury is released into the atmosphere from natural sources like volcanoes and rock erosion, as well as human activities like mining, coal combustion, and cement production **[8] .**
2. **Atmospheric Transport:** Once in the atmosphere, mercury can travel long distances. Prevailing winds can carry mercury around the globe, meaning mercury emitted from one source can be deposited in a very distant location **[8] .**
3. **Atmospheric Deposition:** Eventually, mercury falls back to land and water in the form of rain, snow, or dry particles. Gaseous elemental mercury can also be oxidized into inorganic and organic mercury while in the atmosphere **[8] .**

4. **Conversion to Methylmercury:** In lakes and rivers, certain bacteria can convert inorganic mercury into methylmercury, an organic form of mercury that is highly toxic and bioaccumulates.
5. **Bioaccumulation of Methylmercury:** Methylmercury is readily absorbed by aquatic organisms at the base of the food chain. As larger fish consume contaminated smaller fish, methylmercury becomes concentrated in their tissues, a process called bioaccumulation **[8] .**
6. **Long-Term Storage:** Mercury can also be stored in sediments at the bottom of lakes and oceans. This mercury can be remobilized back into the environment over time **[8] .**

I.7. Tolerable mercury levels

Tolerable levels of mercury for human health vary depending on age, sex, frequency of fish consumption, and other factors.

World Health Organization (WHO) Recommendations for Maximum Levels of Methylmercury in Fish Consumed by Humans:

- **Adults:** 0.5 micrograms of methylmercury per kilogram of body weight per week **[9] .**
- **Pregnant and breastfeeding women:** 1.5 micrograms of methylmercury per kilogram of body weight per week **[9] .**
- **Children:** 0.3 micrograms of methylmercury per kilogram of body weight per week **[9] .**

In the United States, the Environmental Protection Agency (EPA) has set national water quality guidelines for mercury at 2 micrograms per liter. This means drinking water should not contain more than 2 micrograms of mercury per liter **[9] .**

The European Union has established a maximum limit of 0.5 milligrams of mercury per kilogram of body weight per week for fish consumption. This translates to someone weighing 154 pounds (70 kilograms) shouldn't consume more than 35 milligrams of mercury per week **[9] .**

It's important to note that these are just guidelines, and even lower levels of mercury can still be harmful to health. Pregnant women, breastfeeding women, and young children are particularly sensitive to the toxic effects of mercury **[9] .**

I.8. Mercury in natural gas

High concentration of mercury occurs in the natural gas. For 70% of gas deposits mercury concentration in gas ranges from 0.3 to 30 µg/m3. In some regions, the mercury concentration in gas comes up to hundreds µg/m3. Besides its toxicity, mercury, being present in hydrocarbon gas, initiates corrosion of pipelines and catalyst poisoning during gas transportation and processing, and these effects have serious implications for the gas-processing industry.

I.8.1. Problems Caused By Mercury in Natural Gas

Mercury, a toxic heavy metal, can cause several problems in the natural gas industry:

- **Corrosion of pipelines and equipment:** Mercury can react with aluminum, a common material used in gas pipelines and processing plants, leading to a type of corrosion called amalgam corrosion. This can weaken pipelines and equipment, increasing the risk of leaks and accidents **[10] .**

Figure I.2 : Corrosion caused by mercury in gas pipeline

- **Catalyst poisoning:** Mercury can deactivate catalysts used in natural gas processing to remove impurities. This reduces the efficiency of the process and can increase production costs **[10] .**
- **Environmental contamination:** During natural gas production, processing, and transportation, there is a risk of mercury being released into the environment. This can contaminate soil, water, and air, posing a threat to human health and wildlife **[10] .**
- **Health risks:** Workers in the natural gas industry can be exposed to mercury through inhalation or skin contact. Mercury exposure can cause a variety of health

problems, including neurological damage, respiratory problems, and kidney damage **[10] .**

I.8.1.1. Skikda liquefied natural gas plant catastrophic failure 1973

The implication of mercury effects in natural gas was not reported until 1973, when a catastrophic failure of aluminum heat exchangers occurred at Skikda liquefied natural gas plant in Algeria. Investigations determined that mercury corrosion caused the failure. After the Skikda failure, a study on Groningen fields in Holland revealed similar corrosion in the gas gathering system. CO_2 was initially thought to be the cause, but later investigation pointed to mercury with concentrations ranging from 0.001 to as high as 180 ug/Nm".

Although the concentration of mercury in natural gas may considered extremely low, it observes that its effect is cumulative as it amalgamates (forming alloys). Elemental mercury forms an amalgam with the surface layer of the metal it contacts. With aluminum, the corrosion problems occur when mercury comes into contact with an aluminum metal surface, where aluminum diffuses from the interface into the mercury droplet and it is rapidly converted to Al_2O_3 by reaction with air or water.

By this mechanism, metallic mercury actually bores into the aluminum leaving brittle layer of Al_2O_3. To initiate aluminum corrosion, the tightly adhering aluminum oxide layer on the surface of the aluminum must be removed. The mercury/aluminum amalgam process removes this oxide layer in the presence of a catalyst or an aqueous electrolyte.

The aqueous corrosion cell forms aluminum hydroxide and gaseous hydrogen through the following reactions:

$$Al + Hg \text{ --------- } Al\,Hg$$

$$2AlHg + 6\,H_20 \text{ — • } 2Al\,(OH)_3 + 3\,H_2 + 2\,Hg$$

These reactions leave the previously amalgamated mercury free to form additional amalgam with base metal in a continuous process. Metal corrosion does not start at a significant rate if the equipment is maintained below the melting point of mercury (-39 CC) **[50] .**

I.8.2. Detection Methods and Limitations

Mercury, even at low levels, can wreak havoc on natural gas processing equipment and contaminate products. Thankfully, there are several methods to detect mercury in gas streams, each with its own advantages and limitations. Here's a breakdown of the most common ones:

Cold Vapor Atomic Fluorescence Spectrometry (CVAFS): This highly sensitive technique utilizes ultraviolet light to excite mercury atoms, causing them to fluoresce at a specific wavelength. The intensity of this fluorescence is directly proportional to the mercury concentration. CVAFS offers exceptional detection limits (down to parts per trillion) and is suitable for continuous monitoring. However, it requires removing interferences like hydrogen sulfide and moisture from the gas sample **[10] .**

Figure I.3 :Cold Vapor Atomic Fluorescence Spectrometry

Atomic Absorption Spectroscopy (AAS): Similar to ICP-AES, AAS exposes the gas sample to an atomizer that breaks down molecules into their constituent elements. The mercury atoms absorb light at specific frequencies, and the amount of absorption is measured to determine the concentration. AAS is a versatile technique but may be less sensitive than CVAFS for detecting low levels of mercury **[11] .**

Figure I.4 : Atomic Absorption Spectroscopy (AAS) [11]

Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES): This method uses high-temperature plasma to ionize elements in the gas sample. The ionized mercury atoms emit light at characteristic wavelengths, allowing for identification and quantification. ICP-AES boasts a wide detection range for various elements, including mercury. However, it's a complex technique requiring specialized equipment and expertise **[11] .**

I.8.2.1. Gold Sniffers

These portable devices employ gold-coated beads that react with mercury vapor, causing a change in electrical conductivity. While convenient for field measurements, gold sniffers offer limited sensitivity and specificity. They may not be suitable for quantifying mercury levels or differentiating between various mercury compounds **[12] .**

Figure I.5 : Gold Sniffers for mercury detection [12]

I.8.2.2. Limitations of Mercury Detection in Gas

While the methods mentioned above are effective, there are still challenges associated with detecting mercury in gas:

Sampling: Extracting a representative sample from the gas stream is crucial for accurate measurement. Factors like pressure, temperature, and presence of other components can affect the sampling process **[11] .**

Interferences: Other gaseous compounds, such as hydrogen sulfide and certain hydrocarbons, can interfere with the detection methods, leading to inaccurate readings **[10] .**

Mercury Speciation: Mercury exists in various forms (elemental, ionic) with different chemical properties and behaviors. The chosen detection method may not be sensitive to all mercury species present in the gas **[12] .**

Cost and Complexity: Some advanced techniques like CVAFS require sophisticated equipment and skilled personnel, making them costlier to implement **[10] .**

Chapter 2

Mercury removal

II. Chapter 2 Mercury removal

II.1. Introduction

Mercury in natural gas presents significant challenges due to its toxic and corrosive properties, requiring effective removal to meet environmental regulations and protect processing equipment. This chapter examines advanced mercury removal technologies, emphasizing adsorption, absorption, and other modern methods. Adsorption involves capturing mercury vapors on solid materials like activated carbon, while absorption transfers mercury into liquid phases using various chemical solutions. Emerging technologies such as activated carbon injection, gas Scrubbing, Twister supersonic separation are also discussed. The chapter offers a comparative analysis to help select the most efficient and cost-effective mercury removal technology, ensuring safety and regulatory compliance in natural gas processing.

Before liquefied natural gas can be transported in pipelines for commercial use, the amount of mercury in the feed gas will need to be minimized to prevent the corrosion of the aluminum pipelines and aluminum based equipments. Therefore, to meet the requirements for safely transporting and storing natural gas, the impurities after processing of the feed gas should not exceed the levels shown in Table 7. In the feed gas for LNG plant, the Hg should be lower than and 0.01 mg/Nm3.

Table II.1 : Typical composition-based specifications of feed gas to an LNG plant and of pipeline natural gas [13]

Impurity	Feed to LNG Plant	Pipeline Gas
H_2O	< 0.1ppmv	150 ppmv
H_2S	< 4 ppmv	5.7–22.9 mg/Sm3
CO_2	< 50 ppmv	3–4 vol%
Total sulphur	< 20 ppmv	115–419 mg/Sm3
N_2	< 1 vol%	3 vol%
Hg	< 0.01 mg/Nm3	–
C4	<2 vol%	–

C5+	< 0.1 vol%	
Aromatics	< 2 ppmv	–

Crude oil and natural gas from the well bring trace amounts of mercury species to the separator to the refinery for further processing. Because of the different process equipment temperatures and pressures, the presence of mercury in crude oil and natural gas is different at each stage of the extraction and conversion process .Mercury in natural gas is mainly in the form of Hg0, whereas in crude oil and aqueous effluent mercury is mostly in the form of Hg0, Hg2+, and HgR **[13]**.

Mercury species adversely impact the proper functioning of processing equipment. First, condensed mercury from the natural gas stream, even at low concentration levels, can corrode the surface of processing equipment that is made of aluminum alloy, such as the plate-fin structure in low-temperature heat exchangers used in the processing of liquefied natural gas in a refinery, fuel transporting pipelines, and in heaters **[15]**. In addition, Hg^0 can react with the aluminum to form an amalgam that hardly adheres to metal surfaces, leading to the detachment of the dense, protective aluminum oxide film from the equipment surface **[16]**; under the effect of corrosion equipment a wall’s integrity can be impacted, leading to gas leakage and other safety hazards.

II.2. Adsorption

Mercury can be removed from natural gas by efficient adsorption process, and such processes have been studied and developed extensively due to its criticality. Activated carbon and silica gel were in common use in adsorption before the development of molecular sieve adsorbents in the late 1950s, which lead to the potential of separation by adsorption process **[16] .**

II.2.1. The selective of adsorbents for mercury removal from natural gas

There is multiple adsorbents used in mercury removal technology, such as elemental sulfur, metal sulfides, metal oxides, activated carbon, iodine, silver, and gold. In mercury adsorption, the fixation of mercury in a stable form is a necessary characteristic desired in adsorbents to consider the environmental hazard of disposing the spent adsorbents after being saturated, which effect on the choice of adsorbents, in addition to the availability of the adsorbents, the recycling potential and the economic plans **[17] .**

Note: Amalgamation is the process of combining or uniting multiple molecules or compounds into one form**.**

II.2.1.1. Carbon-based adsorbents

Carbon-based adsorbents are materials primarily composed of carbon that are used to adsorb or trap other substances, typically gases, liquids, or dissolved solids. These adsorbents are characterized by their high surface area, porous structure, and affinity for a wide range of molecules **[18] .**

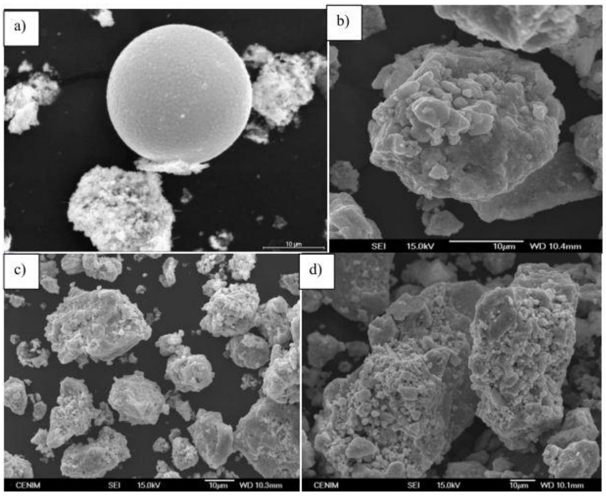


Figure II.1: Hg sphere with sulphur grain adhered in 180 min sample [18]

Sulphur-containing adsorbents

Activated carbon (AC) with a high specific surface area, large pore volume, and wide pore size distribution is a mature adsorbent for removing Hg0 in natural gas. However, raw AC shows low Hg0 adsorption capacity. After AC was modified by elemental sulphur, sulfide, or thiol, the adsorption capacity of Hg0 was enhanced significantly [**19]** , because mercury reacts with powdered sulphur to form mercuric sulphide which is the most stable compound formed between mercury and sulphur **[20] .**

$$Hg + S = HgS \qquad \text{[reaction between mercury and sulfur]}$$

*Activated carbon injection (ACI)***:** This method involves injecting activated carbon into the gas stream, where it adsorbs mercury and other contaminants, facilitating their removal.

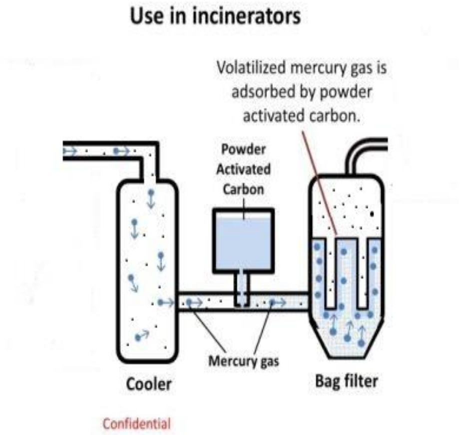


Figure II.2: Mercury removal from a typical incineration plant using Powder activated carbon [25]

Activated carbon is a highly porous material with a large surface area; the process begins by introducing activated carbon materials such as coal, wood, or peat, generally Granular Activated Carbon form or Powder Activated Carbon form into the natural gas stream. As the gas flows through the injection system, the mercury molecules are attracted to and held on the surface of the activated carbon particles. This adsorption process is primarily driven by physical forces, although chemical interactions can also play a role **[21] .**

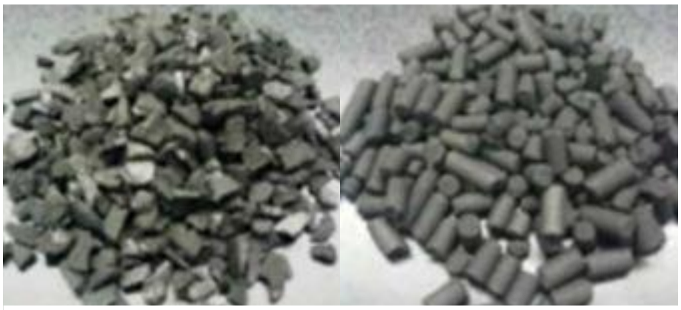


Figure II.3 : Granular Activated Carbon

Figure II.4 : Powder Activated Carbon

Once the mercury-laden activated carbon has been collected, it is separated from the gas stream. This separation is typically achieved using filtration systems that capture the spent carbon, allowing the now purified gas to continue through the processing pipeline **[21] .**

Activated Carbon is very effective in the removal of mercury and although factors like temperature, inlet mercury concentration impact the performance, the removal efficiency of mercury can reach to over 90%. Using Activated Carbon, in conjunction with other flue gas treatment methods, can further improve mercury removal efficiency **[22] .**

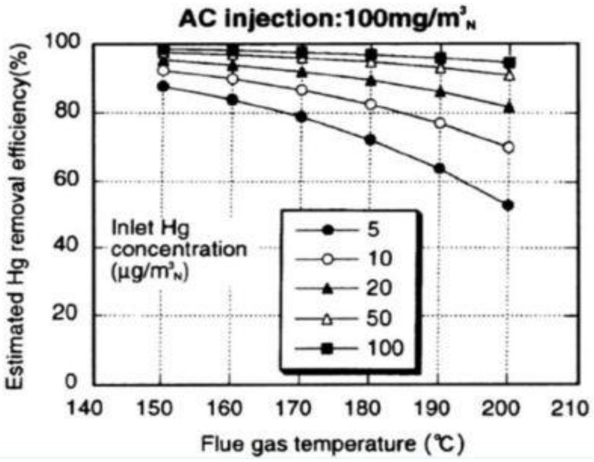


Figure II.5 : Mercury Removal Efficiency of Activated Carbon Injection [22]

II.2.1.2. Metal-containing adsorbents

Silver-modified adsorbents have been widely used for mercury removal in natural gas and its condensate due to their high mercury removal capacity. silver- loaded activated carbon fiber (ACF) exhibited a 48 to 192 times increase in mercury adsorption capacity, compared with a commercial AC **[23] .**

In another example, a self-assembled adsorbent prepared by AC modified with FeOOH

(Iron(III) oxide-hydroxide(nanoparticle was used to adsorb Hg^0 in natural gas. As a result, the maximum adsorption capacity for Hg^0 by FeOOH was 1405.1 µg/g at a temperature of 25 ◦C **[24] .**

chemical fixation of mercury by CuS inside the solid matrix can improve mercury removal capacity **[25] .** H_2S also was used to modify a Fe-Ti spinel and the adsorbents showed a remarkably high adsorption capacity of 0.69 mg/g for Hg0 that remained stable after five cycles of operation **[26] .**

In addition to iron sulfides, zinc sulfides were also found to have a Hg^0 removal capacity of around 0.3 mg/g. For example, after the treatment of zinc sulfides with a cupric solution, the adsorption capacity of the adsorber for Hg^0 reached 3.6 mg/g **[27] .**

II.2.1.3. Other adsorbents

Metal-organic frameworks: Recently, metal–organic frameworks (MOF) have been used to remove mercury from natural gas and crude oil. Studies to date have reported over 20,000 different MOFs with different pore sizes and high specific surface areas **[28] .**

Ionic liquids (ILS) : The ionic liquids (ILS) are low melting point salts that consist of both organic or inorganic ions and may contain more than one cation or anion, such as [Bmim]Cl (Bmim: 1-butyl-3-methylimidazolium), [Bmim][CH_3SO_4] and $[Bmim]_2[CuCl_4]$. The metal ion, halogen, and organic ions in ILS have a strong affinity for heavy metals and are usually supported on solid porous materials **[29] .**

II.2.2. The selective of sorbents for mercury removal from natural gas condensate

Note : A sorbent is a broader term that encompasses materials capable of both adsorption and absorption.

II.2.2.1. Carbon-based adsorbents

Sulphur-containing adsorbents: Considering that elemental sulphur is soluble in liquid hydrocarbons, metal sulfides have been used as an alternative to sulphur to remove mercury from fuel condensates due to their higher stability in non-polar mediums **[30] .**

A metal sulfide-impregnated AC adsorbent can be used in the process; the sulphur disperses into the pores of the AC to increase the contact area between sulphur and mercury, which promotes mercury adsorption efficiency. Second, the C-S bonds are formed between sulphur and the carbonaceous framework. These bonds react with mercury to generate stable HgS compounds, which is the primary mechanism for capturing mercury from natural gas and its condensate **[31].**

However, there are several problems with sulphur-containing adsorbents. Inappropriate sulphur impregnation can occur during the adsorbent preparation process, resulting in low binding energy between the sulphur and carbon and causing the dissolution of sulphur by the water vapor in the natural gas stream. In this case, the net effect is a loss of sulphur active materials, which can pollute and contaminate the downstream processing equipment; this problem can be fixed by adding a guard bed filter after the mercury removal unit. In addition, sulphur-modified adsorbents are rarely recyclable due to the poor stability of the impregnated sulphur. Their mercury removal capacity was found to be slightly lower than that of silver-containing adsorbents **[32] .**

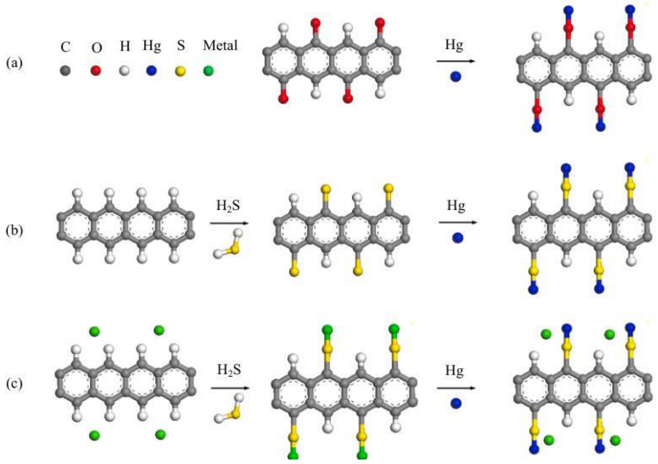


Figure II.6: Schematic diagram of Hg(II) adsorptions on biochars (a) C—O effects (b) C-S effects (c) metal sulphide effects [31]

Metal-containing adsorbents

AgNPS-AC (Ag nanoparticles) had a mercury removal efficiency of 98 % from a condensate (10 mL) with a Hg concentration of 500 µg/L). Notably, the thermal stability of silver is better than that of sulphur, so silver-modified carbon adsorbents can be regenerated by a heat-treatment process. On the other hand, due to the high cost of silver materials, current research is focusing on generation methods to improve the economic cost of these silver- containing adsorbents **[41]**.

Hg^0 had the lowest oxidation barrier on the Fe/AC surface meaning that Fe/AC was a good heterogeneous and effective Hg^0 oxidation catalyst. In addition, $ZnCl_2$ AC also showed an excellent mercury removal efficiency of 82.9 % in simulated coal gas. This was owing to the Zn content on the surface of AC which served as active sites for the chemisorption of Hg^0**[34]** .

In summary, carbon-based materials were widely used for mercury removal due to the simple preparation method, and the high removal efficiency of the adsorber. Some modified carbon adsorbents may have a strong adsorption selectivity for Hg^{2+} and poor adsorption selectivity for HgR. The adsorbents may contain sulphur, silver, and other metals which provide active sites for mercury and improve the mercury removal performance **[34] .**

Table II.2 : Table of sorbents and their properties [35]

Sorbent	Active material	SBET(m^2/g)	Hg	Fraction Adsorption capacity(mg/g)	Adsorption condition(◦C)
Biochar	H_2S	69	Hg^{2+}	0.039	30
Date-pits-base	Silver nanoparticles	900–1100	Hg^{2+}	0.099	Ambient temperature
Ni/Al_2O_3	Ni	-	Hg^0	~100 %	-
Ni-Mo/Al_2O_3	Ni-Mo	-	Hg^0	183	-
Ag/Al_2O_3	Ag	-	Hg^0	99.6 %	-
Agricultural waste biomass	NaOH, H_2O_2, NaOCl, NaOCl/NaOH,	-	Hg^{2+}, MeHg	-	30

II.3. Absorption:

In the realm of mercury removal, absorbents play a pivotal role as specialized agents designed to capture mercury from gas streams or aqueous solutions. These absorbents, typically liquid-based, exhibit a strong affinity for mercury ions or molecules, facilitating their selective removal.

The selection of absorbents for mercury removal depends on several factors, including:

- Affinity for Mercury: The absorbent should have a strong attraction to mercury ions or molecules to ensure efficient capture from the gas stream or solution.
- Chemical Compatibility: The absorbent chosen should be compatible with the composition of the gas stream or aqueous solution being treated. It should not react with other components present in the stream in a way that diminishes its effectiveness for mercury removal or introduces additional pollutants.
- Operating Conditions: The conditions under which the mercury removal process will be carried out, such as temperature, pressure, and ph.
- Regulatory Requirements: Regulations may specify permissible levels of mercury emissions or discharge concentrations, as well as approved methods for mercury removal.
- Regeneration Potential: Absorbents that can be regenerated efficiently without significant loss of performance offer cost savings and reduce waste generation.
- Cost and Availability
- Safety and Handling **[36]**

II.3.1. Sulfur-based Absorbents:

Contain sodium polysulfide (Na_2S_4) or other polysulfide compounds dissolved in an alkaline solution (e.g sodium hydroxide) .The polysulfide reacts with elemental mercury (Hg^0) to form insoluble mercury sulfides (HgS), effectively trapping the mercury **[37].**

Limitations:

- Not ideal for high-temperature applications (>120°C) as polysulfides decompose at elevated temperatures **[38].**
- The spent solution may generate hazardous waste containing mercury sulfide (depending on local regulations).

II.3.2. Gas Scrubbing

In wet scrubbing processes for gaseous control, a liquid is used to remove mercury from an exhaust stream. The removal of mercury in the gaseous stream is done by absorption. Wet scrubbers used for this type of pollutant control are often referred to as absorbers; Most of them have removal efficiencies in excess of 90 percent in the case of mercury.

The scrubbing solution, usually water and other liquids, such as **dimethylaniline** or **amines** these liquids have high solubility for the gaseous stream and relatively inexpensive.

The driving force of the absorption process is related to the amount of soluble gas in the gas stream and the concentration of the solute gas in the liquid film in contact with the gas. Liquids other than water may require absorbent separation and scrubbing liquid regeneration to help lower costs of the scrubbing liquid [**39**]**.**

Wet scrubbers utilize large surface areas to allow intimate contact between the liquid and gas stream. The creation of the large surface area is accomplished by passing the liquid over a variety of media (packing, meshing, grids, or trays) or by creating a spray of droplets **[39].**

II.1. Twister supersonic separation

The twister Supersonic Separator employs a high-velocity supersonic flow to create conditions that facilitate the separation of gas components. The core principle involves cooling the gas rapidly through expansion, causing the heavier hydrocarbons and contaminants to condense into a liquid phase. This phase is then separated from the main gas stream.

Twister has thermodynamics similar to a turbo expander, which transforms pressure to shaft power. Therefore, Twister achieves a similar temperature drop by transforming pressure to kinetic energy (i.e., supersonic velocity). The tube is the heart of the Twister system that combines adiabatic cooling, in which no heat enters or leaves the system, with cyclonic separation in a single, compact device. **Figure II.7** details the cross section and key components of the tube design. As can be seen, adiabatic cooling is achieved in a Laval nozzledan aerodynamically shaped venturi tubed which is used to expand the saturated feed gas to supersonic velocity, resulting in a low temperature and pressure.

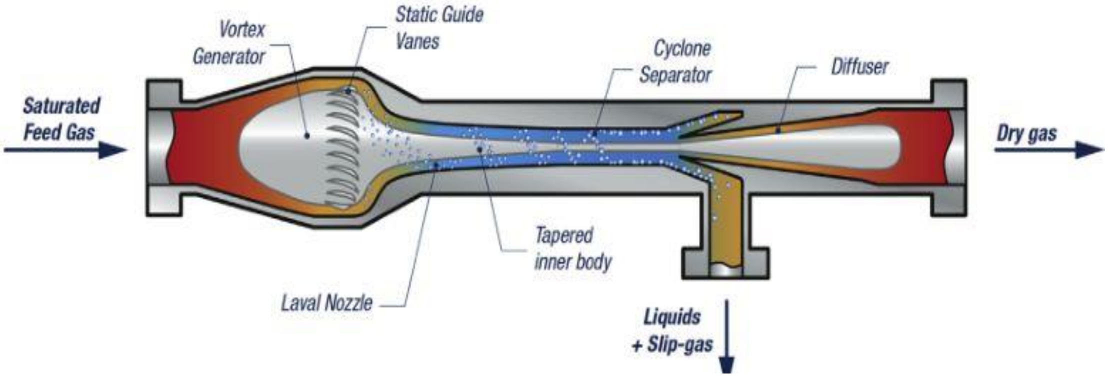


Figure II.7: process of separation by twister separator [24]

This results in the formation of a mist of water and hydrocarbon condensation droplets. The fine, dispersed liquids including mercury formed during the adiabatic expansion are separated using a cyclonic separator as a result of the centrifugal forces exerted by the strong swirling flow and removed from the dry flow with significantly high separation efficiency. The liquid stream contains slip-gas, which will be removed in a compact liquid degassing vessel and recombined with the dry gas stream **[40].**

Note: A cyclonic separator is a device that removes particulates from a gas stream using centrifugal forces. As the gas enters the separator, it is forced into a spiral motion. The centrifugal force pushes the heavier particles and liquids outward to the separator's walls, where they fall to the bottom and are collected.

II.2. Factors Affecting Mercury Removal

Several factors affect the removal efficiency of mercury from natural gas. These factors are summarized as follows: [**43**]

- composition of gas
- presence of higher hydrocarbons
- operating temperature/pressure
- activated carbon characteristics
- concentration of mercury vapor
- presence of water and other impurities
- gas flow rate
- contact time

Chapter 3: Presentation of the Rhourde Nouss region

Chapter 3: Presentation of the Rhourde Nouss region

III. Chapter 3: Presentation of the Rhourde Nouss region

III.1. Introduction:

The RHOURDE NOUSS region is part of the ILLIZI Willaya. It is far from urban centers. It lies 350 km south/southeast of OUARGLA, 1200 km south/southeast of ALGER and 270 km south/southeast of HASSI MESSAOUD. It is linked to Route Nationale N°03 (OUARGLA- ILLIZI) by a 30km road.

Its average altitude is 275 m above sea level. Its climate is desert (dry with very low humidity), with frequent sand sales. It has a wide temperature range between winter and summer (-5°C to 55°C).

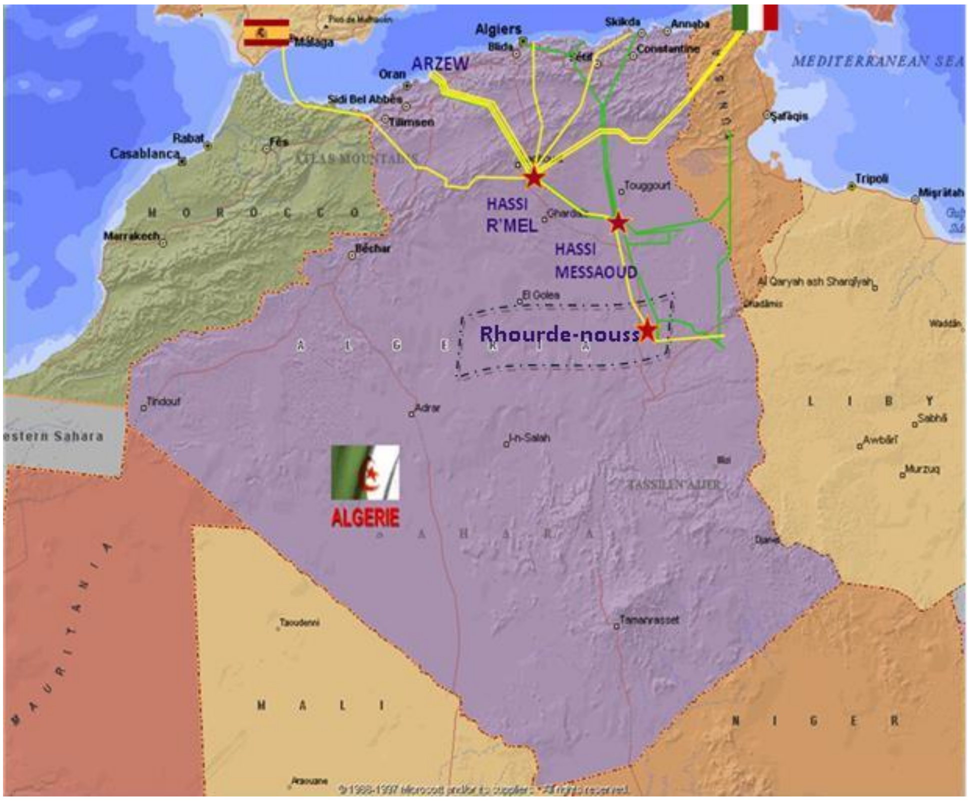


Figure III.1 : Geographical location of the region[42]

III.2. - History :

First gas discovery at RHOURDE NOUSS in 1956. The first RN1 well, drilled in1962, revealed the presence of condensate-rich gas in several reservoirs.

Following the discovery of oil on the RN4 well, an oil processing center was built and put into operation in 1966.

The major stages in the development of the RHOURDE NOUSS region are as follows:

Table III.1: Stages in the development of the region 3 **[42]**.

DATE	DEVELOPMENT STAGES
1956	The first discovery of a gas well at Rhourde Nouss.
1966	The first discovery of an oil well at Rhourde Nouss.
10-May-1966	Commissioning of the Oil Treatment Center.
28-Jan-1988	Start-up of phase A plant. - four trains each with a capacity of 10 million Sm^3 /d of raw gas .
June 14-1989	Commissioning of Rhourde Adra.
April 24-1992	Commissioning of Rhourde Hamra.
29-May-1992	Commissioning of Rhourde Chouf.
June 16-1995	Start-up of the HAMRA plant.
1995	The RHOURDE NOUSS region was SONATRACH's first unit to have installed a DCS system at HAMRA.
23-May-1996	First shipment of LPG (HAMRA).
August 13, 1999	Expansion of phase A with a fifth train with processing capacityof 10,250 million Sm^3/d of raw gas.
February-2000	Start-up LPG plant (Phase B) with 48% processing capacitymillion m^3/d for a production of 3800 t/d of LPG.
06 March 2000	First shipment of LPG (Rhourde Nouss).
2004	Upgrade to DCS control system (4 UTG trains).
2005	Commissioning of the Flared Gas Recovery Unit (SRGT).
2005/2010	Preparation of CTH and QHA development plans.
2007	RN3 well operation.
2008	Upgrade of turbine control system from MARK II to MARK VI.
2013/2014	Start-up of the CPF factory.

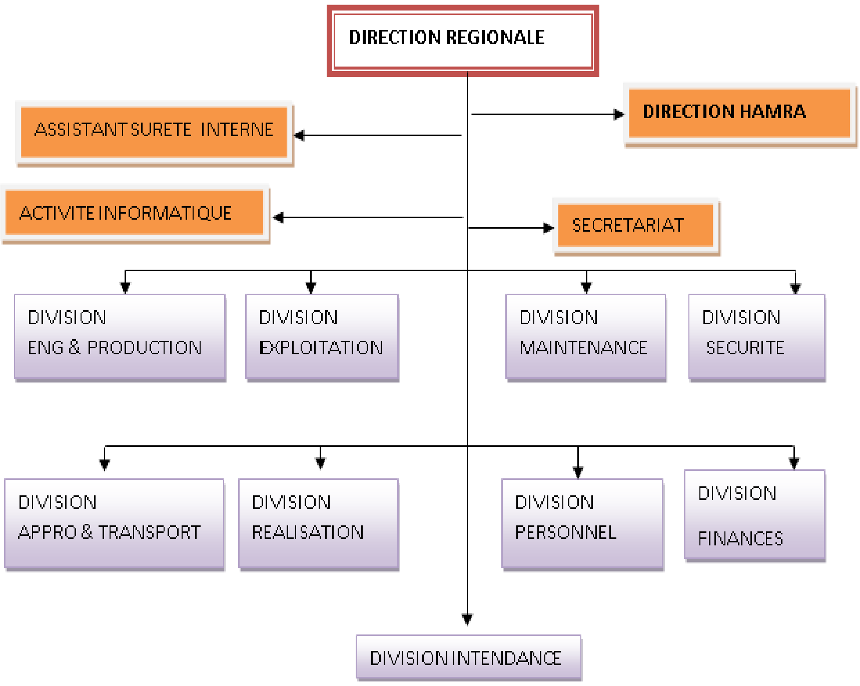


Figure III.2 : The region's organizational chart[42]

III.3. The main fields :

The Rhourde Nouss region is made up of several fields (deposits) within a 100 km radiusof Rhourde Nouss Centre:

- Rhourde Nouss field.
- Rhourde Adra field.
- Rhourde Chouf field.
- Rhourde Hamra field.
- Hamra field.

Other fields, of lesser importance, have been discovered and will be developed later:

- Rhourde Hamra southeast field.
- Rhourde-Nouss 3 field.
- Mouilah field.
- Meksem field. Draa Allal field.Elketaia field.
- Rhourde Adra southeast field.

III.4. Collection networks:

This production is ensured by a number of gas-producing and gas-injecting wells, a set ofmanifolds and collectors (Figure 15), (Figure 16).

- Gas-producing wells: 76.
- Gas injector wells: 36.
- Oil wells: 16.
- Collections: 780 Km (diameter from 4" to 20").
- Manifolds: 37.

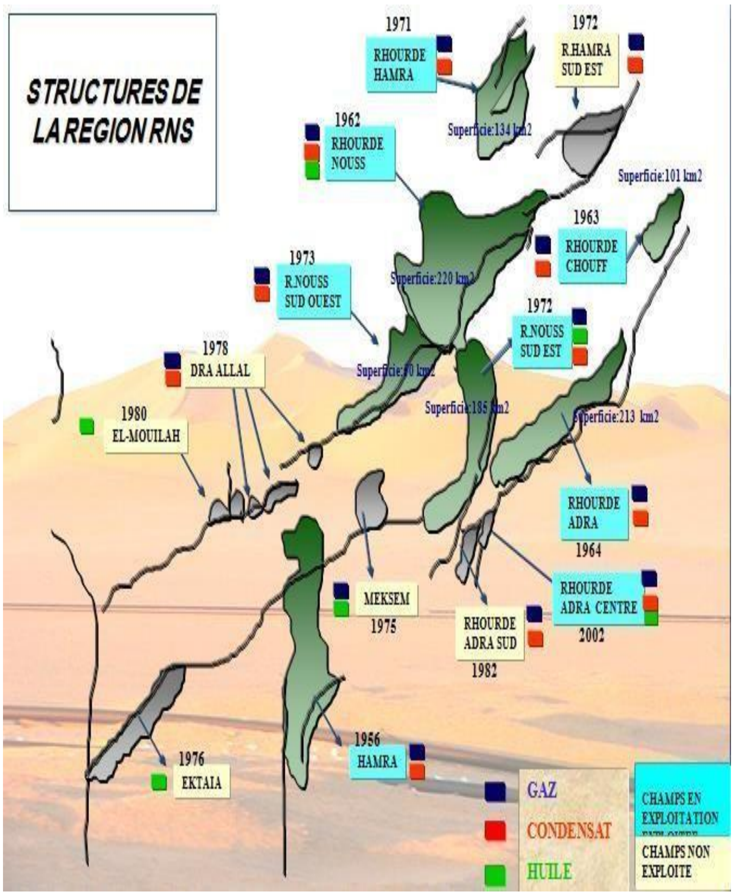


Figure III.3: Simplified structural diagram of the Rhourde Nouss region **[42]**

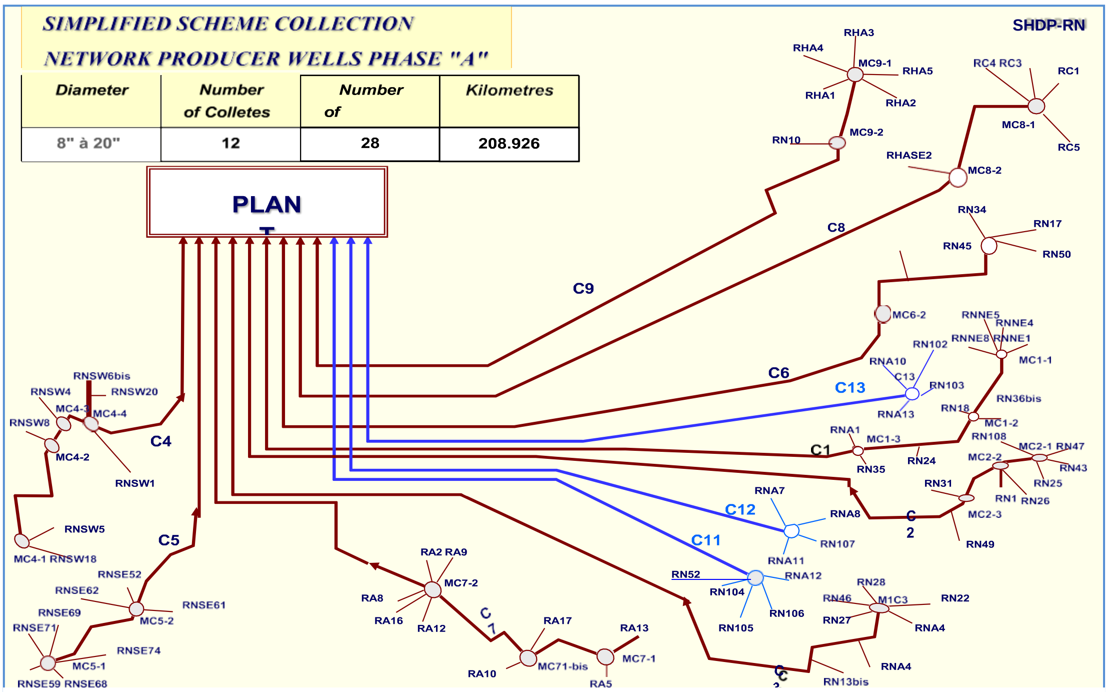


Figure III.4 : Simplified network diagram for producer wells**[42]**

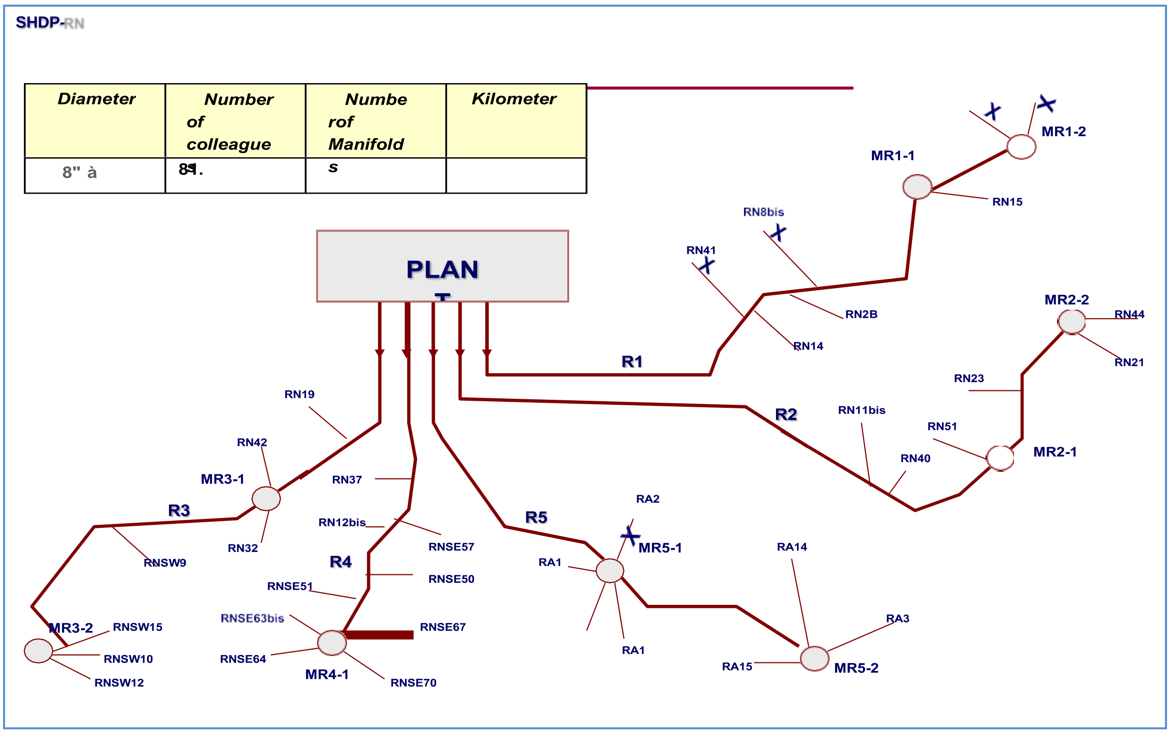


Figure III.5: Simplified service diagram for injector wells**[42]**

III.5. The various complexes in the region:

The RHOURDE NOUSS region is mainly dedicated to gas production. It is equipped with:

- Three wet gas processing plants :
  - Phase A: Treatment of 51 million sm^3 /d to recover condensate.
  - Phase B: Treatment of 48.3 million sm^3 /d to recover LPG and traces of condensate.
  - Phase C: Treatment of 10 million sm^3 /d to recover condensate and sales gas.
- An oil treatment center with a capacity of 2,000 m /d.^{3}
- A power plant generates 21 MW of clean energy for the region.

Phase A:

This plant processes raw gas in 4 identical trains, each comprising a set of equipment designed to: achieve good separation in order to recover the maximum amount of condensate (C5+), ensure gas compression (HP part) towards the B phase and recycle the treated dry gas ($_{c1}$ and $_{c2}$) towards reinjection and dispatch. The fifth train (U-70) only processes the high-pressure "HP" part of the raw gas.

The existing plant currently processes a feedstock of 46 million sm^3 /d of raw gas, and produces 2,690 t/d of condensate.

Phase B:

The plant's facilities are designed to recover the LPG contained in the sales gas producedby the plant (phase A).

The LPG produced is sent in a pipeline to HAOUDH ELHAMRA (HEH), the condensate resulting from fractionation is returned to storage in phase A, and the residual gas is also returned to the phase A facilities for sale or reinjection.

Phase C (CPF):

The new Hamra Quartzite (QH) or CPF processing plant is designed to process 11 million Sm^3 /day of gas (dry basis) from 33 production wells in four fields, in the Rhourde Nouss area. The plant has a nominal output of 10 million Sm^3 /day and produces dry waste gas with a Gross Calorific Value (GCV) of between 9,800 and 9,900 Kcal/Sm^3 and a $_{CO2}$ content of less than 2.0 mol%. The export gas is sent to the GR4 pipeline of the TRC transmission network.

Compression and Separation Center (CSC) :

The Separation and Compression Center (CSC) separates oil, water and gas from the 33 wells in unit 500, grouping them according to pressure level and connecting them to three separators to separate gas and condensate. Gases from the top line of the three separators at different pressures (MP, BP, TBP) are compressed in the compression system to obtain the battery pressure at the Rhourde Nouss gas plant, which is 92 bar. Condensates recovered from the TBP separator are sent to the crude desalter, and then to the stabilization column; after treatment, the desalted and stabilized crude from the column is stored in the crude storage tank.The primary objective of this plant is oil production **[43].**

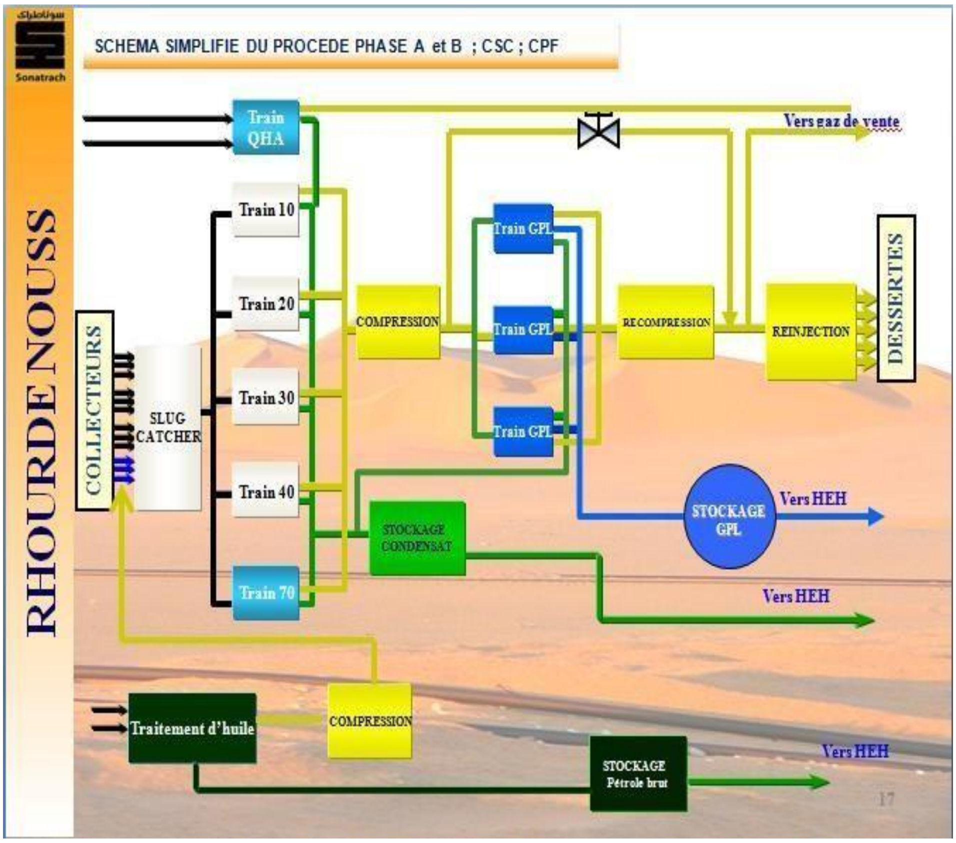


Figure III.6: Descriptive diagram of phases A and B and C and CTH**[42]**

III.6. Description of the CPF Installation

III.6.1. Introduction :

The new Hamra Quartzite (QH) processing plant is designed to handle 10 million Sm^3 /day of gas (dry basis) from 33 production wells in four (04) fields, in the Rhourde Nouss area. The plant has a nominal output of 10 million Sm^3 /day and produces dry residue gas with a Gross Calorific Value (GCV) of between 9,800 and 9,900 Kcal/Sm^3 and a CO_2 content of less than 2.0 mol. The export gas is sent to the GR4 pipeline of the TRC transmission network.

The multiphase mixture of gas, condensate and water enters the plant's slug catcher at a normal operating pressure of around 40 bar, at a temperature of around 50 ºC and containing upto 8.6 mol CO_2. In the slug catcher, the gas is separated from the condensate and free water.

Inside the treatment plant, the gas is compressed by booster compressors (2 x 50%) up to 85 bar and passed through an Acid Gas Removal Unit (AGRU) to reduce the CO_2 content to less than 2.0 mol.

The water-saturated gas leaving the AGRU passes through a molecular sieve dehydration unit to reduce its moisture content to less than 1.0 ppm.

The dry gas then passes through an expansion unit, where the condensate is separated from the gas thanks to the cooling effect caused by the expansion. This process enables the calorific value of the gas to be corrected as required. The dry decarbonated gas is then compressed to 96 bar and cooled to 60°C, before being mixed with the return gas from the LPG plant. The gas leaving the new processing plant, i.e. 8.6 million Sm^3 /day, is mixed with the export gas produced in the existing Rhourde Nouss facilities, i.e. 49 million Sm^3 /day at design conditions. Part of the mixture, i.e. 34 million Sm^3 /day, is sent to the GR4 gas pipeline of the national grid via a new shipping pipeline. This new 28″ pipeline includes a fiscal metering station.

The CO_2 extracted from the gas by the decarbonation unit is compressed in five compression stages to 207 bar. Between the third and fourth compression stages, the sour gas, at a pressure of 55 bar, is passed through a glycol dehydrator to reduce the water content to less than 100 ppmv.

The unstable condensate, at a design flow rate of 145 m^3 /h (110 m^3 /h nominal at operating conditions), is recovered from the wet gas entering the plant and dehydrated to less than 0.1% volume before being sent to the existing Phase A plant facilities for stabilization.

The oily water produced is sent to a treatment unit to be processed in accordance with SONATRACH's quality requirements, i.e. less than 10 mg/L free oil and oil suspended in water,before being sent to an evaporation basin. Treatment capacity is 500 m /day.^{3}

The new Rhourde Nouss QH treatment plant comprises the following two (2) systems:

- Gas collection system and manifolds.
- The Rhourde Nouss gas processing unit, indicated by CPF (Central ProcessingFacility).

The CPF is divided into six (6) sections:

- Multiphase mixture separation (Slug Catcher).
- Unstable condensate pre-treatment.
- Gas treatment.
- Compression and dehydration of CO2.
- Treatment of produced water (de-oiling).

Objectives of the CPF factory :

- Build a plant capable of processing 10 million Sm^3 /d of raw gas
- Produce a sales gas with :
- A gross calorific value (GCV) of between 9800 and 9900 kcal/Sm^3 .
- A $_{CO2}$ content of less than 2 mol%.
- A pressure of 94 bar at the 36-inch junction.
- Water content less than 1 ppmv.
- Compress CO2 to 200 bar and reinject into a depletion well.
- Direct unstabilized condensate to phase A.
- Heavy (associated) gas to be directed to phase A **[42] .**

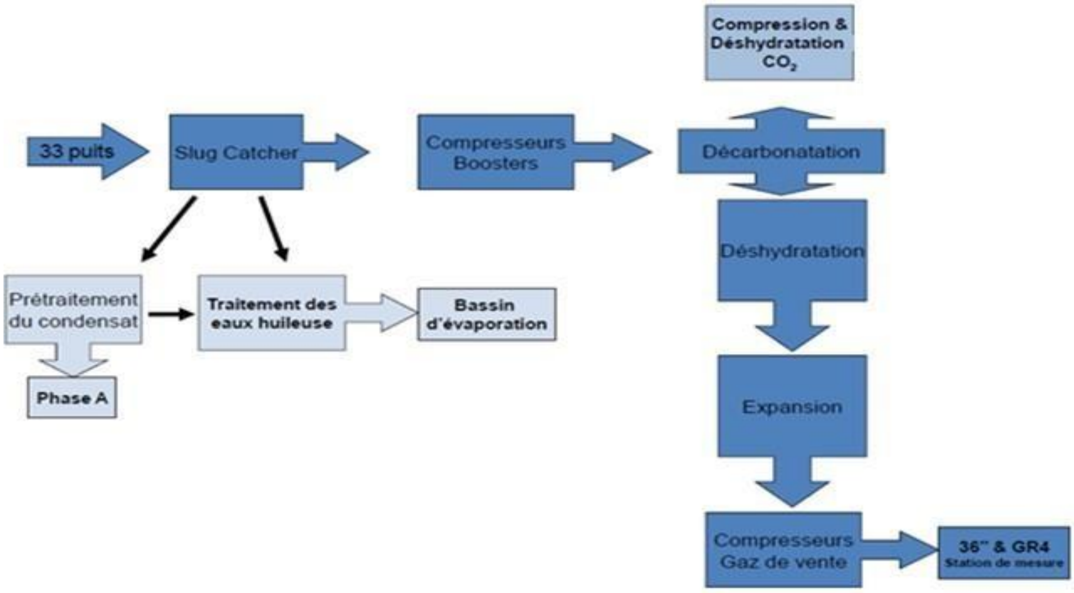


Figure III.7: CPF plant block diagram **[43]**

III.6.2. Process description:

III.6.2.1. Gas collection network and manifolds:

The gas gathering system comprises two (02) existing wells and thirty-one (31) new wells connected by production lines to five (05) manifolds. The manifolds are installed in the Rhourde Nouss Central, Rhourde Nouss South-East, Rhourde Adra and Rhourde Adra South fields, connecting the main lines leading to the CPF intake manifold, downstream of the Slug Catcher **[42] .**

Collectors:

The following manifolds are connected to the production wells on the QH production fields:

- ✓ Rhourde Nouss Central (collectors M1 and M5).
- ✓ Rhourde Nouss Sud-Est (collector M2).
- ✓ Rhourde Adra (collector M3).
- ✓ Rhourde Adra Sud (collector M4).

Each production manifold is equipped with a well test connection, and all production lines ateach manifold connection are fitted with local pressure and temperature indicators.

III.6.2.2. Pre-treatment zone (Slug Catcher and condensate separator) :

The role of this equipment is to capture water and condensate in the raw gas coming from the collection system. The slug catcher is sized to capture the highest anticipated concentrations of condensate and water. The recovered oily water is sent to the wastewater treatment unit (WWTP), and the recovered condensate is transferred to the condensate pre-treatment section. The operating pressure of the slug catcher is controlled at 40 bar **[42] .**

Objectives:

Slug Catcher:

- Stabilize flows and pressure from wells.
- Separate water and condensate from raw gas.

Condensate pre-treatment:

- Separate heavy gas (associated gas), water and solids from non-stabilizedcondensate before sending it to phase A.

Condensate outlet quality:Water: < 0.1 % vol.

- Salt: < 200 ppmv.

Facilities in this zone:

- A: Slug Catcher (G01-VL-20-01).
- B: Condensate separator (G10-VA-20-01).
- C: Pre-filters (G10-MB-20-01 A and B).
- D: Coalescers (G10-VJ-20-01 A and B).

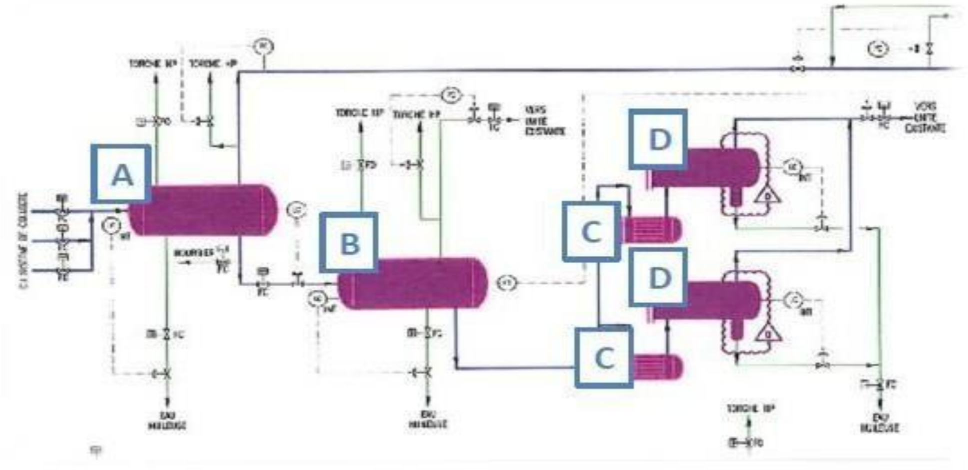


Figure III.8 : The pretreatment zone**[42]**

III.6.2.3. Booster G05 compressor unit:

The wet gas separated in the Slug Catcher is sent to the common suction header, which feeds the two (2) booster compressors in parallel, each designed for 50% capacity (equivalent to 5 million Sm^3 /day for nominal load at CPF).

These compressors consist of a guard balloon, a gas turbine, a compressor and an air cooler. The water and condensate collected in the storage tanks are conveyed to the condensate pre-treatment area.

The role of the two booster compressors is to increase the pressure of the gases coming from the slug catcher and condensate separator to 85 bar. The temperature of the compressed gas risesto around 124°C, then falls back to 55°C after cooling **[42] .**

Objective:

- Increase gas pressure to optimize decarbonation and expansion performance.
- Reduce pipe diameters.
- Increase raw gas pressure from 40 bar (suction) to 85 bar (discharge) to optimize decarbonation and expansion performance.

Equipment :

- Booster compressor intake manifolds.
- 02 Booster compressor suction tanks (G05-VD-23-01/02).
- 02 Siemens booster compressors type STC-SV (G05-KA-23-01/02).
- 02 Gas turbines for Siemens SGT-400 booster compressors (G05-DT-23- 01/02).
- 02 Compressor air coolers (G05-GC-23-01/02 A/B).
- 02 Booster compressor heat recovery units (G05-GW-23-01/02).

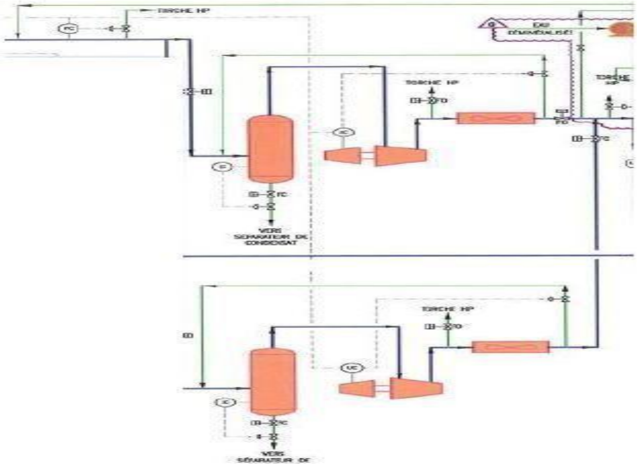


Figure III.9 :Booster G05 compressor unit **[42]**

III.6.2.4. G64 decarbonation unit (AGRU):

The aim of the decarbonation unit is to reduce the amount of carbon dioxide (CO_2) in the feed gas from 8.6 mol% to the final export gas specification of less than 2 mol%. The AGRU is based on the combined technology of countercurrent absorption with an amine solution, followed by a regeneration stage in which the CO_2 is removed from the amine solution.

CO2 capture from the gas takes place in a scrubber tower and an amine solution, specifically a mixture of diethanolamine (DEA) and methyldiethanolamine (MDEA). The acid-gas-rich amine is regenerated in a reboiler, heated with heat transfer oil, and then cooled by heat exchangers and ball-cooled back to the scrubber. The removed CO_2 is directed to the dedicated dehydration and compression unit, while the recovered oily water is sent to the wastewater treatment unit (CPI) **[43] .**

The system is equipped with a drain system connected to a 600 m^3 nitrogen-covered reservoir that can capture all the amine volumes present in the system. It is also equipped with two smallamine make-up tanks.

Gas is processed at temperatures between 55 and 75°C, while amines are processed at temperatures below their flash points (137°C), which limits the fire and explosion hazards involving amines.

Objective:

- Removes CO2 from gas by absorption with amine.
- The amine is continuously regenerated in the regenerator.
- Heat for regeneration is supplied by the heat transfer oil system.
- The absorber operates at 84 bar and between 55°C and 80ºC.

- Equipment :

- Decarbonation unit inlet separator (G64-VD-28-01).
- CO2 absorber (G64-CA-28-01).
- Rich amine flash balloon (G64-VD-28-02).
- Rich/poor amine heat exchanger (G64-GA-28-01A-H).
- Recycled amine air coolers (G64-GC-28-01 A-F).
- Activated carbon amine filters (G64-MB-28-03).
- Amine recirculation pumps (G64-PA-28-01A/B).

- Amine pre-filter (G64-MB-28-02).

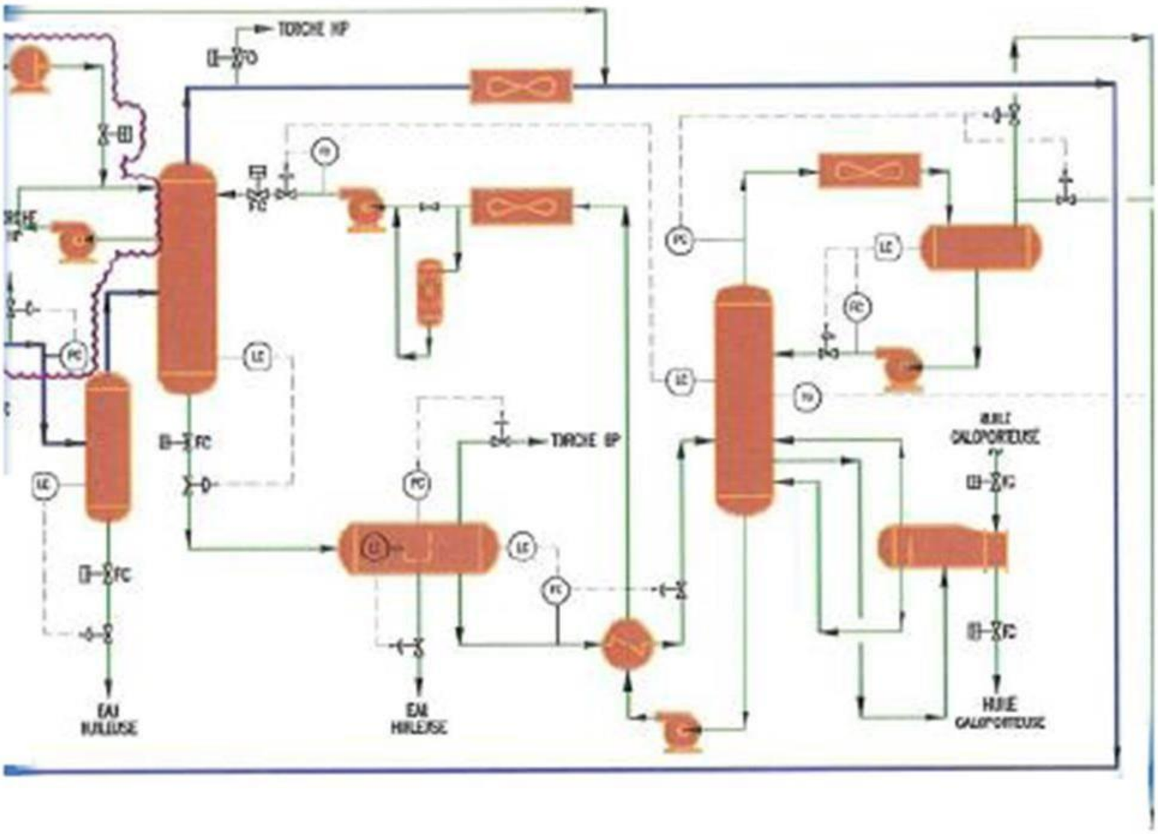


Figure III.10: G64 decarbonation unit **[42]**

III.6.2.5. The G60 dehydration unit:

The aim of the dehydration unit is to reduce the water concentration to less than 1 ppm. The gas first passes through a guard tank, then through a coalescer filter which retains the fine condensate droplets formed during the cooling stage via a heat exchanger. The gas is then dried by passing through filters to stop any particles that may have been carried along by the gas as it passes through the beds.

A small portion of the dried gas is diverted and heated by a furnace to regenerate the beds by counter-current drying. The resulting moist gas is cooled, sent to a separator to allow water condensation, then pressurized by a compressor and returned to the head of the cooling unit. The gas is treated, and the condensate and water collected are sent to the condensate separator and wastewater treatment unit (CPI) respectively **[42] .**

The treated gas is operated at a pressure of around 80 bar and a temperature varying between 40 and 60°C. However, the temperature of the regeneration gas rises to a maximum of 260°C.

Objective:

- Removes water from gas to prevent freezing and hydrates.
- Absorption takes place in 03 molecular sieve dryers.
- The process is cyclical. The screens become saturated and have to be regenerated bycirculating hot, dry gas backwards.
- Absorption operates at 82 bar and 40°C.

Equipment:

- Dehydration inlet exchangers (G60-GA-24-01A/B).
- Dehydration inlet separator (G60-VD-24-01).
- Gas/liquid coalescer (G60-VJ-24-01).
- Molecular sieve dryers (G60-VK-24-01/02/03).
- Molecular sieve filters (G60-MB-24-01A/B).
- Regeneration furnace (G60-FA-24-01).
- Aerocooler for regeneration gas (G60-GC-24-01).
- Regeneration gas separator (G60-VA-24-01).
- BCH301 compressors (G60-KA-24-01A/B).

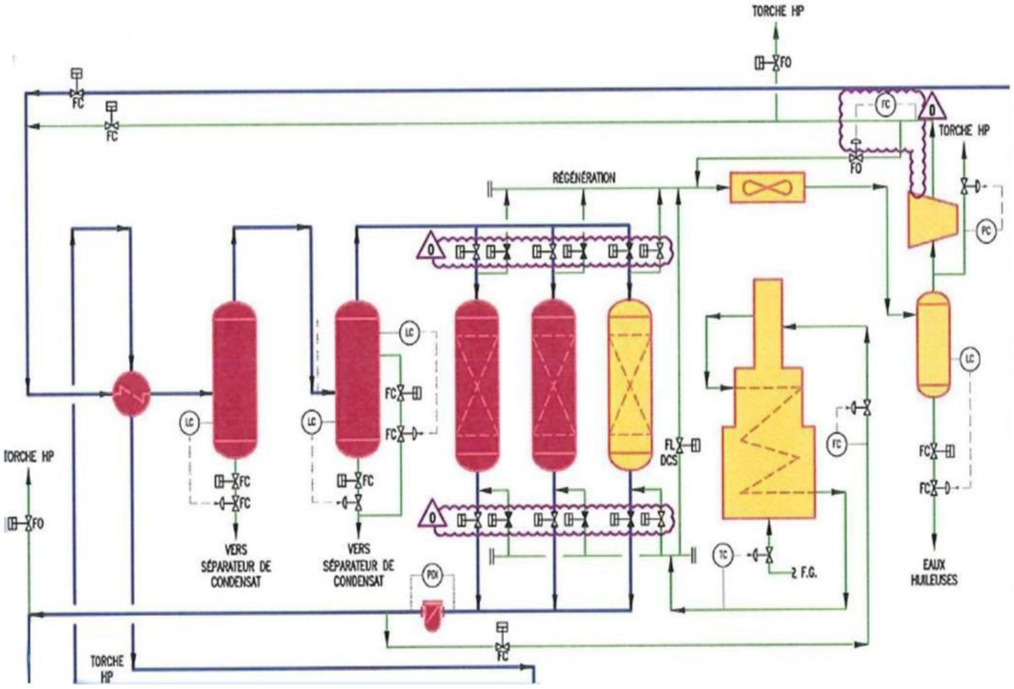


Figure III.11 : G60 dehydration unit **[42]**

III.6.2.6. G67 gas expansion and separation unit:

Gas expansion is the final adjustment of the hydrocarbon-water-gas proportions, enabling the extracted gas to reach a commercial value with a calorific value of between 9800 and 9900 Kcal/Sm^3 . The pressurized gas from the dehydration unit is cooled by a heat exchanger, then passes through a guard balloon to leave the droplets that have formed before entering the turbo expander, where it expands. As it does so, it cools and drives the turbine that drives the compressor, which re-pressurizes it and sends it through the after-cooler. The recovered condensate is sent to the condensate treatment unit.

The gas is then compressed to 96 bar by two parallel compressors and cooled to 60°C by two air coolers. At the outlet of the compression unit, the gas is mixed with sales gas produced fromexisting facilities, and exported to the GR4 national export network via a new pipeline.

Objective:

- Removes heavy hydrocarbons by condensation caused by cooling from expansion.
- The expander outlet operates at 60 bar and 15°C.
- The gas, freed from condensed liquids, is re-compressed by the compressor.
- The unit outlet operates at 66 bar and 55°C.

Equipment :

- Turbo expander inlet exchanger (G67-GA-25-01A/B).
- Turbo-expander suction balloon (G67-VD-25-01).
- Turbo-expander MTC 400 EX (G67-KH-25-01).
- Compressor-expander MTC 150 EX (G67-KA-25-01).
- Compressor-expander suction tank (G67-VD-25-02).
- Air coolers for compressor-expander (G67-GC-25-01A/B).
- Turbo-expander auxiliary system.
- Turbo-expander sealing system package (G67-UK-25-01).
- Sealing gas filters (G67-KMB-25-01A1/A2).

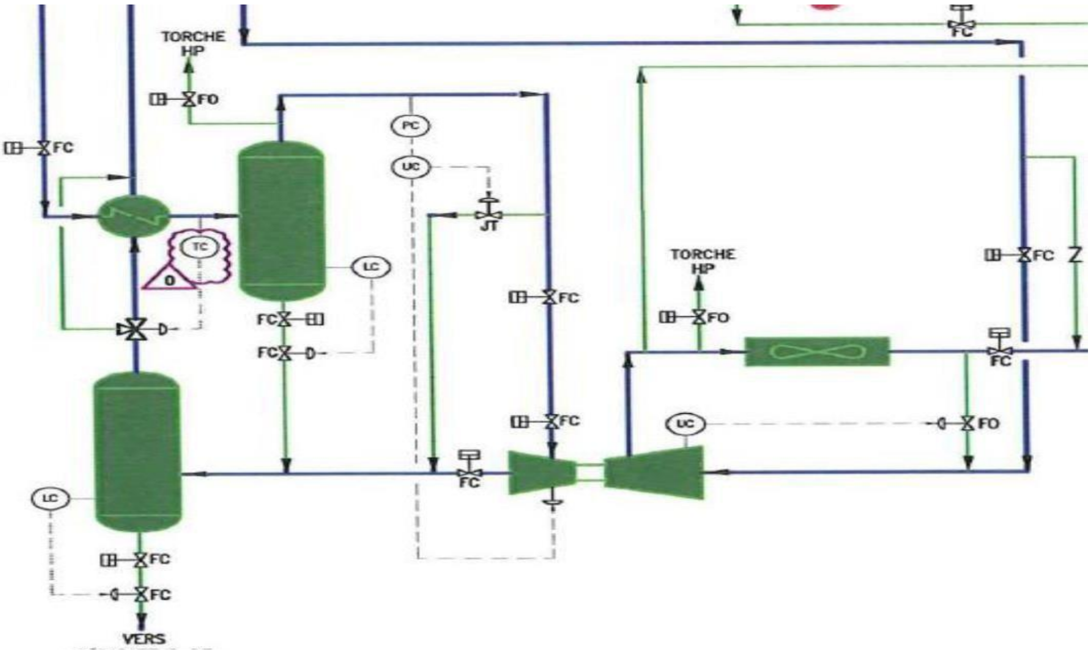


Figure III.12 : G67 gas expansion and separation unit [42]

III.6.2.7. The G 50 sales gas compressor unit:

Decarbonated dry gas from the air cooler of the compressor-expander (G67-GC-25-01A/B), at a pressure of 66.5 bar and a temperature of 55°C, is fed into a common suction manifold, which supplies two parallel 02sales gas compressors, each designed for 50% capacity. The sales gas trains include suction balloons, sales gas compressors with variable-speed turbine drives and air coolers.

To mix the CPF sales gas with the gas from the existing LPG plant, the gas is compressed to 97 bar at a temperature of 60°C. The sales gas is fed into the 36-inch pipeline from the LPG plant. Downstream of this connection, a new 28" pipeline connects to the GR4 pipeline of the TRC transmission network. The new 28" pipeline runs approximately 14 km to the connection with the GR4 pipeline, and is equipped with a fiscal meter (G90-UJ-27-01) and a split-range modulating pressure control system (27-PIC-015A and 27- PIC-015B) **[42] .**

The new pipeline can transport 34 M Sm3/day of gas. The operating pressure at the point of connection to the GR4 pipeline is 74 bar.

Objective:

- Compresses gases for shipping.
- The gas is discharged at 96 bar and 60°C.

Equipment :

- Suction manifolds for sales gas compressors.
- Two suction tanks for gas sales compressors.
- Two Gas Sales Compressors - STC-SV.
- Two Gas Turbines - SGT-100-2S.
- Two compressor air coolers.

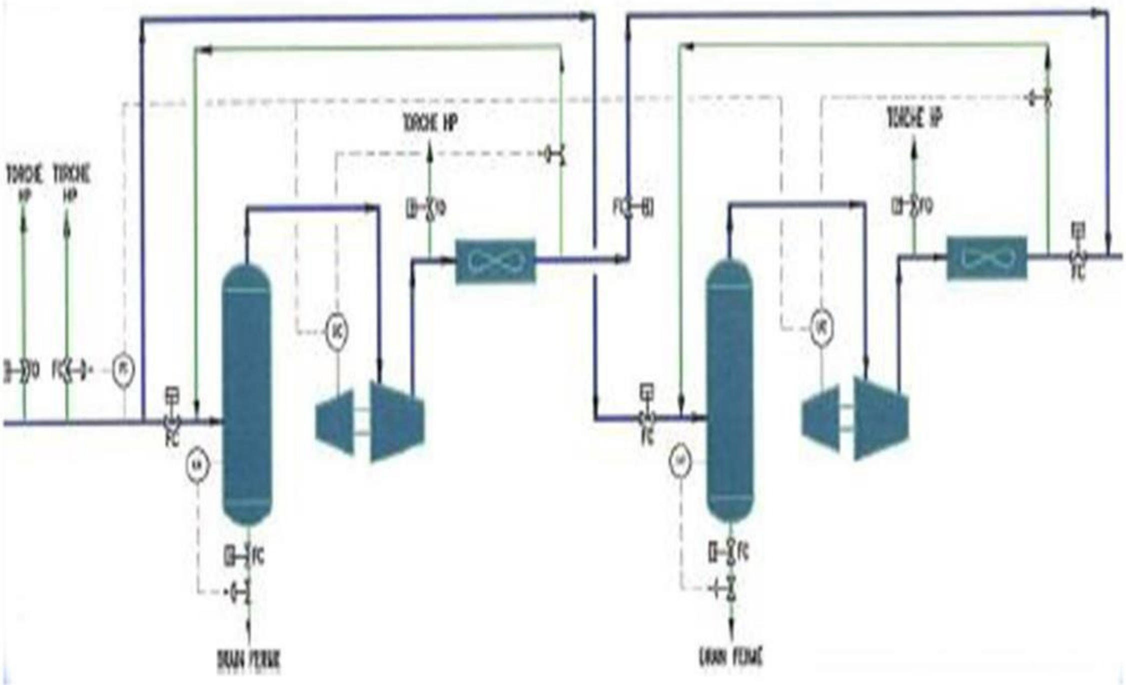


Figure III.13 : the G50 wind gas compressor unit

III.6.2.8. The G 85 CO2 compression and dehydration unit (CCDU):

The CO2 captured in the sour gas extraction system is compressed using a five-stage turbocharger and then dehydrated using triethylene glycol.

The system in the closed-loop system consists of a dehydration absorber, a reconcentrator, coolers and heat exchangers, a buffer tank and a make-up tank. The system operates at temperatures below or slightly above the flash point of triethylene glycol **[43] .**

IV.3.8.1 - Objective:

- Compresses CO_2 in 5 stages up to 200 bar.
- Dehydration of CO_2 with glycol between the 3rd and 4th stages.
- The glycol is continuously regenerated in a reboiler.

III.7. Description of utilities:

III.7.1. Heat transfer oil system :

Heat transfer oil is used in the acid gas extraction system (AGRU) to regenerate and heat amines. The oil used is Torada TC-32 or Therminol-55 with flash points of 200 and 177°C respectively.

The oil is stored in a 480 m^3 tank, from where it is transferred to an expansion tank, then heated in an oven before being sent to the acid gas extraction system. To prevent overheating, a portion of the hot oil can be diverted to an air cooler and returned to the expansion tank. After use, the oil is directed to an underground drainage tank, from where it is pumped to the storagetank.

The reservoir and expansion tank are blanketed with nitrogen, and oil vapours from the expansion and drainage tanks are routed to the low-pressure flare. In addition, the tank is protected by a 350 m retention basin **[42] .**

III.7.2. Lubricating oil system :

A system supplies the plant's various turbochargers with lubricating oil. The closed-loop system comprises a lubricating oil treatment system, an untreated oil tank, a treated oil tank anda fresh oil tank.

III.7.3. Chemical injection system :

The chemicals required for the various stages of the process are injected from six prefabricated modules consisting of tanks and adjustable volumetric metering pumps. In addition, in-line injectors with fittings are installed at various points in the process to inject corrosion inhibitors, emulsifiers and other chemicals as required.

The following chemicals are injected into the process at various points (excluding all special chemicals used for raw water or wastewater treatment):

- Anti-foaming agent.
- Anti-scaling agent.
- Corrosion inhibitor (liquid service).
- Corrosion inhibitor (gas service).
- Methanol (hydrate inhibitor).

III.7.4. Oily water treatment :

The oily water treatment unit is designed for a daily volume of 500 m^3, which corresponds to an average flow rate of 21 m^3/h. Treated water directed to the evaporation basin must contain a maximum of 10 mg/L of free oil and oil in suspension. It is installed upstream of the evaporation basin and downstream of the central treatment plant (CPF). This unit collects water from the following equipment and systems:

- Slug Catcher.
- Condensate pre-treatment.
- Dehydration system.
- Decarbonation unit.
- $CO2$ compression and dehydration unit.
- Open drains.

The purpose of the oily water treatment unit is to remove non-soluble hydrocarbons inorder to meet the 10 mg/L discharge criterion to the evaporation basin **[42] .**

III.7.5. Low-pressure, high-pressure and slurry torches:

There are two flare systems for hydrocarbon discharge: the low-pressure (LP) flare and the high-pressure (HP) flare. Each flare system is sized to handle the highest release scenario associated with that system. In the case of the HP flare system, the system is capable of handling 100% of the CPF's gas capacity (10 M Sm^3 /day).

Each train torch system comprises a guard balloon, two pumps to send liquid to the drainage system, an elevated torch, two gas pumps, a flame generation and flame monitoring system.

Two hydrocarbon purge recovery and flare disposal systems, one operating at low pressure (LP) and the other at high pressure (HP), will serve the entire process unit. Each system is equipped with a pilot-ignition flare connected to the flare gas supply system. This make-up gas is injected at the end of the flares to entrain the hydrocarbons to be destroyed and prevent air from infiltrating the system **[42] .**

III.7.5.1. Objective:

- For evacuating gaseous (HP and BP) and liquid (sludge) hydrocarbons.

III.7.5.2. Equipment :

- HP 850-VD-43-01 torch balloon.
- High-Pressure Torch and Igniter 850-FC-43-01.
- BP 810-VD-43-01 torch balloon.
- Low-pressure torch and igniter 810-FC-43-01.
- Bourbier and Igniter 800-FP-43-01.

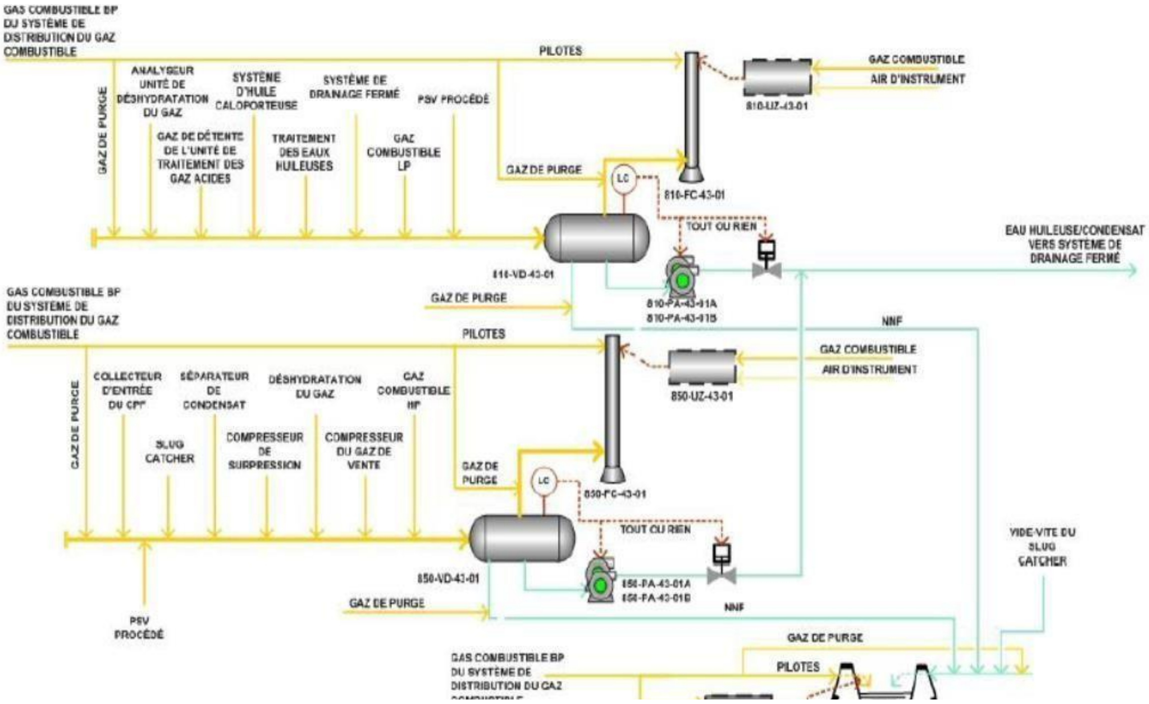


Figure III.14 : Flare system and quagmire[42]

III.7.6. CO2 Chimney Guard Balloon :

Like the flare system, the CO2 release system comprises a manifold, a CO$_2$ stack guard (870- VD-38-10), two (02) pumps (870-PA-38- 01A/B, 2 x 100%) and a CO$_2$ discharge stack (870-FC- 38-01). Only the safety valves for the AGRU regeneration sector, the CO$_2$ compressor and the TEG pressure relief valves are connected to the manifold of the CO$_2$ discharge stack. The CO$_2$ pipeline is depressurized to atmosphere **[43] .**

III.7.7. Fuel gas system :

The plant has a fuel gas system to supply the turbines, furnaces, regenerator, reboiler, flares, etc. Fuel gas is obtained from the plant's natural gas production and distributed to consumption points via a high- and low-pressure distribution network.

III.7.8. Water supply system :

Existing wells will supply the raw water needed for drinking water, demineralization and for the fire-fighting system, whose requirements amount to 30 m^3 /h. The first stage of raw watertreatment consists of two steps:

Injection of biocide for disinfection, anti-scaling agent and sulfuric acid to correct PH; filtration through a basket filter to retain larger particles.

This water is then stored in a raw water reservoir and undergoes further treatment dependingon its intended use **[42] .**

III.7.9. Closed drain network :

The underground network of closed drains collects liquids from process equipment throughout the CPF, including manual maintenance drains, sales gas compressor suction balloon liquid, HP and BP flare suction balloon pump liquid, fuel gas suction balloon liquid and liquid hydrocarbons recovered from water treatment. This network does not collect carrier oil drainsand amine drains, each of which has its own dedicated drainage network.

Open drains from lube oil installations are directed to oil traps where the oils are collected and drained manually.

III.7.10. Instrument air and factory service air :

Compressed air used for instrument air, nitrogen production and the plant's utility stations is produced by the three air compressor batches (420-UK-63-01A/B/C),

including oil-free screw compressors. Each unit is capable of producing 50% of the nominal capacity of the overall compressed air network. This configuration enables one compressor to be maintained while the other two remain in continuous operation.

III.7.11. Nitrogen production :

Nitrogen is produced within the 430-UN-64- nitrogen generator and compressor package from instrumentation air. The instrumentation air is first cooled by passing through four finned heat exchangers; then filtered to remove any particles that might damage the membranes.

Nitrogen is supplied to a variety of continuous users, including the sealing gas systems of booster compressors and sales gas, the buffer gas of certain storage tanks, and the induced gas flotation system of the water treatment unit. It is also used intermittently at utility stations or in emergency situations, to smother a furnace fire. The pressure of the nitrogen network is maintained at 7 bar to guarantee sufficient pressure for the operation of the various continuous users.

The nitrogen system also includes an HP nitrogen storage tank in which is stored a volume of nitrogen at 30 bar, necessary for smothering a fire in a furnace.

III.7.12. Domestic wastewater treatment :

The treatment system is capable of handling a daily volume of domestic wastewater estimated at 15 m³, equivalent to around 100 people. It is a prolonged aeration system with disinfection of the treated water.

The domestic wastewater treatment system includes :

- Wastewater collection and transfer.
- Load equalization.
- Oxidation of organic load and sludge storage.
- Disinfection, temporary storage and transfer of treated water.

Wastewater from the buildings is discharged via the sanitary sewer system to the wastewater chamber (460-RH-66-01), which is equipped with a coarse screen and two 7.5 m³/h wastewater transfer shredder pumps (460-PS-66-01A/B). Water is accumulated and then transferred to the equalization basin (460-RL-66-01), which has a volume of 53 m³ **[42] .**

Chapter 4 : Mercury Removal Unit Rhourde Nouss

IV. Chapter 4: Mercury Removal Unit Rhourde Nouss

IV.1. Problematic description

SH-RN has found that the mercury content in well fluids of Rhourde Nouss area has increased over the production period and as such the CPF cannot operate with the existing turbo-expander unit in service as the high level of mercury would attack the aluminium blades. SH-RN have been running the unit with a JT valve instead of the turbo-expander which means they do not reach the required low temperature in their cold separator, so liquid hydrocarbon recovery is not at optimum.

IV.2. Objectives

This research had objectives:

a. Develop a detailed understanding of the RN Mercury removal unit process, from well fluid extraction to final product output

b. Review the operating parameters (such as temperature, pressure, flow rates, etc.) for each equipment component to understand their optimal operating conditions and performance criteria.

c. analyze a series of experiments upon natural gas stream samples in the laboratory

d. Assess the effectiveness of the mercury removal system through adsorption phenomena in SH-RN.

The Mercury Removal System shall reduce the mercury content in the gas stream from a maximum concentration of 230 µg/m³ to less than 0.01 µg/m³ (10 ng/m³) and is designed to treat up to 10.0 Msm³/d of gas received from SH-RN CPF Slug Catcher.

The flow is split across two trains with each train treating up to 5 Msm³/day of gas at an operating pressureof 40 barg and 55°C maximum operating temperature.

The Hg system is a modular skid unit assembly comprising of the following process equipment packages.

IV.3. Process details

Process design data

Design Flowrate

Maximum Gas Design Flowrate	10.0 Msm³/day
Train 1 Gas Design Flowrate	5.0 Msm³/day
Train 2 Gas Design Flowrate	5.0 Msm³/day

Fluid Properties

Inlet Gas Mercury Concentration	230 µg/m³
Gas Molecular Weight	20.7
H_2S Content	Nil
CO_2 Content	8.5 Mol%
Arrival Pressure at ExHg System Inlet	40 barg
Arrival Temperature at ExHg System	55°C max.

Product Specification

Outlet Gas Mercury Concentration	0.01 µg/m³ (10 ng/m³) max.

Process Flow Diagram

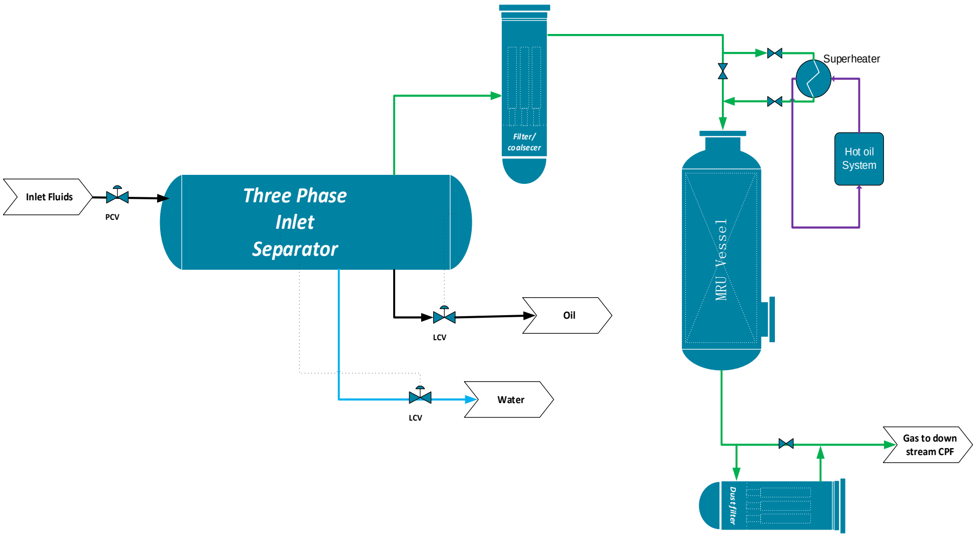


Figure IV.1 : Description of the process of mercury removal

IV.4. Equipment description, control & safety protection

IV.4.1. Inlet gas manifold skid

The Inlet Gas Manifold Skid receives gas and associated liquids from SH-RN CPF Slug Catcher through a 24” flowline and splits the flow through two 16” orifice meter runs to train 1 and train 2 Filter Coalescers ***P&ID No. EP-37246-P-PID-0001*.**

IV.4.2. Inlet three Phase Separator

The Inlet 3 Phase Separator receives well fluid flow from the 12” inlet line and separates the fluid into its three constituent phases; gas, condensate and produced water.

Separated gas is routed to the Filter Coalescer at full line pressure with the separated condensate discharged under level control to Phase ‘A’ condensate header. The separated produced water is routed to SH-RN Phase ‘A’ drain system under level control through LCV ***P&ID No. EP-18136-P-PID-0001* .**

Figure IV.2 : Three Phase Separator

IV.4.3. The Filter coalescers

The Filter Coalescers are vertical two-phase liquid/gas separators with coalescing elements to remove small liquid droplets that may be present in the gas stream prior to entering the MRU Vessel. Bulk liquids are collected in the vessel’s lower chamber and the small liquid droplet remaining in the gas stream are collected in the upper chamber after passing through the coalescing elements ***P&ID No. EP-37246-P-PID-***

Figure IV.3: Filter coaliscer

***0011 and 0021*.**

Design Details

Vessel Dimensions:	914mm OD x 4267mm S/S
Corrosion Allowance:	3mm
Operating Pressure:	40 barg

Design Pressure:	90 barg / FV
Operating Temperature:	55°C max.
Design Temperature:	-29 to 93°C
Coalescing Element Efficiency:	99.97% removal of 0.3 micron aerosols

Liquid Level Control

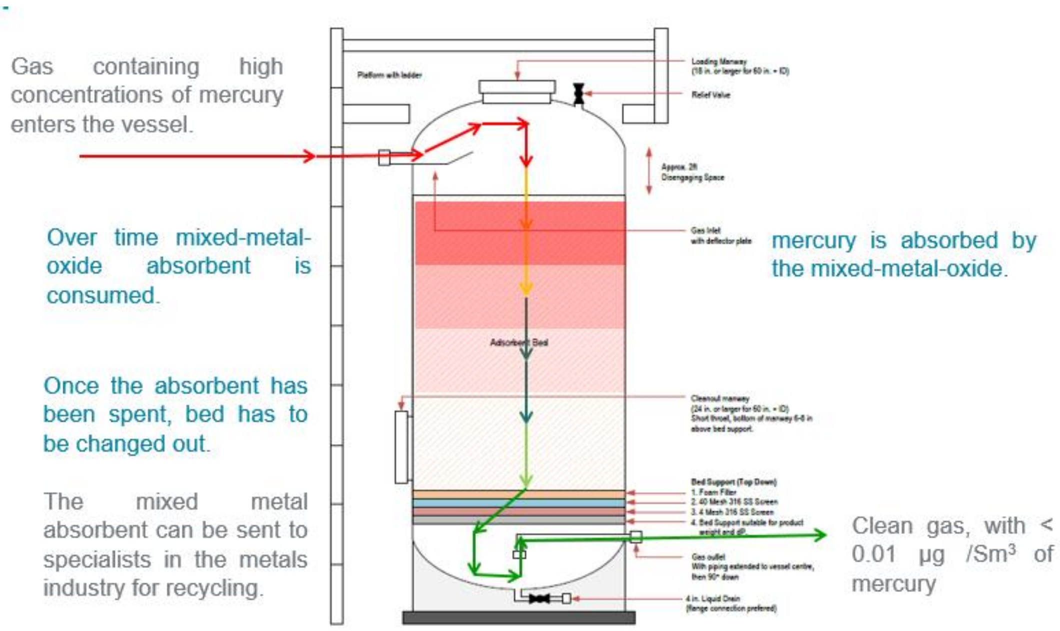
The liquid level in Filter Coalescer lower vessel compartment is controlled by guided wave radar leveltransmitter, controlling level control valve under PID function (direct acting) to maintain the liquid level at the (adjustable) NLL set-point.

IV.4.4. The MRU vessels

The MRU Vessel is a vertical vessel with an absorbent bed media provided by Johnson Matthey to remove mercury from the gas stream. The vessel has a specially designed inlet gas distributor; the absorbent bed is supported and held in position by layers of ceramic balls of varying sizes. The mercury is irreversibly trapped in the absorbent structure that will be disposed of after its expected five-year lifespan.

***P&ID No EP-37246-P-PID-0012 and 0022* .**

Figure IV.4: Mercury removal vessal



Gas containing high concentrations of mercury enters the vessel.

Over time mixed-metal-oxide absorbent is consumed.

Once the absorbent has been spent, bed has to be changed out.

The mixed metal absorbent can be sent to specialists in the metals industry for recycling.

mercury is absorbed by the mixed-metal-oxide.

Clean gas, with < 0.01 µg /Sm³ of mercury

Figure IV.5: Representation of the MRU Vessel's operation and components diagram

IV.4.4.1. Flow and Operation

Gas Inlet:

- Entry Point: The gas containing high concentrations of mercury enters the vessel from the inlet located near the top.
- Distributor: The gas inlet is equipped with a deflector plate to ensure even distribution of the gas across the absorbent bed.

Absorbent Bed:

- Mixed-Metal-Oxide Absorbent: The core component of the vessel is the mixed-metal-oxide absorbent bed, which captures mercury from the gas stream.
- Consumption Over Time: The absorbent material gradually gets consumed as it captures mercury, necessitating periodic replacement.
- Positioning and Support: The absorbent bed is supported by multiple layers of ceramic balls and screens, ensuring stability and optimal gas flow through the bed.

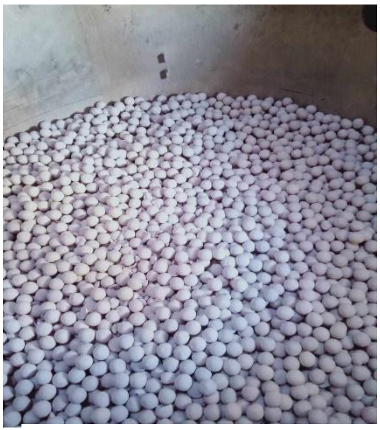


Figure IV.6: Metal-Oxide Absorbent

Clean Gas Outlet:

- Discharge Point: After mercury removal, the cleaned gas exits the vessel through an outlet at the bottom, with mercury levels reduced to less than 0.01 µg/Sm³.
- Flow Direction: The gas flows downward through the absorbent bed and exits via the gas

outlet piping, which extends to the vessel center before turning 90 degrees down.

Maintenance and Disposal:

- Bed Change-Out: When the absorbent is spent, it needs to be replaced. The spent absorbent can be sent to specialists for recycling in the metals industry.
- Relief Valve and Cleanout Manway: These features facilitate safe operation and maintenance, providing access for bed replacement and vessel inspection.

IV.4.4.2. Structural Details

- Disengaging Space: Approximately 2 feet of space at the top allows for proper gas distribution before it contacts the absorbent bed.
- Support Layers: The bed is supported by several layers, including foam, perforated stainless steel screens, and ceramic balls to ensure the stability and proper distribution of the gas flow.
- Drain and Inspection Ports: A liquid drain and various manways provide access for maintenance, inspection, and removal of any condensate or liquid buildup.

Design Details

Vessel Dimensions:	2438mm ID x 7500mm T/T
Corrosion Allowance:	3mm
Operating Pressure:	40 barg
Design Pressure:	90 barg / FV
Operating Temperature:	55°C max.
Design Temperature:	-29 to 93°C
Absorbent MediaType:	Johnson Matthey Pursapec high porosity, spherical mixed metal oxide and metal sulphide absorbent.
Absorbent Media Hold Down and Support:	Johnson Matthey Katalco 92-2 alumino ceramic balls

The MRU Vessel internals comprises a special inlet distributor, a gas outlet collector, absorbent media and ceramic balls to support the media.

Pressure Indication

The MRU Vessel operating pressure is monitored locally by viewing pressure gauge.

Sampling

The MRU Vessel is equipped with 4 off 2” sample point nozzles with 1” sample probes into the absorbent media section for taking periodic gas samples to monitor the media for degradation over its expected 5-year lifespan.

Overpressure Protection

MRU Vessel overpressure protection is from two duty/standby pressure relief valves situated on the vessel vent piping and discharge to the flare header.

IV.4.5. The Guard Bed Filters

The Guard Bed Filter is a horizontal unit with filter elements to remove dust/solid particles that may be present in the gas stream prior to SH-RN facility. The filter elements will remove 99.9% of solid particles above 5 microns ***P&ID No. EP-37246-P-PID-0013 and 0023***.

Figure IV.7: Guard Bed Filter

Design Details

Vessel Dimensions:	914mm OD x 2743mm S/S
Corrosion Allowance:	3mm
Operating Pressure:	40 barg
Design Pressure:	90 barg / FV
Operating Temperature:	55°C max.
Design Temperature:	-29 to 93°C
Filter Element Type:	12 off Pentair Intersep Filter Elements 6” O.D x 36” long, part no. GE1811L002V
Filter Element Efficiency:	99.9% removal of all solid particles >5 microns

Pressure Indication

The Guard Bed Filter operating pressure is monitored locally by viewing pressure gauge.

Overpressure Protection

Guard Bed Filter overpressure protection is from a single pressure relief valve situated on the vessel vent piping and discharges to the flare header.

IV.4.6. Outlet gas skid

The Outlet Gas Skid receives treated gas from Hg system train 1 and train 2 from 16" lines and returns to SH-RN CPF Slug Catcher gas outlet through a single 24" line. ***EP-37246-P-PID-0001, PID-0013 and PID-0023*** **.**

IV.4.7. Flare header and condensate pump

Hg System flare gas released during start-up and depressurization (blowdown) is directed to SH- RN existing flare system through separate train 1 and train 2 flare headers.

A liquid knock-out pot collects condensed liquids from a low point in each of the flare headers and discharges the liquids to SH-RN closed drain header by means of a Condensate Pump

Methanol Injection

Methanol is and piped to the outlet of Train 1 and Train 2 Blowdown Valves for diluting gas hydrate formation during low temperature blowdown ***P&ID Nos. EP-37246-P-PID-0002*****.**

IV.5. Process control and safety shutdown system (ICSS)

The ExHg System is controlled by a Siemens Simatic 7 PLC based integrated process control and safety shutdown system (ICSS).

The operator interface (HMI) is via graphic PC-based flat screen LCD display in the Local Control Room with a fibre optic cable link to SH-RN Central Control Room for remote control. Communication between the PLC system and the operator interface is by Ethernet network. Refer to the system architecture diagram in figure IV.8 below **[49] .**

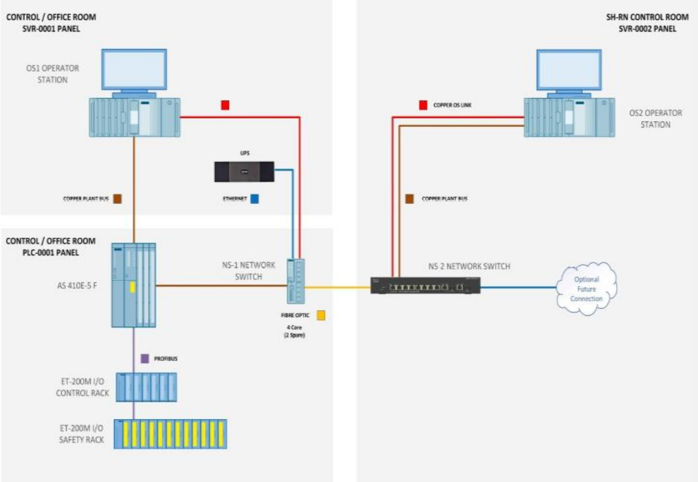


Figure IV.8 :ExHg System ICSS System Architecture

IV.5.1. Process Control

The process control system monitors and controls the Filter Coalescer liquid levels and provides high and low alarms when a level deviates from its set point value.

Process alarms are provided at the ICSS to warn operators of upset operating conditions, and to provide the operators with time to effect a recovery.

IV.5.2. Safety Shutdown

The safety shutdown system is the primary protection to prevent and minimize, as far as practicably possible, the occurrence and consequences of hazardous incidents resulting from process system failures.

The safety shutdown system is designed to prevent escalation of an upset condition and to ensure minimal damage to the environment, safety of personnel and protection of investment.

IV.5.3. Operator Interface (HMI)

Two LCD flat screen displays are provided in the control room for the operator interface. The display has identical headers and footers. Header tabs provide direct access to the main displays, the header also has a dropdown menu to provide access to trend displays. The footer displays alarms, number of alarms, number of unacknowledged alarms, date, time and the current user. Screenshots of some HMI screens are shown in Figs IV.9 and IV.10 below:

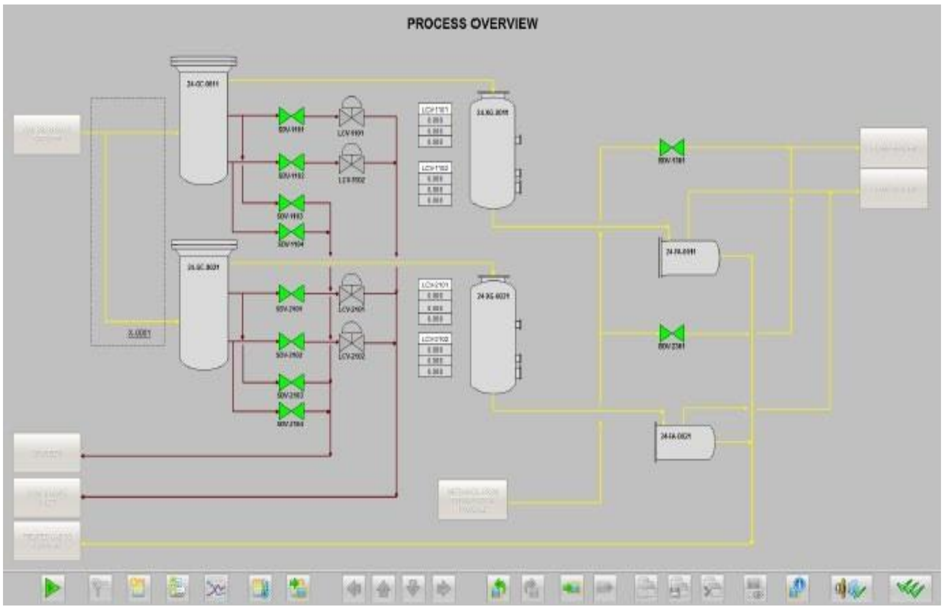


Figure IV.9 : ExHg System Screenshot – Process Overview

Figure IV.10 : ExHg System Screenshot – F&G and Emergency Shutdown

IV.6. Mercury Analysis

IV.6.1. Principle

Mercury is determined by combustion followed by gold amalgamation and detection by Atomic Absorption (AA).

A known mass / volume of sample is introduced in to the analyzer. The sample is thermally decomposed in a furnace automatically set at approximately 750°C, the combustion products are passed through a catalytic absorber where oxidation is completed and any additional species (e.g. Sulphur, halides) are removed. The product gas is then carried through a gold amalgamator, which traps any mercury present before the combustion gases are flushed to waste. The gold amalgamator is then heated rapidly and any mercury released from the mercury-gold amalgam is carried by a flow of gas to a dual cuvette measuring system. Mercury detection is by cold vapor atomic absorption, where UV radiation at 253.65 nm (which is specific for elemental mercury vapor) is passed through the gas, and the absorption is measured by a UV diode detector. The radiation absorbed is proportional to the mass of mercury **[50]**.

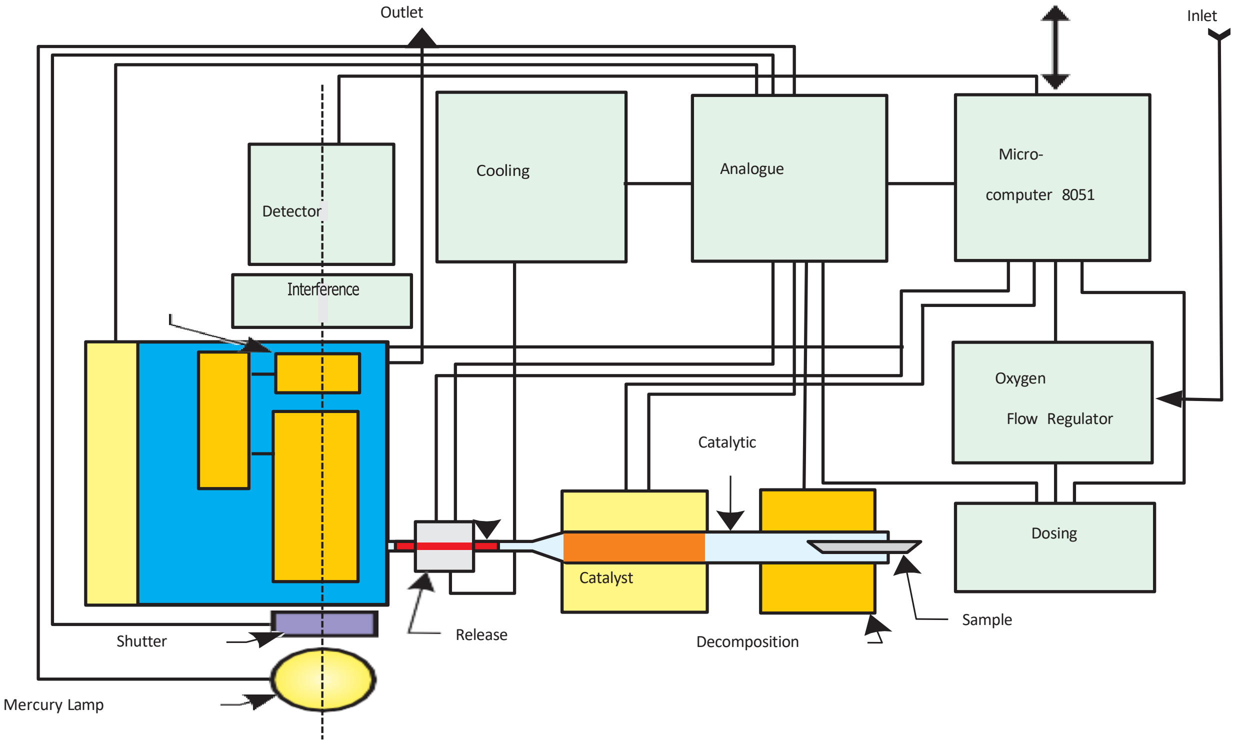


Figure IV.11 : Flow diagram of Leco instrument

IV.6.2. Samples

Samples submitted for testing shall be received in suitable containers, accompanied by all relevant documentation where appropriate, and transferred to the reception area of the relevant laboratory. Prior to analysis, the samples shall be stored under conditions compatible with their vulnerability so that their integrity is maintained.

Figure IV.12: Tedlar gas bags

The most common sampling container for gases are tedlar gas bags – gases, LPG (that is gaseous at atmospheric conditions).

Gases shall be impinged onto a suitable trap prior to analysis; the trap used shall have been cleaned prior to use. The volume of gas impinged shall be measured using a wet test meter or equivalent and recorded on the worksheet.

The sand trap employed shall be introduced directly in to the analyser. Gloves must be worn when handling the trap to avoid any contamination. The trap shall be analysed at least twice to ensure that all the mercury has been removed **[44] .**

Sample Volumes

Most samples shall be analysed with trial and error to determine the optimum volume of sample introduction (by introducing a small volume of sample into the analyser to estimate the mass of mercury and to avoid overload / or exceeding the analysers maximum calibration point, 500 ng). The range of sample introduction volumes possible with the AMA 254 is listed in Table 7 below [45] .

Table IV.1 : Sample Introduction Volumes (AMA 254)

Sample Type	**Minimum sample introduction**	**Maximum Sample Introduction**	**Concentration Range**
Aqueous liquids	5 µL	500 µL	0.03 - 100,000 ng/mL
Hydrocarbon liquids	5 µL	20 µL	0.8 – 25,000 ng/mL
Solids	0.02 g	0.5 g	1 - 25,000 ng/g
Gases*	0.1 L	100 L	0.0002 - 5,000 ng/L

IV.6.3. Apparatus Preparation

The instrument shall be set up in accordance with the manufacturer’s instructions and relevant laboratory procedures.

Instrument calibration

The 0.5 ng calibration point shall be checked by injecting 25 µL of STD1 (20 ng/mL) and 75 µL of deionised water (to maintain constant injection volume) and the 5 ng calibration point checked by injecting 50 µL of STD2 (100 ng/mL) and 50 µL of deionised water. Calibration checks shall be run in at least duplicate.

Calibration shall be carried out using calibration standards (STDs) to introduce into the instrument known masses of mercury across a suitable range. The absorbance of UV light measured by the instrument for each mass is recorded by the software and used to generate a calibration curve.

Each calibration point shall be repeated until the absorbance recorded for at least two replicates are in good agreement.

The software will indicate whether a calibration point is within the acceptable range, and will display statistical information as the calibration curves are created. The operator manual gives examples of calibration curves and the response (in absorption units, AU) for given standards.

Once a calibration has been completed, it should be checked using the control standards (CTLs) at various points along the calibration curve. The calibration shall be accepted if results are within ± 10% of the expected value [44] .

Blanks

a series of internal blanks shall be analysed following the respective analyser’s procedure, the blank values are run each day, and that they remain stable. High blanks may be indicative of environmental contamination [44] .

IV.6.4. Calculation

The concentration of mercury in gases shall be calculated from the following equation:

$$C = \frac{M}{V}$$

Where:

- C = mercury concentration in µg/m^3 or µg/kg
- M = mass of mercury determined by the analyser (ng)
- V = volume of gas taken for analysis

IV.6.5. Discussion of Results

Table IV.2 : Results of Concentration of mercury from the inlet and the outlet of MRU vessel

Date	Inlet ExHg (ug/sm^3)	outlet ExHg (ug/sm^3)
01/04/2024	71.94	0.15
02/04/2024	78.45	0.17
03/04/2024	66.44	0.04
04/04/2024	82.19	0.2
05/04/2024	78.14	0.16
06/04/2024	98.28	0.18
07/04/2024	85.10	0.16
08/04/2024	83.18	0.17
09/04/2024	81.48	0.15
10/04/2024	83.41	0.13
11/04/2024	81.61	0.09
12/04/2024	105.13	0.09
13/04/2024	94.06	0.09
14/04/2024	87.30	0.084
15/04/2024	116.62	0.12
16/04/2024	96.35	0.11
17/04/2024	88.39	0.13
18/04/2024	81.60	0.11
19/04/2024	76.37	0.19
20/04/2024	82.34	0.21
21/04/2024	86.59	0.37
22/04/2024	88.18	0.22
23/04/2024	102.66	0.49
24/04/2024	96.75	0.21
25/04/2024	67.27	0.44
26/04/2024	39.06	0.13

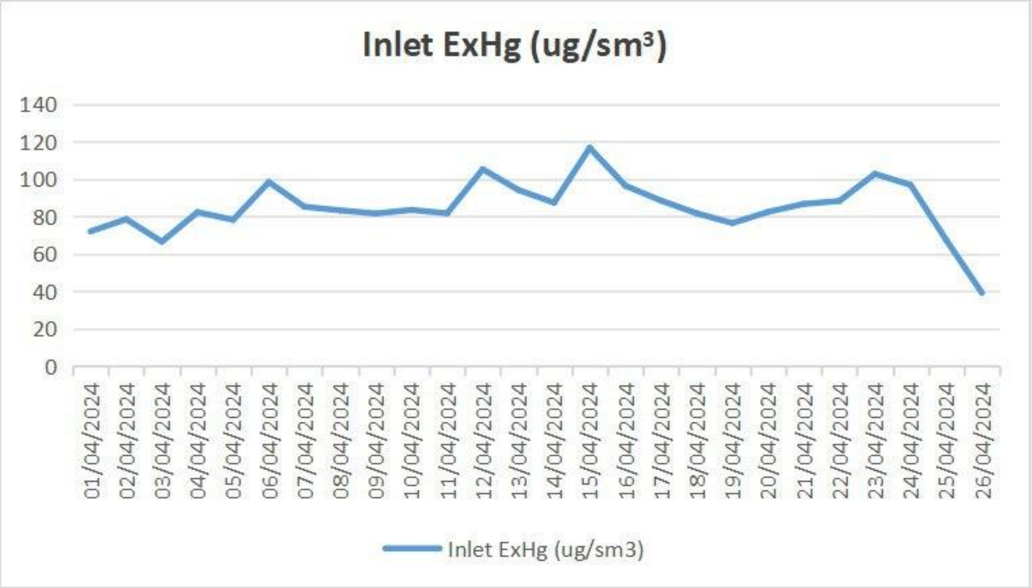


Figure IV.13 : Concentration of mercury in natural gas at the inlet of MRU vessel in fuction of time

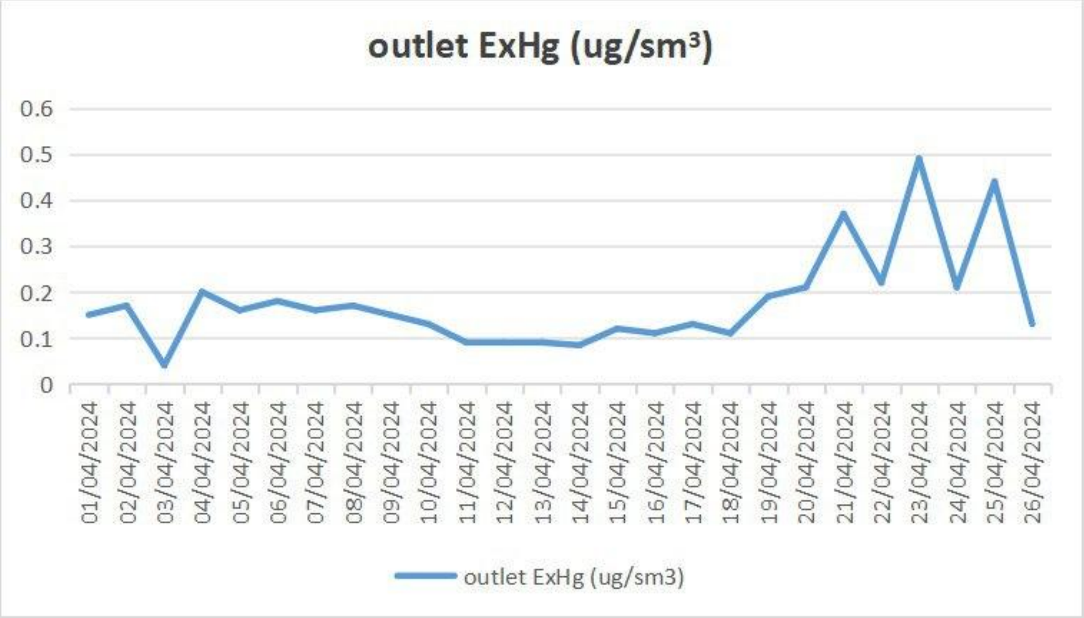


Figure IV.14 : Concentration of mercury in natural gas at the outlet of MRU vessel in function of time

Table 8 and figures IV.13 and IV.14 represent the concentration of mercury in natural gas in function of time (April /2024) , the results of samples analyses based on the data are obtained from the inlet and the outlet of MRU vessel of train 1 in CPF Rhourde - Nouss at the conditions of ($P_{moy\,=}$ 40 bar , T= Ambient , flow rate Q = 5 Msm³/d) .

We notice that the concentration of mercury in natural gas at the inlet of MRU in CPF Rhourde - Nouss is around **80 ug/sm^{3,}** while the concentration of mercury in natural gas at the outlet of MRU is around **0.20 ug/sm^3** , this demonstrates the drop of mercury concentration in natural gas from high to low concentrations after the treatment with MRU system .

General conclusion

The Mercury Removal System is designed to significantly reduce mercury content from high to low concentration in natural gas , it is capable of treating up to 10.0 Msm^3/d of gas. By splitting the flow across two trains, each handling up to 5 Msm^3/day at 40 barg and 55°C, the system ensures robust and efficient mercury removal. The modular skid unit assembly of the system simplifies integration and maintenance, underscoring its practical and operational advantages.

Through a detailed study of the Rhourd Nouss Mercury Removal Unit process, we have developed an in-depth understanding of the system from well fluid extraction to the final product output. Our review of operating parameters for each component has provided valuable insights into their optimal conditions and performance criteria. Laboratory experiments on natural gas stream samples have further elucidated the adsorption phenomena critical to the effectiveness of the mercury removal system.

Ultimately, the implementation of this advanced mercury removal system will enable Sonatrach Rhourd Nouss to safely and efficiently operate the CPF, protect critical equipment, and optimize hydrocarbon recovery, ensuring continued production success and compliance with stringent environmental standards.

To further increase the efficiency of the mercury removal process, it is suggested to :

- Connect train 1 and train 2 in series, where the inlet of the MRU vessel of train 2 will receive the outlet treated and filtred gas of guard bed filter of train 1 .the MRU vessel of train 2 shall remove the resident mercury of the train 1 resulting natural gas with the standards values (less than 10 $\mu g/m^3$).This changing reduces the flow of gas stream to 5 Msm^3/d and the dimensions of the MRU unit should be changed to bigger dimensions to not stop the producing wells .
- Optimize the adsorption conditions by series of experiments on the parameters such as temperature, pressure, and flow rates, Determine which parameter is critical to the performance of the mercury removal system and have the most significant impact on the desired result.

General conclusion

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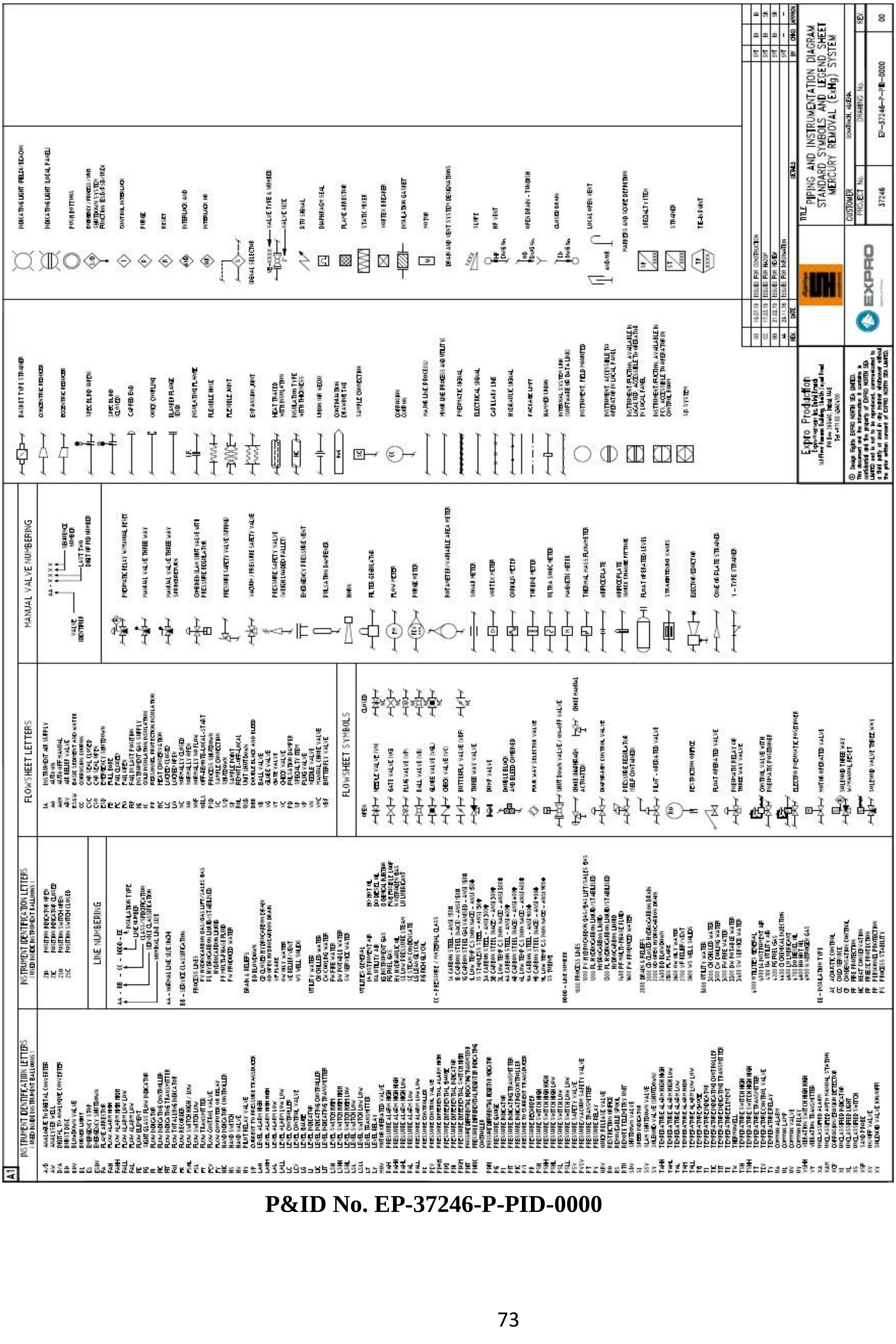
Attachments



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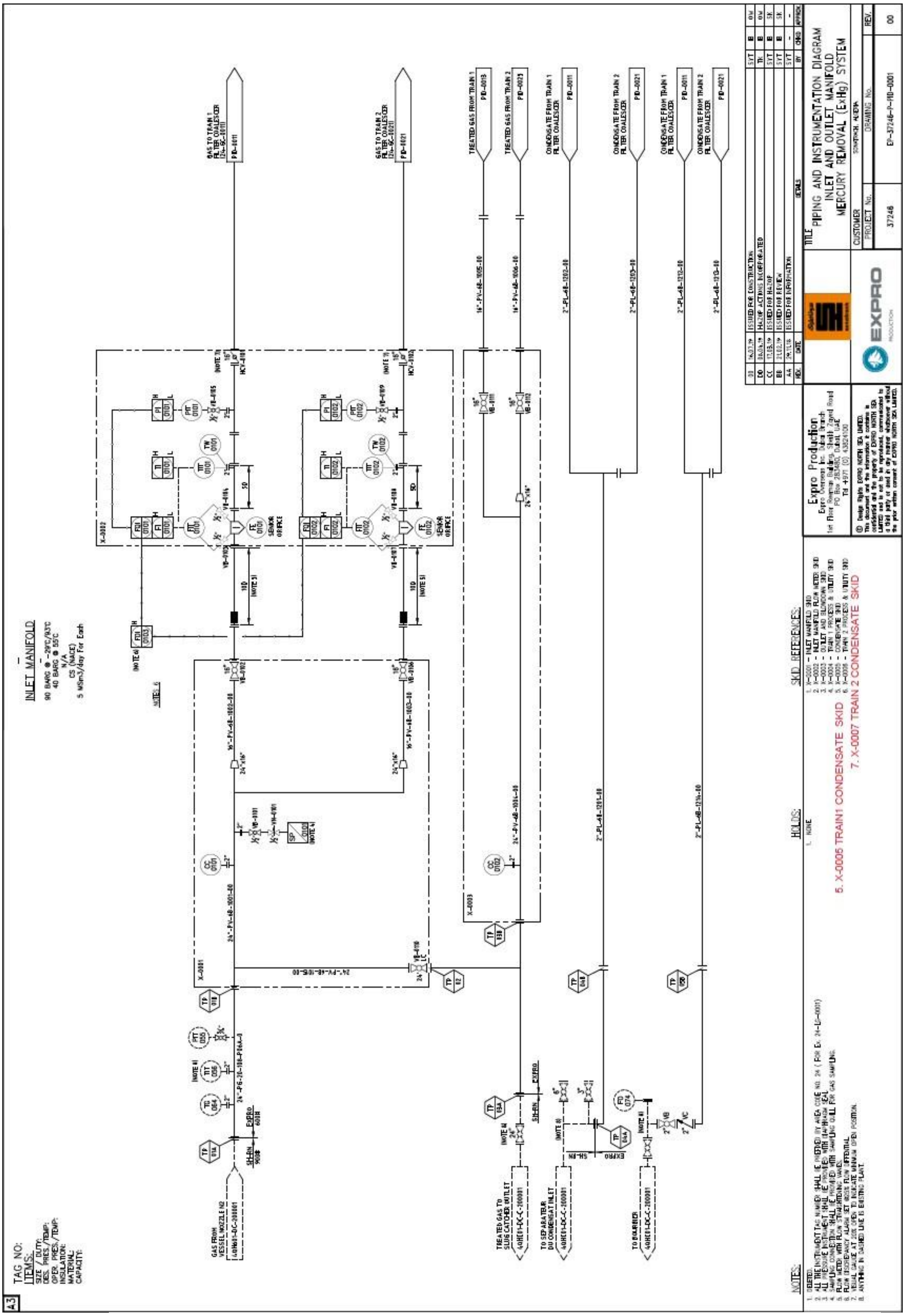

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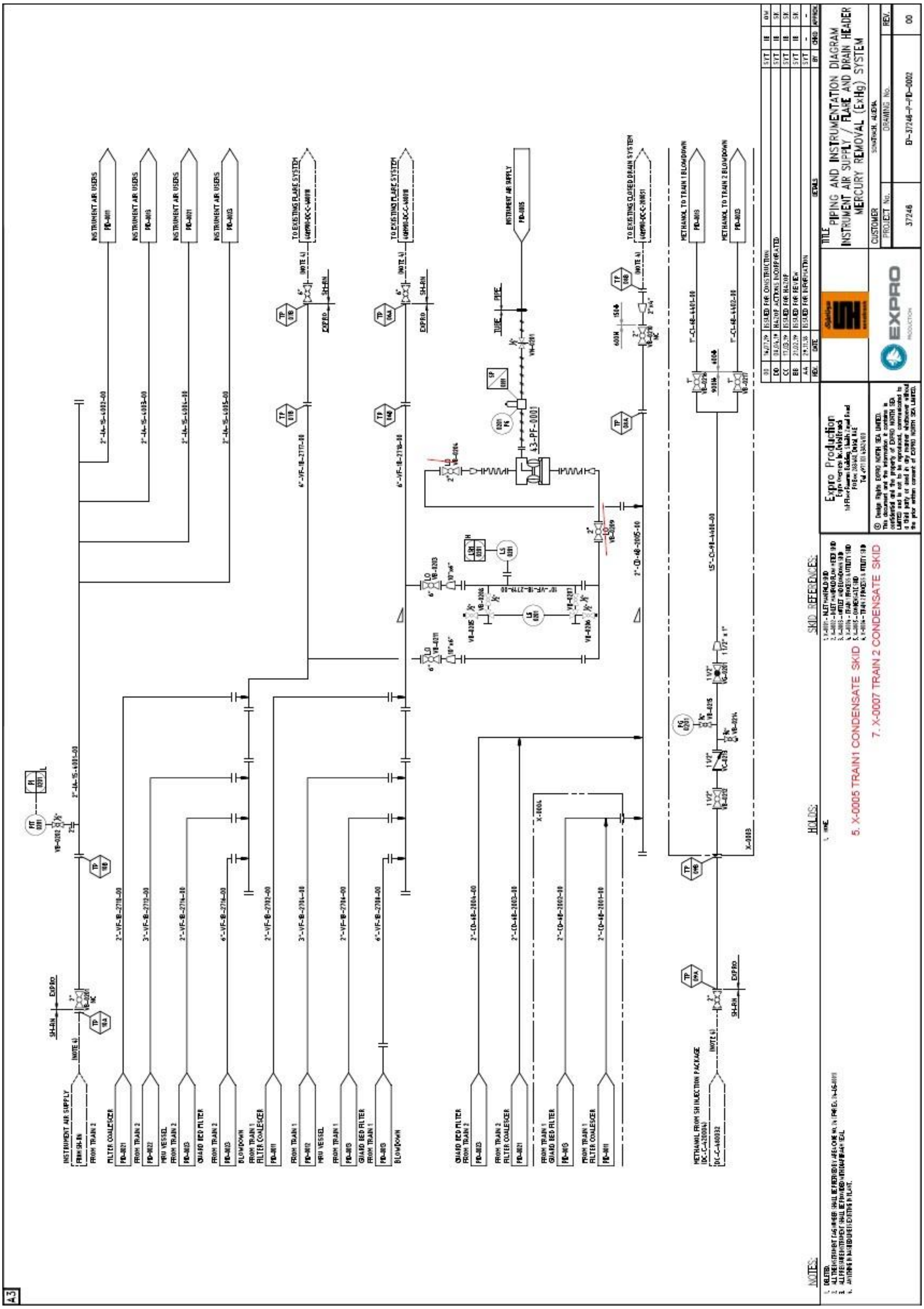

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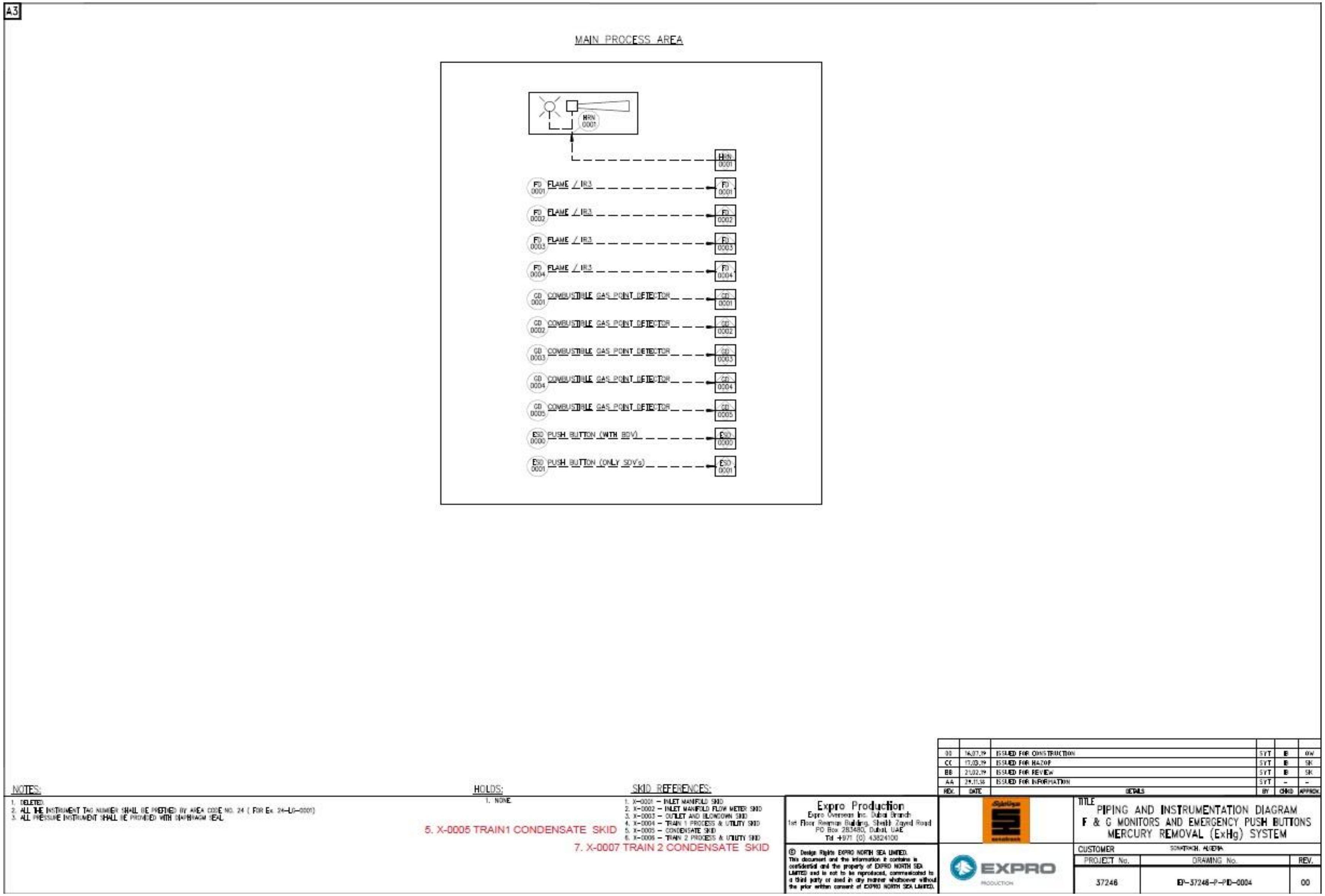

NOTES:

1. DELETED.
2. ALL THE INSTRUMENT TAG NUMBER SHALL BE PREFIXED BY AREA CODE NO. 24 (FOR Ex. 24–LG–0001)
3. ALL PRESSURE INSTRUMENT SHALL BE PROVIDED WITH DIAPHRAGM SEAL.

HOLDS:

1. NONE.

SKID REFERENCES:

1. X–0001 – INLET MANIFOLD SKID
2. X–0002 – INLET MANIFOLD FLOW METER SKID
3. X–0003 – OUTLET AND BLOWDOWN SKID
4. X–0004 – TRAIN 1 PROCESS & UTILITY SKID
5. X–0005 – CONDENSATE SKID
6. X–0006 – TRAIN 2 PROCESS & UTILITY SKID

5. X-0005 TRAIN1 CONDENSATE SKID

7. X-0007 TRAIN 2 CONDENSATE SKID

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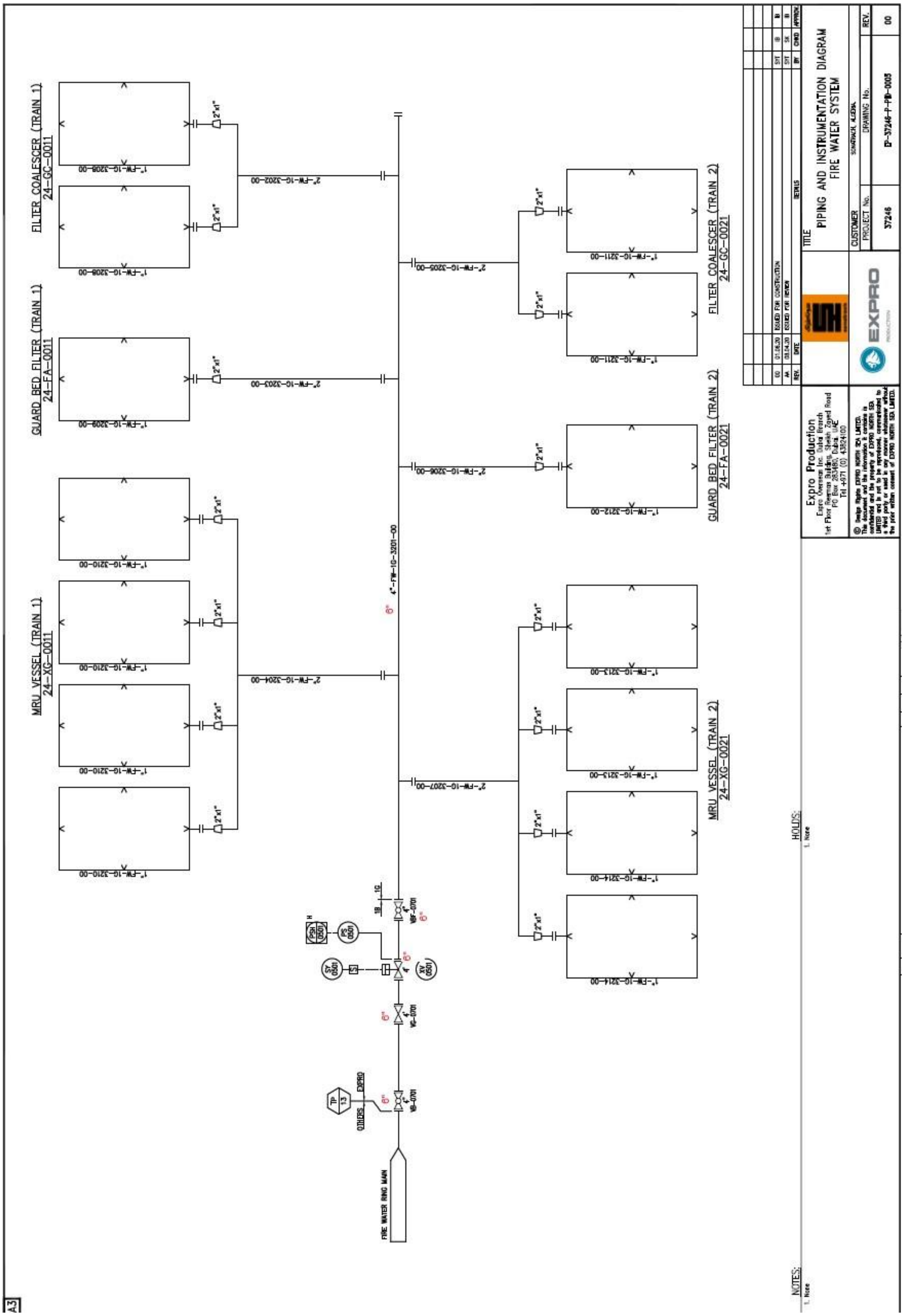
REV.	DATE	DETAILS	BY	CHKD	APPROV.
00	16.07.19	ISSUED FOR CONSTRUCTION	SYT	B	OW
CC	17.03.19	ISSUED FOR HAZOP	SYT	B	SK
BB	21.02.19	ISSUED FOR REVIEW	SYT	B	SK
AA	29.11.18	ISSUED FOR INFORMATION	SYT	–	–

TITLE
PIPING AND INSTRUMENTATION DIAGRAM
F & G MONITORS AND EMERGENCY PUSH BUTTONS
MERCURY REMOVAL (ExHg) SYSTEM

CUSTOMER SONATRACH, ALGERIA

PROJECT No.	DRAWING No.	REV.
37246	EP–37246–P–PID–0004	00

P&ID No. EP-37246-P-PID-0004



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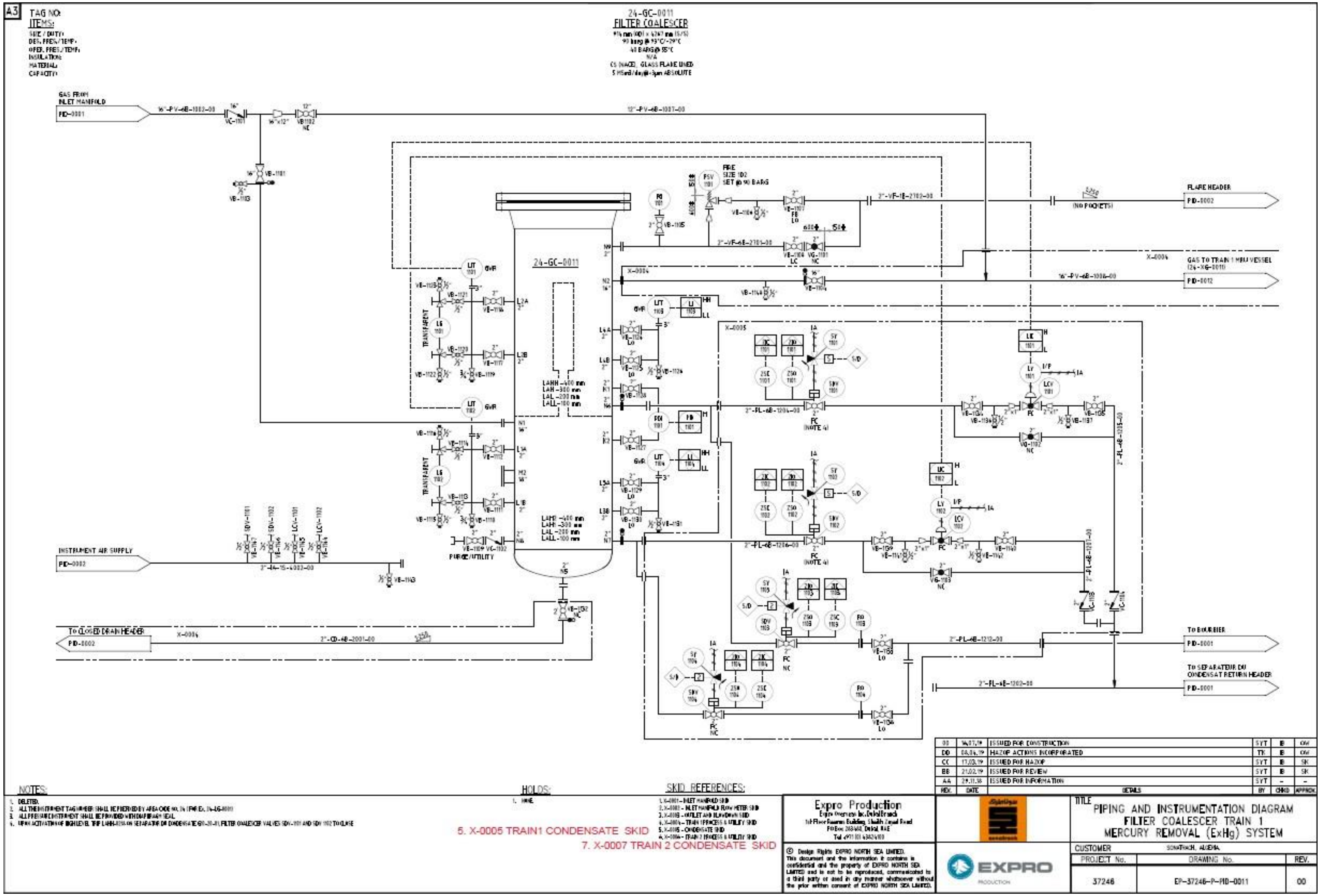

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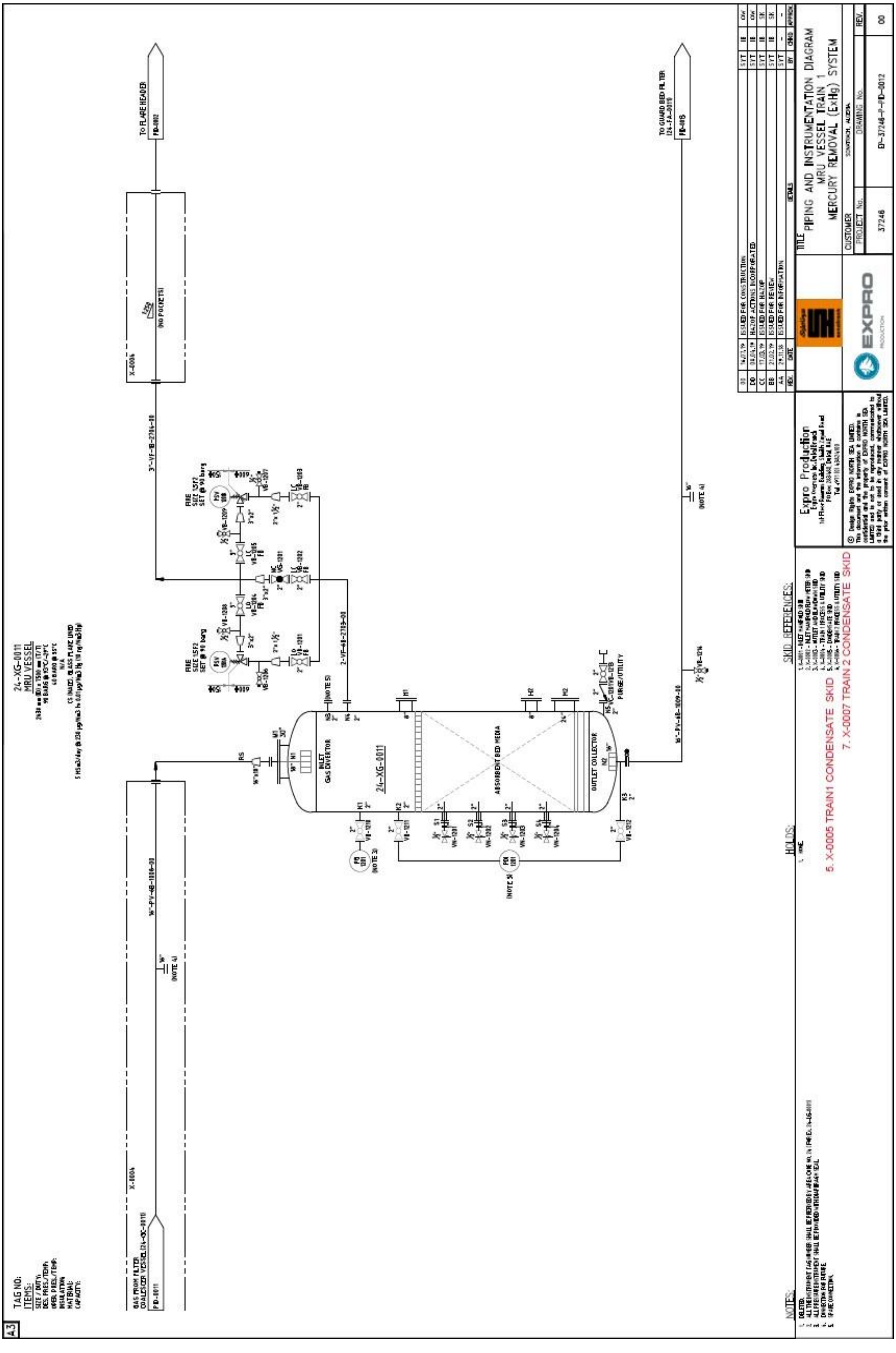

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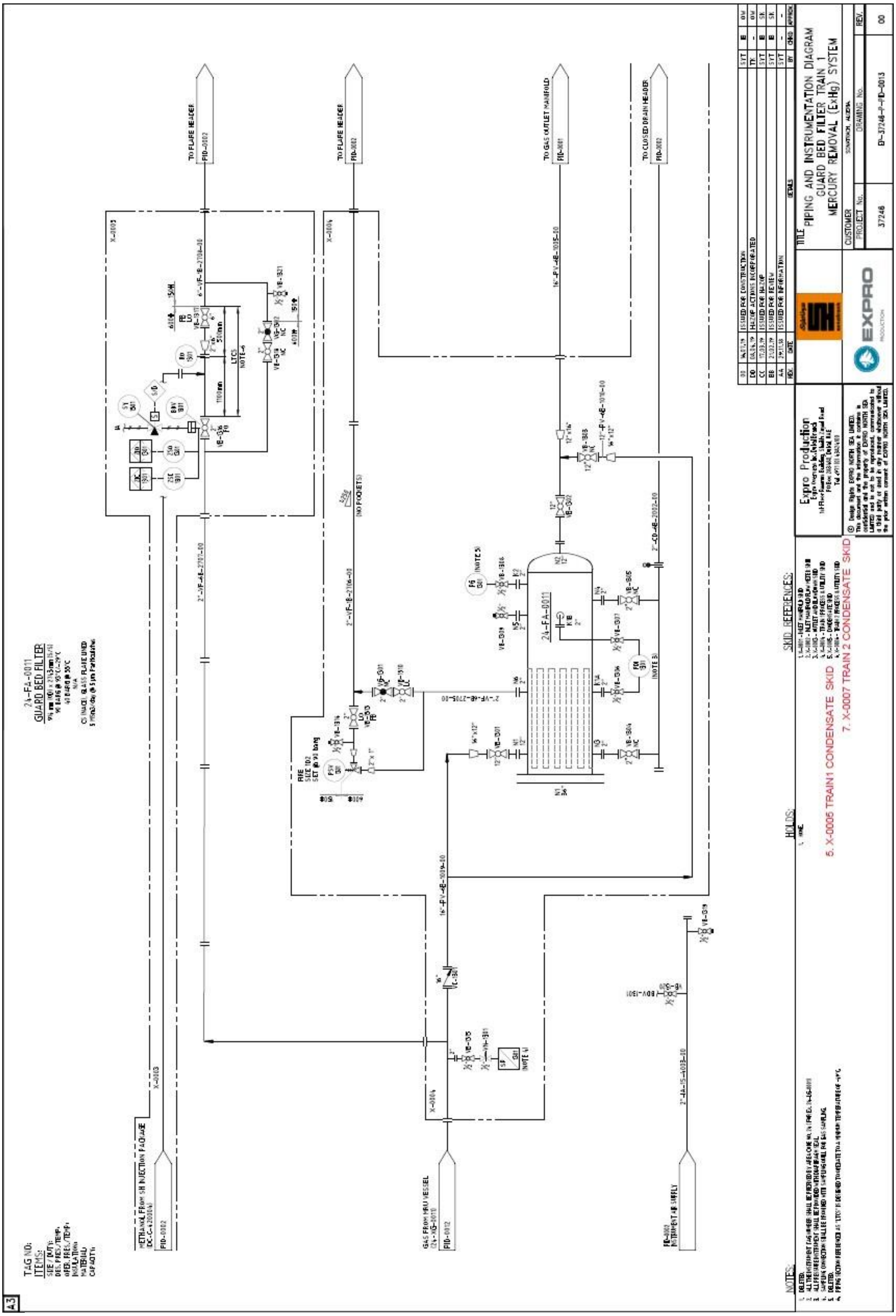

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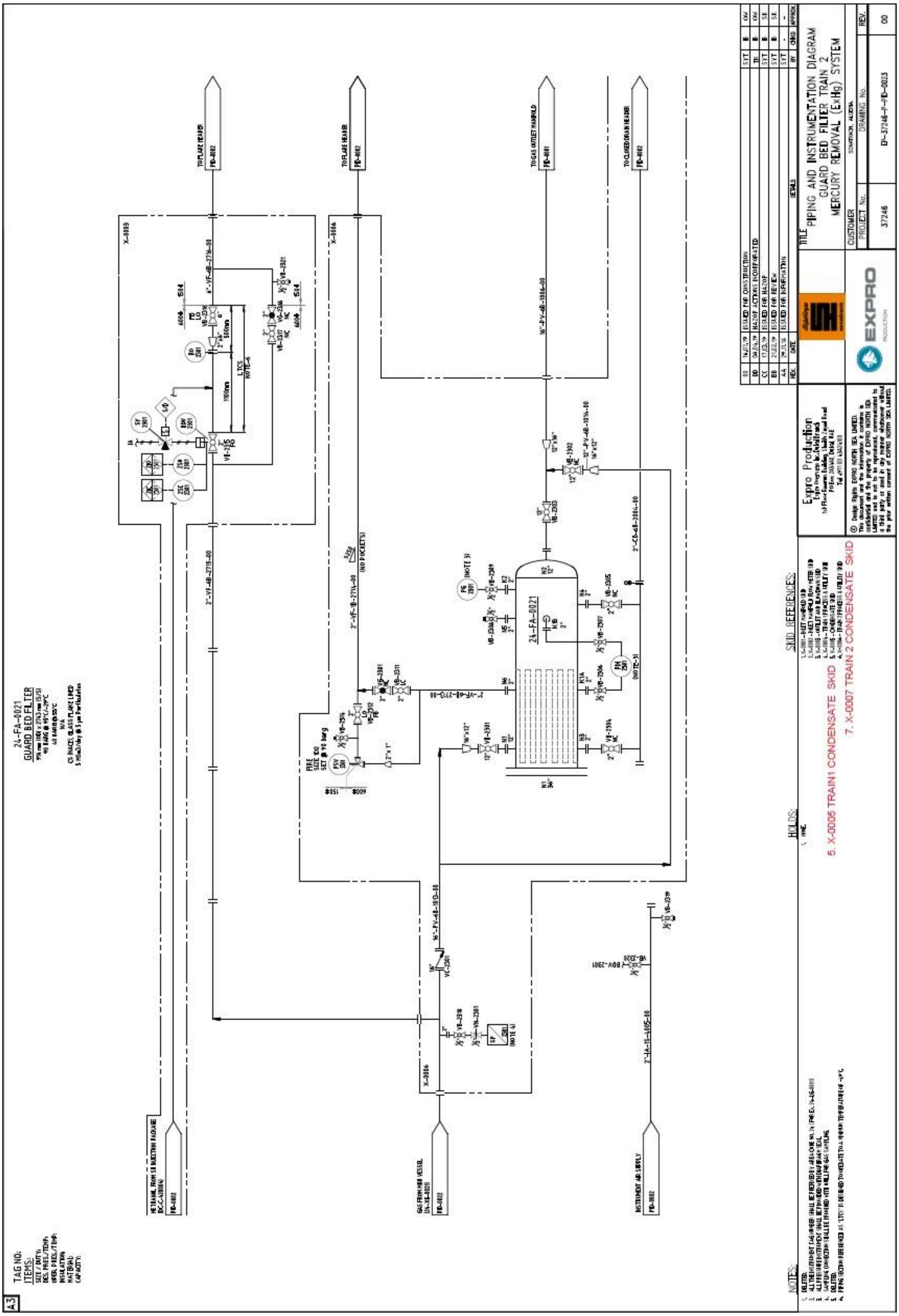

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