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CONTAMINATION OF THE PRE-COOLING PROPANE CYCLE BY ETHANE IN LNG PLANT. CASE STUDY: GL2/Z PLANT-ARZEW, ALGERIA

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Abstract

Ethane contamination poses significant challenges to the operation of C3MR cooling cycles and LNG production. This study investigates the impact of ethane contamination on the propane pre-cooling cycle of the GL2/Z plant (Arzew-Algeria), quantifying its economic, environmental, and technological implications. The propane cycle was simulated using ASPEN-HYSYS v12 software, with results showing good agreement with operating data. The study reveals that ethane levels in propane must not exceed 2% molar composition, as above 6 mol% of ethane in propane, the contaminated propane is flared. In April 2024, 1455.6 tons of propane was lost, totaling approximately $582,240. Through simulation and analysis, we predict the behavior of the propane cycle under progressive ethane contamination and identify potential adjustments to protect critical equipment. Results indicate that ethane contamination leads to malfunctions in the propane cycle, affecting the performance of the MR cycle. Significant issues, such as ethane leaks from specific exchangers, cause the flaring of propane. Quantifying the economic repercussions reveals substantial financial burdens associated with ethane contamination, including increased electricity consumption and costs related to flaring contaminated propane Moreover, the downstream effects beyond the propane pre-cooling loop, causing disruptions in the entire LNG liquefaction process due to elevated temperatures, underscore the need for comprehensive mitigation strategies. This study highlights the complex and multifaceted nature of ethane contamination's impact on C3MR cooling cycles, emphasizing the importance of effective monitoring and mitigation measures for continued operational efficiency and profitability in LNG production facilities.

Keywords: Propane Pre-Cooling, C_3MR, Liquefied Natural Gas (LNG), Ethane, APCI, Compressor Performance, Process Simulation.

1. INTRODUCTION

In recent years, demand for natural gas (NG) as a relatively clean fossil fuel has increased significantly. Algeria has played an active role in meeting this demand since its economy is largely based on the export of hydrocarbons, with LNG representing a substantial portion of these exports.

The gas reserves in the Hassi R'mel-Algeria area are considerable. Approximately 70% of this gas, which is extracted, is transported to the Arzew industrial zone, where the plants are located, forming the giant LNG plant on the Mediterranean coast.

The GL2/Z plant is a liquefaction unit processing for NG from the Hassi-R'mel gas fields. The natural gas is liquefied at -162°C to facilitate storage and transportation, reducing its volume by 600 times after final treatment. The plant's production exceeds 8,870 m^3/day per train, with six trains, and the LNG is transported by LNG tanker to Europe and the USA.

The GL2/Z plant uses the APCI (Air Products and Chemicals, Inc.) process for gas liquefaction, employing two refrigeration loops: propane and mixed refrigerant (MR). The propane loop is crucial in the LNG cycle, removing heat from the MR cycle and pre-cooling the natural gas to separate heavy and light components to avoid any possible plugging downstream of the liquefaction process.

The APCI LNG cycle, created by Air Products and Chemicals, Inc., is the most common in the LNG industry [1]. Mixed refrigerants do not require high-boiling components because propane pre-cooling is used as the first step in the refrigeration cycle. Methane, ethane, propane, iso-butane, ethylene, and nitrogen are the refrigerant components chosen for this process based on traditional practices in the natural gas liquefaction industry. LNG production needs refrigeration intensively because a specific natural gas flow is chilled at approximately -162°C during this process.

The LNG industry frequently uses three cascade refrigeration cycles: the mixed refrigerant cycle pre-cooled with propane (C3MR), the double mixed refrigerant (DMR) cycle, and the Phillips cascade cycle. The performance of these cycles has been compared with a focus on maximizing LNG production, and the C3MR cycle is considered the most energy-efficient [2].

The primary factor contributing to an LNG plant's operating costs is the refrigerant's compression [3, 4]. This study focuses on optimizing C3MR cycles.

C3MR cascade cycles have been optimized by adjusting the refrigerant composition (C1, C2, C3, and n-C4) [5]. A parametric study modified the MR refrigerant composition, propane cycle pressure, pre-cooling temperature, and compressor speed [6]. An optimization study was conducted using the ASPEN Plus optimization tool to maximize the cycle's energy efficiency by modifying the refrigerant composition and compressor pressure ratios [7].

Potential power shaft economies in the C3MR cycle were examined using absorption chillers to replace two stages of the pre-cooling cycle [8]. The same C3MR cycle was modeled and optimized, focusing on pre-cooling with propane and mixed refrigerant [9]. A method was developed using refrigerant temperature-enthalpy diagrams and composite graphs to set limits for operating variables [10]. Additionally, linear and quadratic regressions from extensive Aspen Plus simulations were used to model the thermodynamic properties of mixed refrigerants and natural gas [11].

Two variants of the C3MR pre-cooling cycle were successfully optimized using a non-linear solver integrated with HYSYS [12]. A thermodynamic estimation of the pre-cooling system found that a propane cycle had significant advantages over an ethane/propane mixed refrigerant cycle [13]. The final LNG flash gas was used to provide cooling at different points in the process, improving the energy efficiency of a C3MR cycle by reducing the required refrigerant flow [14].

The efficiency of a three-stage propane pre-cooling cycle in the LNG process was optimized using a sequential probability search method [15]. Performance improvements were achieved by increasing pre-cooling stages and sub-cooling temperatures, optimizing the cycle for minimal energy consumption of compressors and air coolers, and simulating the unit with Aspen HYSYS version 7.3 [16]. All parameters affecting the C3MR process's performance and efficiency are analyzed and optimized, introducing an innovative optimization method for mixed refrigerant composition [17]

A dynamic matrix control strategy was proposed to augment the energy efficiency and robustness of a C3MR liquefaction process [18].

A natural gas liquefaction process was developed using mixed refrigerant and propane, integrated with cryogenic distillation to separate ethane. This process enables the simultaneous production of liquefied natural gas (LNG) and liquefied ethane. The C3MR cycle was optimized to produce high-purity LNG and ethane while reducing the energy demand on the compressor [19].

To optimize the performance of the three-stage compressor, we studied and evaluated the impact of ethane contamination of the propane circulating in this pre-cooling circuit.

This study is significant in LNG production as it sheds light on the economic and operational implications of ethane contamination in the C3MR cycle. This study highlights the financial burdens that ethane contamination can impose on LNG production facilities by quantifying the costs associated with ethane contamination, including flaring contaminated propane, increased electricity consumption, and potential plant shutdowns. Additionally, by exploring the downstream effects of ethane contamination beyond the propane pre-cooling loop, such as the disruption of the entire LNG liquefaction process due to elevated temperatures in the MR, this study underscores the need for comprehensive mitigation strategies to address ethane contamination throughout the liquefaction process.

2. PROBLEMATIC

Refrigeration systems play a critical role in natural gas liquefaction technology. Two refrigeration cycles are used in the GL2/Z plant:

- A propane pre-cooling cycle.
- A multi-component refrigerant (MR) refrigeration cycle.

The propane loop condenses part of the MR and pre-cools the natural gas to separate its heavy components easily and prevent any possible plugging downstream of the liquefaction process.

The GL2/Z propane cycle faces significant challenges due to undesirable light hydrocarbons, particularly ethane. This contamination leads to several problems:

- Modification of thermodynamic parameters: causes operational issues in the compressor.
- Increased pressure in the accumulator: results in higher operational pressures.
- Additional propane refrigerant consumption: increases the overall refrigerant usage.
- Considerable losses of refrigerants: lead to significant losses of both propane and ethane.
- Negative environmental impact: flaring of contaminated fluids results in harmful emissions.

By addressing these issues, we aim to enhance the efficiency and sustainability of the propane pre-cooling circuit.

2.1. Description of LNG production process and pre-cooling propane circuit

2.1.1. Description of LNG production process

The LNG (Liquefied Natural Gas) liquefaction process involves several key steps to convert natural gas into its liquid form. These steps are designed to purify and cool the natural gas to extremely low temperatures, making it easier to transport and store. Here are the main steps in the LNG liquefaction process:

- Mercury removal: Mercury is typically removed using activated carbon beds or other mercury adsorbents to protect aluminum heat exchangers from corrosion.
- Carbon dioxide removal: The natural gas is purified by removing carbon dioxide (CO2). These impurities must be removed to prevent freezing and equipment corrosion during the cooling process. CO2 is removed using amine solvents.
- Water Removal: Any remaining water vapor is removed using molecular sieves or glycol dehydration to prevent ice formation in the cryogenic sections of the plant.

- Propane Pre-Cooling (C3): The natural gas is initially cooled using a propane refrigeration cycle, which cools the gas to approximately -30°C. This step condenses heavier hydrocarbons, which are then separated and removed.
- Mixed Refrigerant Cooling (MR): The pre-cooled gas is further cooled using a mixed refrigerant cycle, which brings the temperature down to around -160°C. This mixed refrigerant is a blend of nitrogen, methane, ethane, and propane, optimized for efficient heat exchange.
- Fractionation: Heavy hydrocarbons (such as pentane and higher) are removed to prevent freezing in the cryogenic section. This step also helps in recovering valuable natural gas liquids (NGLs).
- Cryogenic Heat Exchangers: Plate heat exchangers are used in this stage to achieve the required low temperatures.
- Cryogenic Condensation: At these cryogenic temperatures, the natural gas condenses into a liquid. The LNG is typically at atmospheric pressure and -162°C (-260°F).
- -LNG Storage: The liquefied natural gas is stored in insulated tanks designed to minimize heat influx and prevent vaporization.

This sequence ensures that the natural gas is efficiently and safely liquefied, allowing it to be transported and stored in its liquid form, which is 600 times more compact than its gaseous state. There are 6 production trains of LNG in the GL2/Z plant. A simplified schematic of the train LNG is shown in Figure 1.

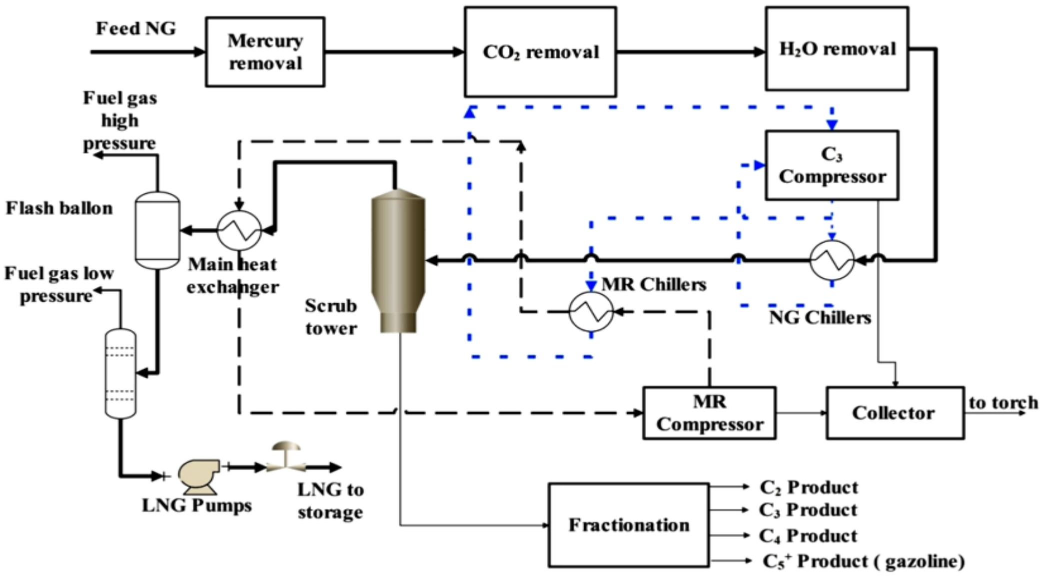

Fig 1: Schematic diagram of LNG production process.

2.1.2 Description of pre-cooling propane circuit

The propane refrigeration cycle operates at three pressure and temperature levels. After compression in compressor 101J, the propane vapors are cooled and condensed in coolers 102CA and 102CB using seawater in a counter-current flow.

The propane is then directed to accumulator 102F, supplying various circuits and equipment, including the propane/NG exchangers (141C, 104C, and 105C) and the aspiration drums (X01F, X02F, and X03F). The propane vapors generated in the exchangers 526C, 115C, 104C, 105C, and 141C return to 101J via the aspiration drum, where they are compressed and the cycle is renewed.

The depropanizer 152E produces propane, which is divided into two streams: one for production and the other as an additive in the propane pre-cooling circuit. The ethane level in the propane must not exceed 2% molar of the composition.

If the ethane concentration reaches approximately 6% molar, the contaminated propane is sent to the flare. Figure 2 shows a simplified schematic of the propane pre-cooling loop. Table 1 details the equipment's roles in the propane cycle.

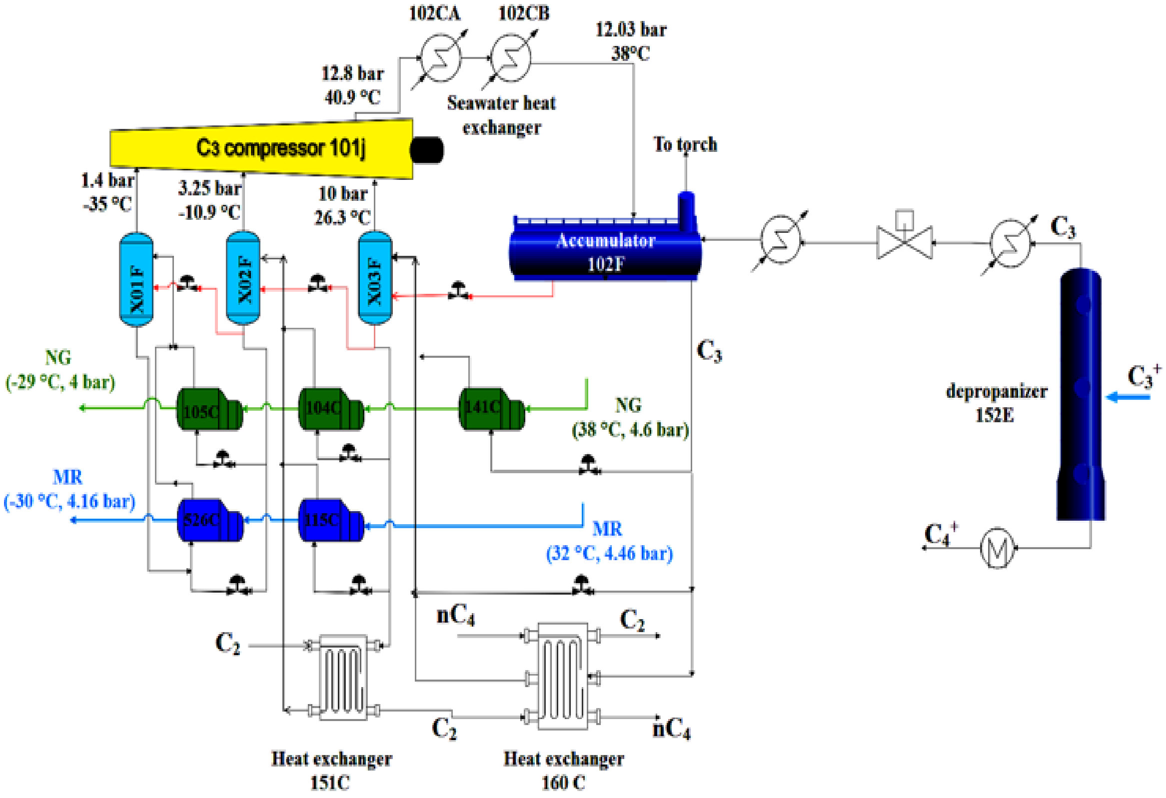

Fig 2: Schematics of propane pre-cooling cycle

Table 1: Propane cycle equipments.

Equipments	Role
101 j	It is a compressor whose function is to move the fluid from a lower pressure to a higher pressure. It is also a compressor with three suction stages: high pressure, medium pressure and low pressure.
102 CA/CB	These condensers maintain a constant propane level to prevent propane vapors from passing into the 102F accumulator.
141C, 104C, 105C	These coolers are used to cool the NG.
526C, 115C	These coolers are used to refrigerate the MR.
X01 to X03 F	These aspiration drums separate the propane to protect the compressor against the aspiration of liquid, they refrigerate the propane vapors when the compressor is in recycling mode and also provide a reserve of liquid propane to supply the coolers and auxiliary circuits.
151 C	Condenser at the top of the depropanizer to condense the vapors at the top of the 152E. It is a plate heat exchanger (ethane/propane) located upstream of the propane cycle.
160 C	This butane sub-cooler is used to refrigerate the ethane and propane and to sub-cool the butane. It is a plate heat exchanger upstream of the propane loop.

2.2. Probable causes of contamination

By analyzing the equipments of the propane loop we suggested two assumptions of contamination of the loop by ethane and light hydrocarbons:

- 1st assumption: The quality of the propane added from the fractionation section means that the depropaniser column (152E) is the source of additional propane for the accumulator (102F).
- 2nd assumption: The contamination may originate upstream of the propane circuit in the following equipments:
- 151 C plate heat exchanger (ethane/propane).
- 160 C plate heat exchanger (ethane/propane/nbutane).

Hydrocarbon contamination was detected by specific daily chromatographic analysis, which recorded the presence of impurities such as ethane, i-butane and n-butane. These components are present in the propane circuit as a result of certain accidental phenomena.

The chromatographic analysis was carried out on propane samples taken from various items of equipment in the propane circuit between 1st and 7th April 2024. These analyses are presented in tables 2, 3, 4 and 5 below.

In the tables, green indicates that the value complies with the manufacturer's standard (2% molar ethane), while red indicates a value exceeding 2%.

Table 2: Chromatographic analysis of propane refrigerant at heat exchanger 151C.

Date	Input (% molare)						Output (% molare)					
	N2	C1	C2	C3	iC4	nC4	N2	C1	C2	C3	iC4	nC4
01/04/2024	0.024	0.026	1.387	98.463	0.026	0.074	0.023	0.028	3.663	96.179	0.023	0.084
02/04/2024	0.025	0.032	1.681	98.182	0.018	0.062	0.024	0.03	3.784	96.091	0.019	0.052
03/04/2024	0.026	0.031	1.448	98.401	0.021	0.073	0.023	0.029	4.622	95.222	0.025	0.079
04/04/2024	0.032	0.027	1.869	97.963	0.023	0.086	0.028	0.025	3.966	95.865	0.024	0.092
05/04/2024	0.043	0.041	1.295	98.522	0.027	0.072	0.033	0.038	4.529	95.297	0.022	0.081
06/04/2024	0.036	0.034	1.725	98.115	0.015	0.075	0.035	0.031	3.822	96.012	0.019	0.081
07/04/2024	0.024	0.041	1.436	98.402	0.016	0.081	0.022	0.04	3.603	96.225	0.019	0.091

Table 3: Chromatographic analysis of propane refrigerant at the 160C exchanger.

Date	Input (% molare)						Output (% molare)					
	N2	C1	C2	C3	iC4	nC4	N2	C1	C2	C3	iC4	nC4
01/04/2024	0.024	0.025	2.285	97.570	0.023	0.073	0.022	0.026	4.562	95.295	0.021	0.074
02/04/2024	0.023	0.026	2.281	97.579	0.019	0.072	0.023	0.027	4.454	95.401	0.023	0.072
03/04/2024	0.024	0.031	2.492	97.362	0.020	0.071	0.024	0.030	4.962	94.890	0.021	0.073
04/04/2024	0.028	0.032	2.169	97.684	0.021	0.066	0.026	0.029	4.312	95.537	0.024	0.072
05/04/2024	0.033	0.031	2.578	97.267	0.023	0.068	0.031	0.028	4.616	95.231	0.023	0.071
06/04/2024	0.031	0.029	2.125	97.725	0.021	0.069	0.031	0.030	4.213	95.633	0.022	0.071
07/04/2024	0.029	0.031	2.036	97.811	0.022	0.071	0.032	0.032	4.102	95.740	0.021	0.073

Table 4: Analysis of propane produced by the depropanizer.

Date	N2	C1	C2	C3	iC4	nC4
01/04/2024	0.021	0.035	1.310	98.543	0.030	0.061
02/04/2024	0.024	0.036	1.281	98.568	0.029	0.062
03/04/2024	0.022	0.033	1.473	98.381	0.030	0.061
04/04/2024	0.025	0.031	1.249	98.601	0.031	0.063
05/04/2024	0.021	0.032	1.578	98.271	0.033	0.065
06/04/2024	0.021	0.034	1.125	98.727	0.031	0.062
07/04/2024	0.022	0.033	1.036	98.816	0.032	0.061

Table 5: Analysis of propane refrigerant.

Date	N2	C1	C2	C3	iC4	nC4
01/04/2024	0.022	0.033	2.131	97.718	0.031	0.065
02/04/2024	0.023	0.034	2.102	97.745	0.030	0.066
03/04/2024	0.024	0.032	2.294	97.555	0.031	0.064
04/04/2024	0.026	0.030	2.070	97.778	0.032	0.064
05/04/2024	0.022	0.031	2.399	97.449	0.034	0.065
06/04/2024	0.023	0.033	1.946	97.903	0.032	0.063
07/04/2024	0.024	0.032	1.857	97.992	0.033	0.062

After analyzing Tables 2 and 3, it is evident that operational issues are present in the exchangers 151C and 160C. The analysis in Table 4 confirms that the propane produced by the depropanizer (152E) meets design standards.

A portion of the propane contaminated with light hydrocarbons, mainly ethane, is directed to the flare. To purify the contaminated propane, propane from the depropanizer is used as an additive (Table 5). Based on this information, it is reasonable to conclude that only the 151C and 160C exchangers could be potential sources of contamination. The issues with the exchangers are as follows:

- Perforation of heat exchanger tubes due to corrosion caused by the presence of traces of mercury in the fluid or erosion due to the high flow speed of the fluid caused by the presence of extraneous particles.
- Metal cracking caused by rapid variations in temperature.

2.3. Impacts of contamination

Evaluation of the actual losses of refrigerants: The study of the quantity of propane used as a supplement for the propane cycle during the month of April showed abnormally high quantities of propane added.

The quantity of propane lost during the month of April 2024 was 1455.6 T, considering that one ton of propane is commercialized at a price of approximately 400 $ [20]. The financial losses caused by the repeated atmospheric flaring of contaminated propane totaled $582,240. The GL2/Z plant realized a net loss in April 2024 as a consequence of the propane cycle failure.

The contamination of the propane cycle by ethane and light hydrocarbons is followed by a considerable increase in the quantities of flared gases, thus contributing to atmospheric pollution, which remains a major problem, particularly in towns bordering industrial areas, where statistics show a large number of cases of chronic respiratory problems.

The presence of non-condensables can have a significant technical impact on the operating conditions of the refrigeration and energy installation, as well as on the efficiency and longevity of the equipment.

3. METHODOLOGY

The objective was to evaluate the impact of ethane contamination of the propane circulating in this cycle on the performance of the loop's key component, the 101j compressor.

In effect, the observed impact of this contamination goes beyond the loop itself, as there is a risk of causing one of the strategic pieces of equipment in the refrigeration loop to shut down, with all the financial consequences associated with the loss of production.

Figure 3 shows the propane pre-cooling loop's simulation with operating data using ASPEN-Hysys V12 and the Peng-Robinson thermodynamic model. Table 6 presents the validation of simulation values with the values measured in exploitation on 01/04/2024.

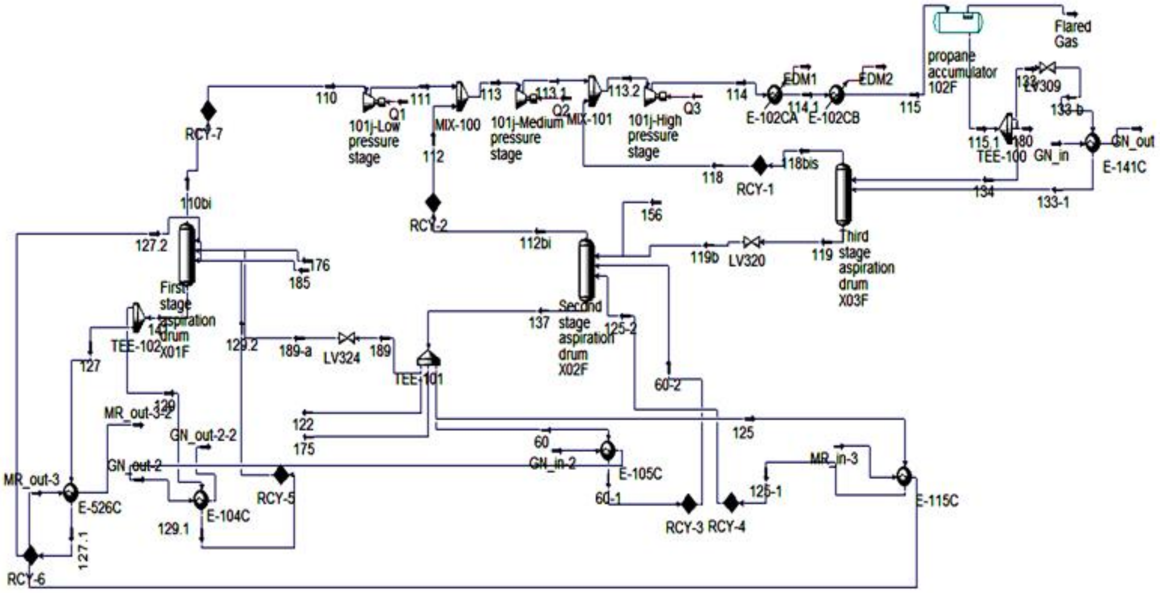

Fig 3: Simulation of propane cycle.

Table 6: Results obtained by simulation compared to operating values.

Parameters	Operating values	Simulation results
1st stage compressor (low pressure stage)		
Inlet pressure (kPa)	140	140
Output pressure (kPa)	227	227
Inlet temperature (°C)	-35	-34.5
Output temperature (°C)	-18.2	-18.1
Suction flow rate (Kg/h)	115000	115300
Power (Kw)	7055	7122
2nd stage compressor (medium pressure stage)		
Inlet pressure (kPa)	325	327
Output pressure (kPa)	519	520
Inlet temperature (°C)	-10.9	-11.1
Output temperature (°C)	19.5	19.55
Suction flow rate (Kg/h)	125000	120200
Power (Kw)	8731	8760
3rd stage compressor (high pressure stage)		
Inlet pressure (kPa)	1000	1010
Output pressure (kPa)	1279	1286
Inlet temperature (°C)	26.3	25.9
Output temperature (°C)	40.9	40.85
Suction flow rate (Kg/h)	182000	171300
Discharge flow rate (Kg/h)	422000	406800
Power (Kw)	9043	9055
Accumulator		
Temperature (°C)	38	37.8
pressure (kPa)	1203	1208

The simulation results and the operating parameters are in good agreement. After validating the simulation results, in the next section we studied the influence of increasing ethane in the propane composition in the pre-cooling loop.

4. RESULTS AND DISCUSSION

In this part we assume that the refrigerant circulating in the propane pre-cooling loop is 100% molar propane. The molar percentage of ethane in the propane is gradually increased in order to examine the influence of this contamination on the compressor operating parameters and on the MR used in the MR cryogenic circuit.

Figure 4 below shows an increase in the outlet temperature of the three compression stages as a function of the increase in the percentage of ethane present in the propane. In our case, the pressure is constant because, after a change in composition, the density changes and the mixture becomes lighter, so its density decreases and its volume increases. Hence, according to the law of perfect gases, the temperature increases proportionally with the volume. This increase in temperature will cause an increase in the temperature of MR and problems with the liquefaction of NG in the main heat exchanger.

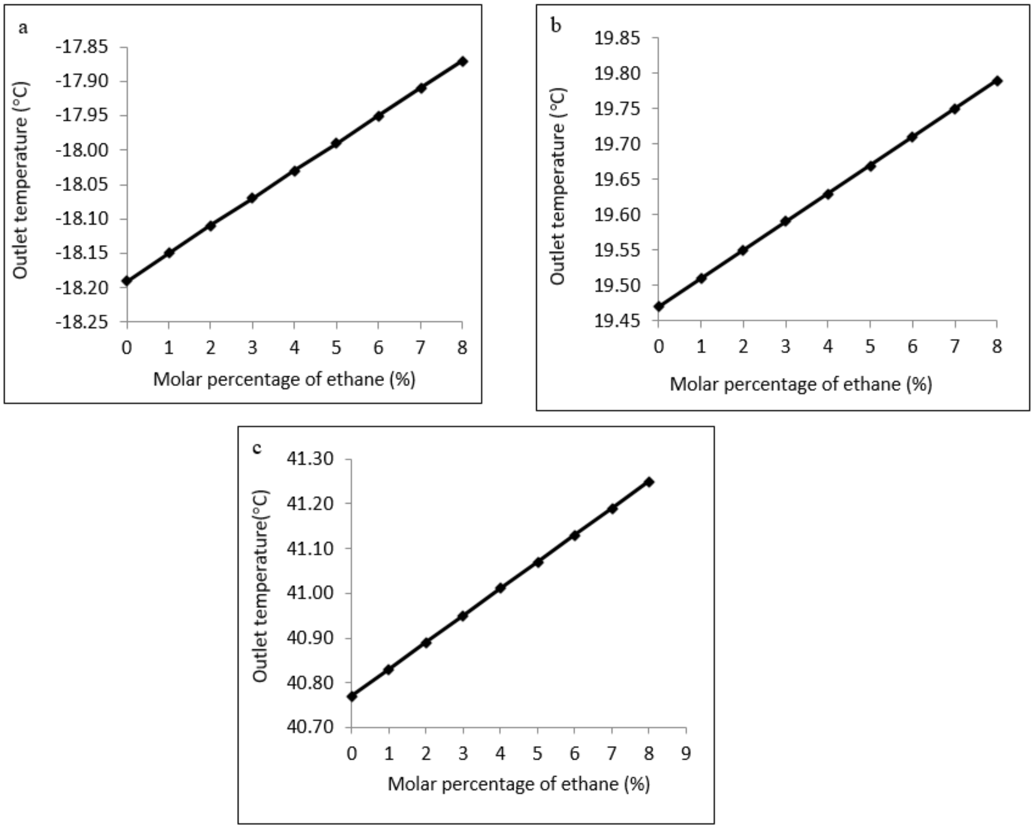

Fig 4: Evolution of the discharge temperature of compressor. a:1st stage, b:2nd stage, c: 3rd stage.

Figure 5 illustrates that as the molar percentage of ethane increases, the power required by the compressor also increases. Despite a constant flow rate, the presence of ethane in the gas (propane) lightens it, necessitating more energy for compression. This phenomenon is due to the fact that a lighter product requires more power than a heavier one to compress at the same suction and discharge pressure. Consequently, this increased energy requirement results in additional electricity consumption and compressor wear over time. Precisely, the increase in electricity consumption for the three compressor stages with 6% ethane contamination (as fixed by the constructor) is calculated as follows: (7135-7117) + (8813-8741) + (9073-9043) = 120 kW/h. This amounts to 1,051,200 kW per year (assuming a price of $0.092857 per kW), resulting in an estimated loss of approximately $97,611 per year in electricity.

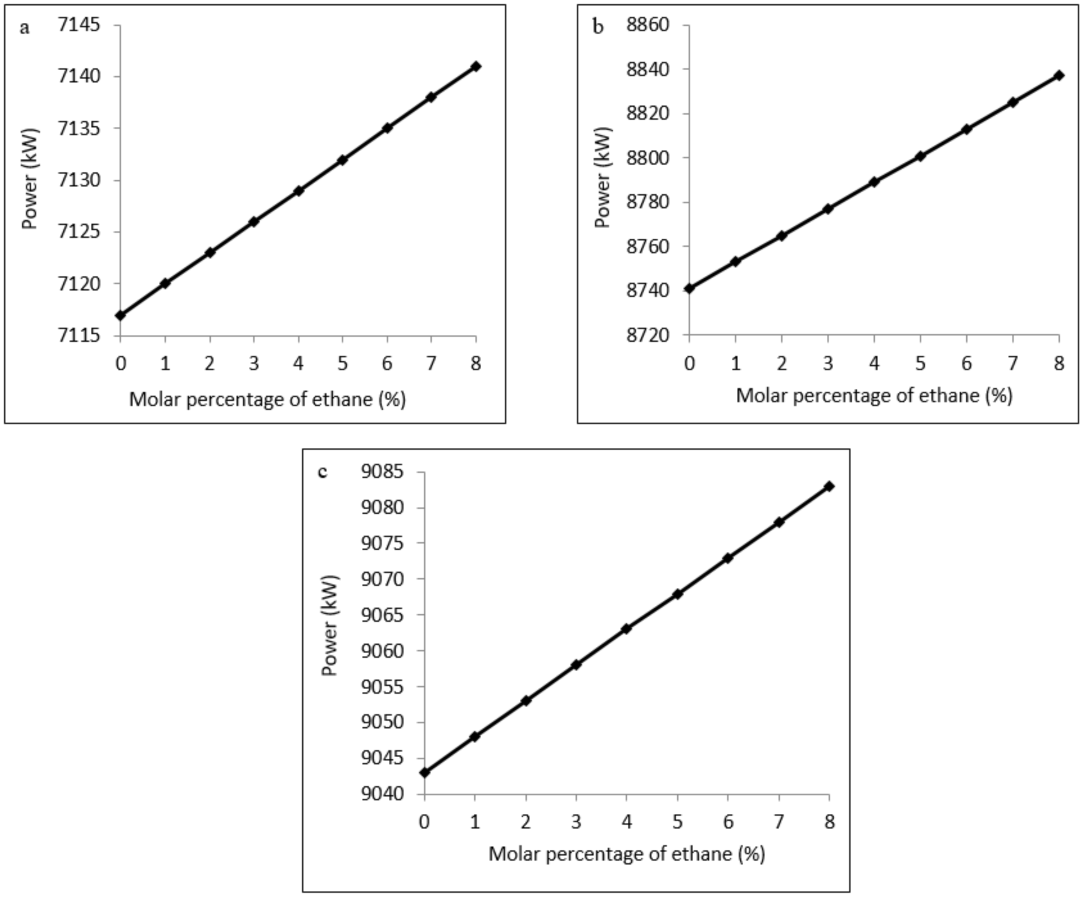

Fig 5: Evolution of compressor power. a:1st stage, b:2nd stage, c: 3rd stage.

The graph in Figure 6 illustrates the change in flare flow rate relative to the percentage of ethane. The escalation in flow rate is attributed to the rising fraction of impure propane, which expands with the increase in ethane percentage. This, in turn, augments the overall quantity of vapor mixture. Examining Figure 7, which depicts the variation of the final temperature of MR as a function of the percentage of ethane present in the propane, it can be seen that the temperature increases with the increase in ethane. This elevation is due to the reduction in the quantity of propane used to refrigerate MR because of losses to FG. The variation of the vapor fraction increases until it attains a value of 1, primarily due to the temperature increase resulting from the reduced propane flow used to refrigerate the MR. In the scenario of an 8% ethane contamination, the quantity of liquid propane becomes zero (flow rate equals 0), hence the stopping of the propane supply for the refrigeration of MR and GN. In the vapor phase, all the uncondensed propane is directed to the FG outlet.

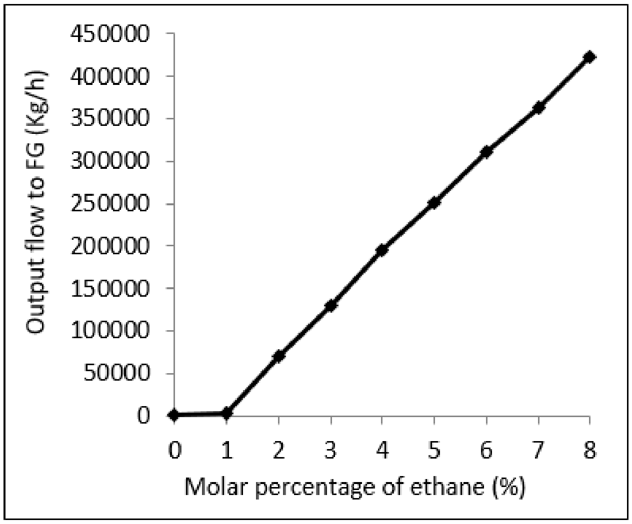

Fig 6: Variation of contaminated propane flow to FG.

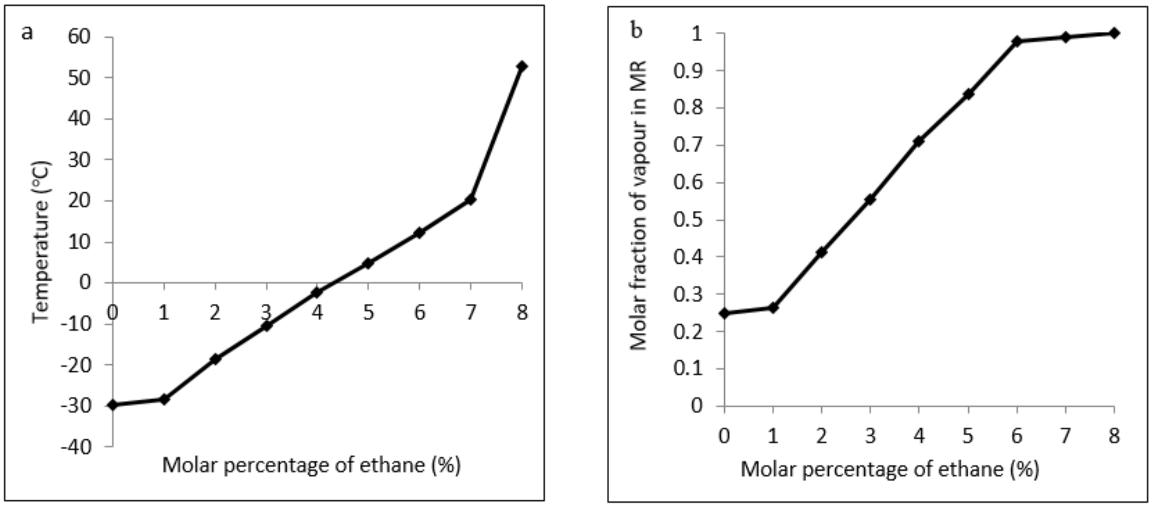

Fig 7: Variations in the parameters of MR. a: final temperature of MR, b: molar fraction of vapour in MR.

It's important to note that even though the trends in outlet temperature and compressor duties may seem linear, the economic effects of ethane contamination are significant. For instance, the economic impact of flaring 1455.6 tons of propane in April 2024 was estimated at $582,240. Additionally, the increase in electricity consumption due to compressor operation with 6% ethane contamination, as specified by the manufacturer, resulted in an annual loss of approximately $97,611. This demonstrates the practical implications of ethane contamination on operational costs and equipment wear. Moreover, observed temperature changes, like the rise in MR temperature from -30°C at 0% ethane to 12.28°C at 6% ethane, underscore the challenges posed by ethane contamination, as it can impair the liquefaction process. These findings demonstrate that while some parameters may seem straightforward, the overall impact of ethane contamination on the C3MR plant is complex and multifaceted, affecting various aspects of plant operation and economics.

5. CONCLUSION

The results of the simulation helped us to predict the behavior of the propane cycle in the event of progressive contamination by ethane and to anticipate any adjustments that may be necessary to protect the 101j compressor in particular. In our study, we were able to carry out a study of the contamination of the propane loop by ethane in the GL2/Z plant, as well as the different sources of contamination and their economic, environmental and technological impact.

We identified significant issues with the propane loop, especially ethane leaks from exchangers 151C and 160C, leading to substantial amounts of flared propane.

This study has provided valuable insights into the impact of ethane contamination on C3MR cooling cycles and LNG production. By quantifying the economic repercussions of ethane contamination, including the costs associated with flaring contaminated propane and increased electricity consumption, this study has highlighted the significant financial burdens that ethane contamination can impose on LNG production facilities. Furthermore, by exploring the downstream effects of ethane contamination beyond the propane pre-cooling loop, such as the disruption of the entire LNG liquefaction process due to elevated temperatures in the MR, this study has underscored the need for comprehensive mitigation strategies to address ethane contamination throughout the liquefaction process.

The results of this study demonstrate that while the trends in some parameters may appear straightforward, the overall impact of ethane contamination on C3MR plants is complex and multifaceted, affecting various aspects of plant operation and economics. Therefore, it is essential for LNG production facilities to implement effective monitoring and mitigation measures to prevent and address ethane contamination, ensuring the continued efficiency and profitability of their operations.

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