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Analyzing the Flare Gas Recovery System in an Egyptian Gas Plant

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Abstract-
This research focuses on the utilization of Flare Gas Recovery Units (FGRUs) to capture and repurpose gases like Methane and LPG, which are typically flared during industrial processes. Flaring poses environmental risks and economic losses. The study aims to design a specialized unit to reclaim flared gases, preventing hydrocarbon emissions while ensuring safety. It seeks to optimize recovery processes to maximize the extraction of valuable products like sales gas and LPG for energy use. The research examines the operational aspects of Flare Gas Recovery Systems (FGRS), employing liquid ring compressors for gas compression and recovery. Economic and environmental analyses underscore the benefits of adopting FGRUs, particularly in the context of Egypt, where routine flaring contributes significantly to greenhouse gas emissions. By advocating for effective measurement and recovery strategies, the study aims to advance sustainable industrial practices, minimizing environmental impact while maximizing resource utilization and economic gains.

Keywords- Simulation; Flare Gas; gas processing Plant; Hydrocarbon, zero flaring

I. INTRODUCTION

Gas flaring, a common practice in industrial operations, emits significant CO_2 globally, posing environmental challenges. Flare gas is actually wasted, impacting energy conservataion and emissions reduction efforts. Utilizing flare gas could potentially meet half of Africa's electricity needs, highlighting its value for energy conservation. Recovering and reusing flare gases in refineries and petrochemical plants is crucial for cost-effectiveness and sustainability. Efforts to manage flare gases efficiently are essential to mitigate environmental impact and optimize resource utilization [1]. Intermittent flarinfg refers to the release of gases during unexpected shutdowns or abnormal operational conditions in high or medium-pressure flares, necessitating consideration during the design of seal drums and connection facilities. Flaring emissions contribute to air quality degradation and prompting the use of flare gas recovery systems (FGRS) to reduce CO_2 emissions and recover hydrocarbons for reuse. Gases sent to flares originate from process relief , where potentially combustible gases are released untreated into the atmoasphere. This venting can be categorized as normal process venting, occurring during routine off-gassing, or emergency venting, which happens during abnormal conditions.[2]
Normal venting in refineries involves releasing gases from various processes, including inert gas purging or the intentional introduction of gases not used in the process. Emergency venting is done to release excess pressure due to abnormal conditions like fires or equipment failures. Venting is crucial for protecting processes, equipment, and people from hazardous conditions. In flaring, vented gases are captured and directed to flare systems for open air combustion. Gas flaring is preferred over direct venting to the atmosphere because it burns gases, reducing their global warming potential compared to direct Methane emissions [3]. Countries around the world are pushing for reductions in flaring within the oil and gas industries to improve environmental safety. The Kyoto Protocol, adopted in 1997 and enforced in 2005, requires industrialized nations to cut greenhouse gas emissions. While it urges countries to adopt emission-reducing policies, it prompted Nigeria to establish regulations for controlling industrial emissions, initially through the construction of flare systems. However, despite flaring being less polluting than direct venting to the atmosphere, it still had significant environmental impacts. This led to the necessity of flare gas recovery systems (FGRS) in refineries and the wider oil and gas sector due to environmental and economic considerations. Stakeholders have begun integrating FGRS into existing process plants to reclaim components like Hydrogen, Methane, and Propane from flare gas, depending on the composition and desired products [4]. Several studies have delved into optimizing Flare Gas Recovery Units (FGRUs) within oil and gas processing facilities. Behrang et al. (2020) conducted a comparative analysis of compression technologies to identify the most efficient

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design for FGRUs in conventional facilities, specifically targeting the persistent flaring caused by blanket gas from oil storage tanks [5]. Pemii et al. (2020) utilized Pinch Analysis to integrate flare networks in facilities, aiming to optimize them for reduced cost and environmental impact [6]. Semmari et al. (2020) explored the application of the Organic Rankine Cycle (ORC) to produce electricity and provide cooling by harnessing heat from gas flaring [7]. Sinha et al. (2019) emphasized the significance of flare gas recovery for sustainability in the oil and gas sector, highlighting its role in mitigating greenhouse gas emissions [8]. Telema et al. (2019) proposed a solution for controlling flare gases in Nigeria by extracting Natural Gas Liquids (NGLs), demonstrating high-efficiency and minimal pollution [9]. Chen et al. (2019) developed an integrated process combining FGR and desalination to monetize flare emissions while producing freshwater [10]. Godwin et al. (2018) optimized LPG recovery from stranded natural gas streams, showcasing economic benefits [11]. Rezaei et al. (2018) conducted a cost-benefit analysis of manufacturing valuable products from flare gas, revealing significant savings and environmental advantages [12]. Evbuomwan et al. (2018) simulated a flare gas recovery unit for a Nigerian refinery, achieving high efficiency and profitability [13]. Hamworthy (2015) designed a custom Combustion Flare Gas Recovery Unit tailored to specific project requirements. These studies collectively advance sustainable practices in the oil and gas industry by underlining the importance of flare gas recovery in minimizing environmental impact and maximizing resource utilization[14].

Additionally, the global flare gas recovery system market is poised for substantial growth, with an expected increase of USD 1.40 billion between 2021 and 2026, driven by the growing significance of environmental preservation efforts (New York, 2022). Key players in the market include Baker Hughes Co., EMTIVAC Engineering Pty. Ltd., GENERON, Honeywell International Inc., Ingersoll Rand Inc., Kavin Engineering and Services Pvt. Ltd., Koch Industries Inc., and MAN Energy Solutions SE, among others. This projected growth underscores the increasing recognition of the importance of flare gas recovery systems in addressing environmental concerns and maximizing the efficiency of oil and gas operations globally. Environmental and economic considerations have increased the use of gas recovery systems. Regarding our comprehensive process evaluation, we devised a practical method to approach zero flaring. This study presents the results of the case study of reducing, recovering, and reusing flare gases from plants. Flare gases are compressed and sent to underground storage. Flare gas recovery reduces noise and thermal radiation, operating and maintenance costs, air pollution and emission and fuel gas and steam consumption [15].

II. MATERIALS AND METHODS

Thus plqnt is considered one of the most important gas plants in Egypt. The company is in north Egypt.The produced sales gas is used as a raw material and fuel for some consumers such as Fertilizers Company and most of the industrial companies and playing an important role in LPG production.

In this field, gas is desired to meet the pipeline specification and recover the most profitable condensate. To achieve this, it is processed through several units in this field, a flare is desired to:

- Extensive relief during start-up or shutdown
- Relief of excess process plant gas
- Handling emergency releases from safety valves, blow-downs, and de-pressuring,But the flaring has a serious Environmental impact.
- C_{O2} from flaring represents around 0.6% of anthropogenic greenhouse gas emissions.
  Directly venting the gas as Methane would be even worse in case of improperly-designed or operated flares.
- Flaring creates local air and noise pollution.
- Flaring is a Serious Economic Loss Too

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Table 1 shows the feed gas composition

Table 1 Feed Gas Composition

COMPOSITION

Overall Phase — Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (lbmole/hr)	MOLE FRACTION	MASS FLOW (tonne/d)	MASS FRACTION	LIQUID VOLUME FLOW (barrel/day)	LIQUID VOLUME FRACTION
Nitrogen	6.6086 *	0.0040 *	2.0153 *	0.0046 *	15.7199 *	0.0021 *
CO2	1.6992 *	0.0010 *	0.8141 *	0.0019 *	6.2041 *	0.0008 *
Methane	1121.9533 *	0.6812 *	195.9472 *	0.4457 *	4116.5446 *	0.5597 *
H2S	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Ethane	231.6993 *	0.1407 *	75.8470 *	0.1725 *	1341.2566 *	0.1824 *
Propane	164.6357 *	0.1000 *	79.0341 *	0.1798 *	981.1134 *	0.1334 *
i-Butane	23.5694 *	0.0143 *	14.9137 *	0.0339 *	166.9212 *	0.0227 *
n-Butane	52.5001 *	0.0319 *	33.2198 *	0.0756 *	358.2606 *	0.0487 *
i-Pentane	15.2495 *	0.0093 *	11.9779 *	0.0272 *	120.8428 *	0.0164 *
n-Pentane	14.7111 *	0.0089 *	11.5550 *	0.0263 *	115.4123 *	0.0157 *
n-Hexane	10.2068 *	0.0062 *	9.5756 *	0.0218 *	90.8889 *	0.0124 *
Mcyclopentan	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Benzene	0.2569 *	0.0002 *	0.2184 *	0.0005 *	1.5574 *	0.0002 *
n-Heptane	2.6755 *	0.0016 *	2.9186 *	0.0066 *	26.7286 *	0.0036 *
Toluene	0.0786 *	0.0000 *	0.0788 *	0.0002 *	0.5698 *	0.0001 *
n-Octane	1.0059 *	0.0006 *	1.2508 *	0.0028 *	11.1537 *	0.0015 *
E-Benzene	0.0251 *	0.0000 *	0.0291 *	0.0001 *	0.2101 *	0.0000 *
m-Xylene	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
p-Xylene	0.0738 *	0.0000 *	0.0853 *	0.0002 *	0.6211 *	0.0001 *
o-Xylene	0.0299 *	0.0000 *	0.0345 *	0.0001 *	0.2458 *	0.0000 *
n-Nonane	0.0918 *	0.0001 *	0.1282 *	0.0003 *	1.1192 *	0.0002 *
n-Decane	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Ammonia	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *

Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 2 of 4

III. Methods

Aspen HYSYS (or simplified Aspen HYSYS) is a chemical process simulator used to mathematically model chemical processes ranging from single operations to entire chemical plants and refineries. Many of the key computations in chemical engineering, including mass balance, energy balance, vapour-liquid equilibrium, heat transfer, mass transfer, chemical kinetics, fractionation, and pressure drop, can be performed using HYSYS. For steady-state and dynamic simulation, process design, performance modelling, and optimization, HYSYS is widely used in industry and academia.[16]

IV. Results and discussions

FGR is the process of recovering waste gases that would normally be flared. These gases are then used elsewhere in the facility, therefore reducing emissions and waste, and consequently increasing efficiency. The process involves capturing the gas from the flare knock-out vessel and compressing it using liquid ring compressors. The recovered gases can then be reused within the facility's fuel gas system, as a refinery feedstock, or for re-injection. FGR can be used in any industry that uses flaring. These include refining, production, LNG, biogas and pharmaceuticals. Flare gas recovery reduces noise and thermal radiation, operating and maintenance costs, air pollution and emission, and fuel gas and steam consumption.[28]

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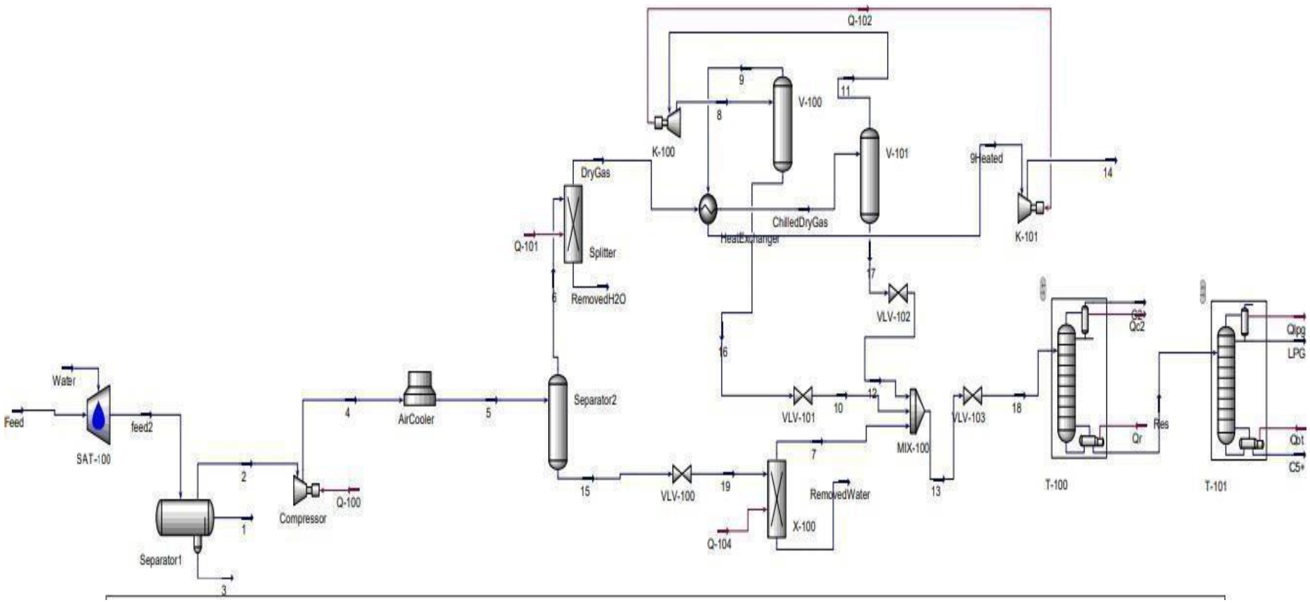

Figure 1 Flared Gas Recovery System HYSYS Print

Steps for execution Simulation Case:

A. STEP 1 SATURATION OF FEED:

To get saturated gas, the feed gas is mixed with an excess amount of water before entering a two-phase separator that separates the feed into the water at the bottom and the desired saturated wet gas at the top.

➢ **Feed data is:**

Temp: 43°C Pressure:15.3 psia
Molar Flow (Flow Rate): 15 MMSCFD (Million standard cubic feet per day)

➢ **Required Units operationsare (With the given order):**

1-3 Phase Separator
2-Compressor
3-Air Cooler
4-2 Phase Separator

➢ **Required Product data is:**

Temp:45°C
Pressure drop at Air cooler: 10 psia Pressure at 2 Phase Separator:1000 psia

a. Feed Components and fractions are used as given in the HYSYS sheet.
b. Selected Fluid Package to be Peng-Robinson Package
c. The feed stream is created by the given data.

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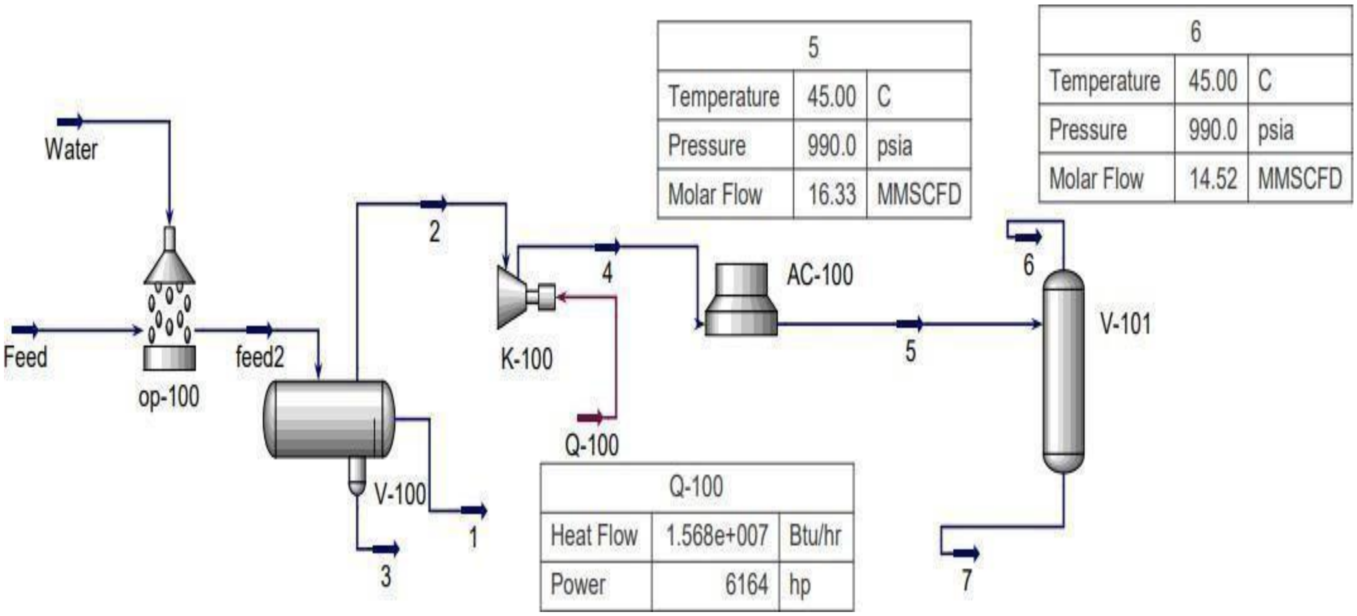

Figure 2 Case 1 HYSYS Print

B. Step 2 Dehydration with Tri-ethylene Glycol

Saturated wet gas is introduced into the bottom of the contactor in counter current with TEG fed at the top. By contacting the two streams, TEG which has a high affinity towards water will absorb water vapor from the gas resulting in lowering the gas water content and hence the water dew point

- **Gas Feed data is:**

Temp:30°C Pressure:1000 psia
Molar Flow (Flow Rate):13.48 MMSCFD (Million standard cubic feet per day)
Air Cooler outlet temperature is 45° C

- **TEG feed data is:**

Temp:35°C Pressure:1262 psia Molar Flow : 0.19 MMSCFD
The Pressure adjusted at 1262 psia to avoid back pressure from the contactor

- **Required Units are (With the given order):**

1- Absorber (Contactor)2-TEG Feed

- **Required Product data is:**

1- Dry Gas
2- TEG Recovery

-while checking the composition of the stream (Dry Gas) we noticed that there is water in the stream 3862 kg/hr of water still in the feed
-TEG failed to dehydrate the stream
- component splitter is used to simulate a solid desiccant

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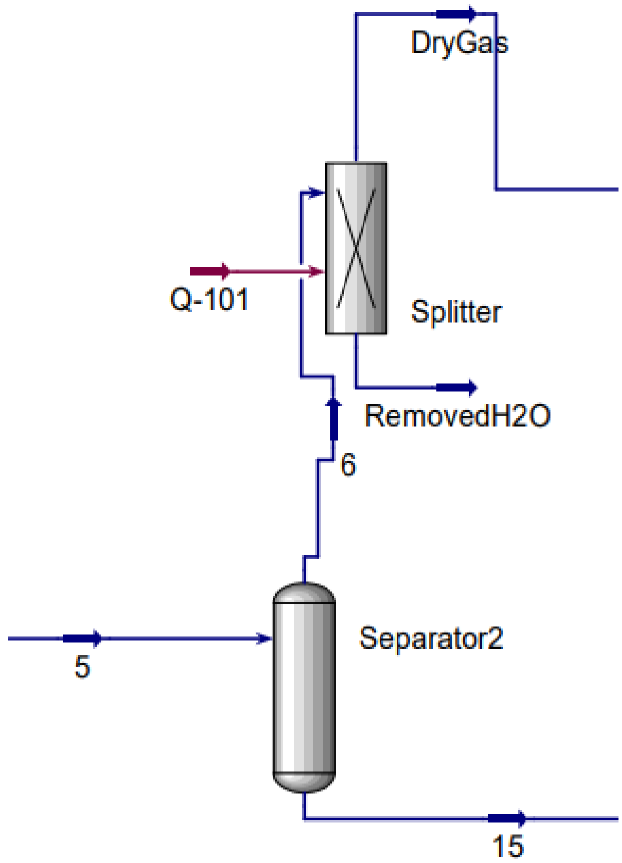

Figure 3 Case 2 HYSYS Print

C. Step 3 Heat Exchanger

Required:

a- Install Heat Exchanger between Stream (9) & Stream (Dry Gas) a Heat Exchanger was installed Directly but not working

b- Found that the Heat Exchanger is not working due to an error in the Turbo Expander

c- As we know Turbo Expander works only on gaseous streams only

d- We found that there is a liquid (Chilled Gas) stream entering the turbo expander

e- To Solve this problem, we have to add V-101 to separate liquid from vapour and produce a vapour stream (stream to enter the turbo expander.

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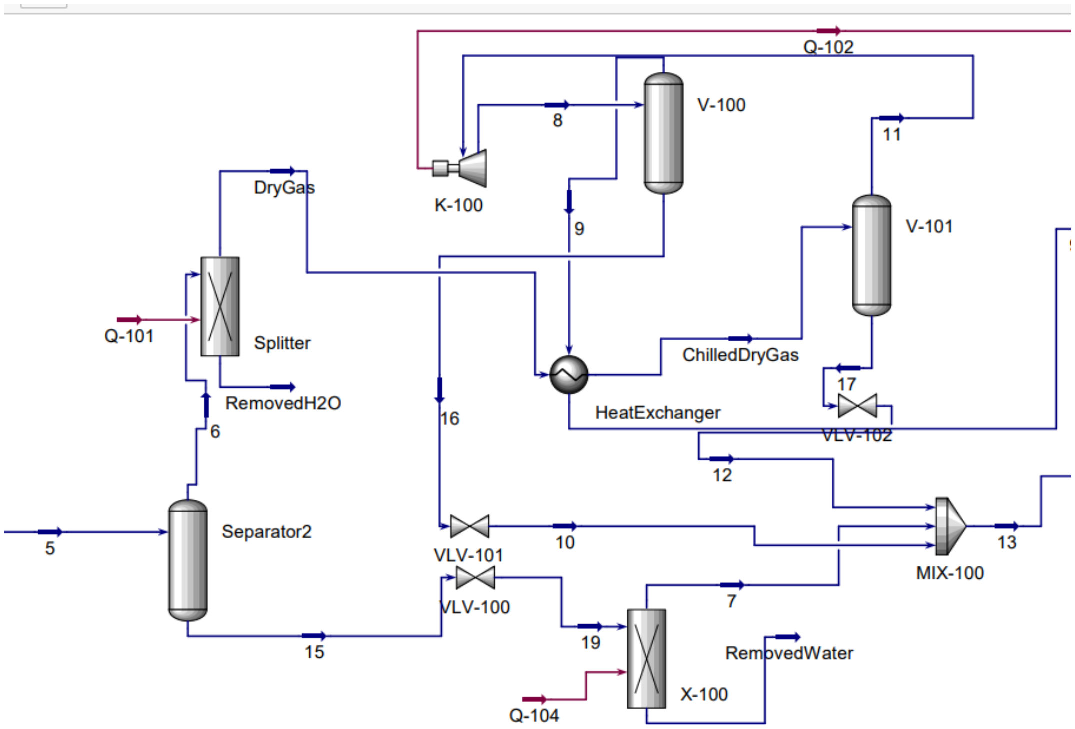

Figure 4 Case 3 HYSYS Print

D. Step 4 Increase Recovery of Butane

a. The current recovery is 66% (calculated from stream 5 the feed stream)
b. We increased the pressure drop in the turbo expander to produce a cooler stream -26.22
c. Removed all unnecessary inputs in the heat exchanger letting Hysys to calculate them installing a mixer to mix all liquid streams
d. Installing heater after outlet mixer stream to heat the liquid stream for the upstream process
e. We've installed vlv-100, vlv-101, vlv-102 on streams 15, 16 & 17 respectively it must apply delta p in streams to force liquids to move for next equipment
f. We have a temperature cross in the heat exchanger

E. Step 5 Installing Ethane and LPG Fractionators

-After mixing 3 liquid feeds (12,10,7) with MIX-100 and installing VLV-103 to adjust the pressure to make the feed ready for the next operations
-Feed 18 enters the first fractionator T-100 to extract Ethane from the top and residue from the bottom
-The bottom-feed of the first fractionator T-100 will be the inlet feed for the second fractionator-101 to extract Propane and Butane (LPG) from the top and C_5^+ from the bottom

F. Optimization:

The optimization aims to increase the recovery of valuable products and increase profitability by adjusting Temperatures, Pressures and fractionator specs across the plant.
before optimizing the mass flow of Butane in the entering feed of the plant is 4513.76 Ib/hr and the product of the plant for Butane is 799.33 Ib/hr which means the percentage of recovery is 17%which is extremely low. Step 1: After increasing the recovery rate of butane in fractionator T-101 to 99% by increasing the number of plates, we found that the mass flow of butane in the product increased to 2078.67 Ib/hr which means the percentage of recovery increased to 46%.
Step 2: The temperature across the air cooler was modified to 35°C to increase mass flow to 3408.33Ib/hr which means the percentage of recovery increased to 75%.

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Step 3: By lowering the Temperature of the Chilled Dry Gas feed to 12°C increase the Concentration of the product which means increasing the mass flow of Butane to 3926.97 Ib/hr
So, the recovery of plants has increased from 17% to 87% by optimizing plant.

G. Return on Investment and Pay Back Period:

The determination and analysis of profits obtainable from the total cost of investment and the choice of the best investment among various alternatives are major goals of the investment analysis. The calculations of ROI are mainly consisting of the following two major terms:

- Total capital investment includes the cost of purchased equipment, installation and foundation, instrumentation, piping, and commissioning works.

$$Return\ on\ investment = \frac{net\ profit}{cost\ of\ investment} * 100$$

- The net profit resulting from productivity increases after excluding the annual increase in operating cost.

The pay-back period which is the period required for the return on an investment to "repay" the sum of the original investment can be calculated as below:
Payback Period = 1/ROI
The return from FGR Unit is calculated as below: Return = Annual flow rate of relieved gases (MMSCF)* Annual avg cost of gas ($/ MSCF)

- **Product of plant:**

LPG= 61.72 tons/day Sales Gas=11.54 MMSCFD Condensate=370.1 bbls/day

- **Product Prices:**

LPG=800 USD /ton
Sales Gas=12000 USD/MMSCF Condensate=120 USD/bbls

- **Total Plant Daily Sales:**

LPG=61.72 ton/d * 800 USD=49376 USD
Sales Gas=11.54 MMSCFD * 12000 USD=138480 USD
Condensate =370.1 bbls/d * 120 USD= 44412 USD
So Total Plant Sales per day is 49476+138480+44412=232268 USD/day
Annual Sales =232268 * 365 days= **69680400 USD/year**

- **Plant Feasibility:**

Plant Income = Annual Sales * Availability
Plant Income =69680400 * 0.99= 68983596 USD/year Total Daily Running Cost = 12000 USD/day
Total Yearly Running Cost =12000 * 300 day =3600000 USD/year
Net Plant Income after running cost (Net Profit) = Plant Income - Total Yearly Running Cost 68983596 USD - 3600000 USD = 65383596 USD/year
Fixed Cost of Plant (Cost of Investment) = 25000000 USD
At Break Even Point = number of years * Annual Sales = (number of years * yearly running cost) + Fixed cost of plant
n*6968040 = (n*3600000) + 25000000
The Breakeven point is 7.4 years
Return on Investment (ROI)= (1/ Payback Period) *100
(1/7.4) *100 = 13.5135%
So, the plant is economically feasible.
Amount of CO_2 Emissions Reduced:
By using the Combustion Equation

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For Methane:

	$CH_4 + 2\ O_2$ →	$CO_2 + 2\ H_2O$
Molecular Weights(g/mol):	16.04 + (2*32) →	44 + (2*18)
Mass Flow (Ton/day):	195.94 + 783.76 →	**538.835** + 440.865

For Propane:

	$2\ C_3H_8 + 9\ O2$ →	$4\ CO_2 + 2\ CO + 8\ H_2O$
Molecular Weights(g/mol):	(2*44.1) + (9*32) →	(4*44) + (2*28.01) + (8*18)
Mass Flow (Ton/day):	79.0341 + 258.07 →	**157.784** + 50.22 + 129.096

For Butane:

	$2\ C_4H_{10} + 13\ O_2$→	$8\ CO_2 + 10\ H_2O$
Molecular Weights(g/mol):	(2*58.12) + (13*32) →	(8*44) + (10*18)
Mass Flow (Ton/day):	48.12 + 172.211 →	**145.692** + 74.502

For Pentane:

	$C_5H_{12} + 8\ O_2$	$5\ CO_2 + 6\ H_2O$
Molecular Weights(g/mol):	(72.15) + (8*32) →	(5*44) + (6*18)
Mass Flow (Ton/day):	23.52 + 83.45 →	**71.698** + 35.197

So the FGRU has reduced the CO_2 emissions by **914** tons of CO_2 **per day**

V. CONCLUSIONS

Based on the results of the Payback period and ROI, we find that the ROI >>> 10% and the payback period >>>5 years. These results indicate these points:

- The FGR Unit is economically feasible because the ROI is higher than 10%.
- The ROI can be increased, and the Payback period can be decreased if the FGR unit is used for a petrochemical complex

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LIST OF ABBREVIATIONS

FGRS	Flared Gas Recovery System
FGR	Flared Gas Recovery
FGRU	Flared Gas Recovery Unit
LNG	Liquefied Natural Gas
NGLs	Natural Gas Liquids
GGFRP	Global Gas Flaring Reduction Partnership
US	United States
GHG	Greenhouse Gas
EBRD	European Bank for Reconstruction and Development
C1	Methane
C2	Ethane
C3	Propane
C_5^+	Pentane and heavier
MMCFD	Million Cubic Feet Per Day