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Optimization of Butane Boil off Gas Re-Liquefaction Process Using Alternative Technique to Conventional Refrigeration System

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Abstract

Improving energy efficiency is a critical issue related to the boil-off gas phenomenon that occurs inside a cryogenic hydrocarbon fixed tank as a result of temperature differences between the tank and the surrounding climate. Software Aspen HYSYS and UniSim Design were used to model the re-liquefaction process by modifying the pure propane refrigeration closed loop, which represents a part of the re-liquefaction process of butane, with an economizer heat exchanger. The inlet stream of the economizer will be divided into two inlets. The JT-valve will be fitted on one inlet to reduce the temperature and pressure of the stream, which will work as the cooling stream. The results of the modified process showed an improvement in the overall performance of the BOG re-liquefaction process, reducing the environmental impact of the refrigeration loop and saving consumed energy. Also, the operating conditions for the process after enhancement are nearly identical to the existing process. Butane recovered temperature after applying the modification is equal to -2°C, which is approximately equal to the butane storage temperature. The modification saves approximately 24% of the consumed power for the re-liquefaction process.

Keywords: *Boil-off gas (BOG); Butane; Re-liquefaction process; Pure propane refrigeration system; Economizer heat exchanger; Terminals.*

1. Introduction

The worldwide demand for optimizing energy efficiency has increased due to some economic and environmental issues. The hydrocarbon storage tanks face challenges in minimizing energy losses and optimizing processes to improve sustainability. One essential issue is in butane storage facility is the Boil Off Gas (BOG) that is generated due to heat ingress into the storage tank. The continuous vaporization of the butane liquid can lead to energy losses, higher operational cost and potential safety hazard.

Some research assessed theoretical models, computer simulations, and empirical findings that have been presented to clarify BOG formation phenomena and create an integrated understanding of the variety of processes that affect the operation, highlighting important discoveries, open-ended issues, and promising directions for future research [1-2]. Also, LPG and LNG as products in tankers and cargos, in which BOG is formed, are discussed to analyze various locations for more accurate results.

The increase in LPG and LNG production is driven by global demand for petroleum and natural gas. Improvements in the re-liquefaction process have a direct impact on company profitability and cost efficiency [1]. This study evaluates the difference between the existing re-liquefaction process of the butane and the modified process. Also, supporting more effective optimization and design strategies for re-liquefaction systems, ultimately enhancing the performance and applicability of butane [2].

Sometimes, the re-liquefying process for the BOG wasn't an option. The gas can be burned in onboard boilers or engines to generate heat or power. Now, better heat recovery can be achieved by using waste energy utilization systems. This, combined with the lower cost and weight of LNG, helped decreasing transportation expenses. So, while it might seems complicated, using BOG to heat things up and save energy can make the whole operation more efficient and cost-effective [3].

Refrigeration is the mechanical transfer of heat from a high to a low-temperature source. There are two kinds of methods: cyclic and non-cyclic [4]. Refrigerant R290 was used in an experiment to the thermal performance of a refrigeration unit using a flash-type economizer. The results should showed that adding the economizer can significantly improve the unit's COP and cooling capacity, which saved energy [5]. In comparison to the Claude cycle, the Kaptiza cycle worked better and was more economical for LNG BOG re-liquefaction plants [6]. The plant needed to carefully consider the costs (insulation, holding capacity) and benefits of each option. Whichever option was chosen, efficient BOG management was crucial [7]. Phase change materials (PCMs) for thermal storage, suction line heat exchangers (SLHX), and modifying the geometric configuration of refrigerator condensers are just a few of the techniques that Borikar and Gupta investigated in order to enhance refrigerator performance [8].

Using LN_2 to liquefy BOG without compression; was divided into two stages, the first of which involved producing LN_2 and the other used LN_2's latent heat to liquefy BOG. This strategy substituted conventional N_2-RBC-based approaches for pre-cooling by effectively utilizing onshore LNG cold energy and providing both financial and environmental advantages [9-10].

The dynamic behavior of a BOG re-liquefaction process in ships fueled by LNG throughout the length of the whole operational cycle. It considered a range of options and limitations associated with small-scale and maritime situations, with the goal of greatly enhancing operability [11]. Every system thermodynamic aspect of the optimised plants was improved when compared to the base scenario. When the compressor pressure ratio increased, exergetic efficiency decreased [12]. The sensitivity analysis showed that plant exergetic efficiency was improved by larger expander mass ratios and higher pressure ratios in compressors [10].

Adding BOG liquefaction systems to LNG ships using the Joule Thomson cycle, comparing to a fuel supply system led to lower TAC by at least 9.4%, especially noticeable when LNG prices were at 5 USD/MMBtu. The implementation of simple re-liquefaction processes helped reduce cargo loss, make the investment in additional facilities more economically viable by offsetting capital costs [13]. Optimizing the BOG handling process aimed to minimize capital and operating costs [14]. Various process integration options for BOG recondensation are explored, emphasizing the need for optimization to achieve economic efficiency [15]. In this work, the modified refrigeration system of the existing re-liquefaction process of butane BOG using a heat exchanger economizer. Software Aspen HYSYS and UniSim Design were used to model the existing and modified processes. The inlet stream of the economizer will be divided into two inlets by using the JT-valve on one inlet to reduce the temperature and pressure of the stream.

2. Methodology

The methodology is used to explain the steps of substituting the closed loop of the pure propane refrigeration system that is existing in use at an Egyptian company to cool down the hot liquid butane during the re-liquefaction process. There is an economizer heat exchanger in the new process. The study was executed in the case of the holding mode, which means that the influencing factor for raising the temperature of the butane storage tank is the ambient air temperature, which contributes to the tank's increased temperature through heat exchange. Butane is kept apart under specific pressure in double-walled, complete containment tanks with a suspended deck. In this process, the rate of BOG generation depends on the heat ingress into the storage tank only.

2.1. Specification of storage tank

API 620, particularly Annex L and R [16], provides essential specifications for the design, fabrication, and inspection of large, low-pressure storage tanks used for liquefied gases. These standards ensure that storage systems can withstand operating pressures, environmental factors, and potential hazards associated with LPG storage tanks. The tank is double-walled full containment with a suspended deck. There are 2 storage tanks for butane. Each tank has a specified re-liquefaction compression system. Table 1 illustrates the specification of the butane storage tank.

Table 1. Butane storage tank specification.

Specification	Inner tank	Outer tank
Nominal diameter	49 m	51 m
Height	30 m	32.8 m
Tank maximum capacity	53876 m^3	
Design pressure (min/max)	-0.005/0.14 barg	
Design temperature (min/max)	-48°C	-48/45°C

The tank consists of an inner and an outer tank, a concrete foundation and a suspended deck. The space between the inner tank and the outer tank is filled with insulation material. The inner and outer tanks are connected through pipes which act as heat bridges. The inner tank is not gas tight so that the space between the two tanks is filled with LPG/ Propane/ Butane vapors.

2.2. Butane BOG re-liquefaction process description

There are two storage tanks of butane with two re-liquefaction systems, every tank has its separate system. The butane BOG is formed inside the storage tank due to temperature fluctuations, composition changes, and insufficient refrigeration. BOG Flows from the tank's top to the suction of the screw compressor, which compresses the stream and produces pressurized butane hot vapors. The discharge of hot vapors from the compressor enters the air cooler (condenser), which condenses them and produces liquid butane with a high temperature, which is collected in a horizontal liquid receiver as a surge drum. The hot/high pressure liquid butane enters the sub-cooler to be sub-cooled by exchanging with a cold pure propane as refrigerant (pure propane -38°C, 0.2 barg), the liquid butane leaves the sub-cooler with a temperature nearly equal to the tank temperature. Finally, the exit flow passes through a liquid control valve (LCV) to control the quantity of the flow that enters the tank and also maintain the stream operating condition, nearly equal to the tank pressure and temperature as illustrated in Figure 1.

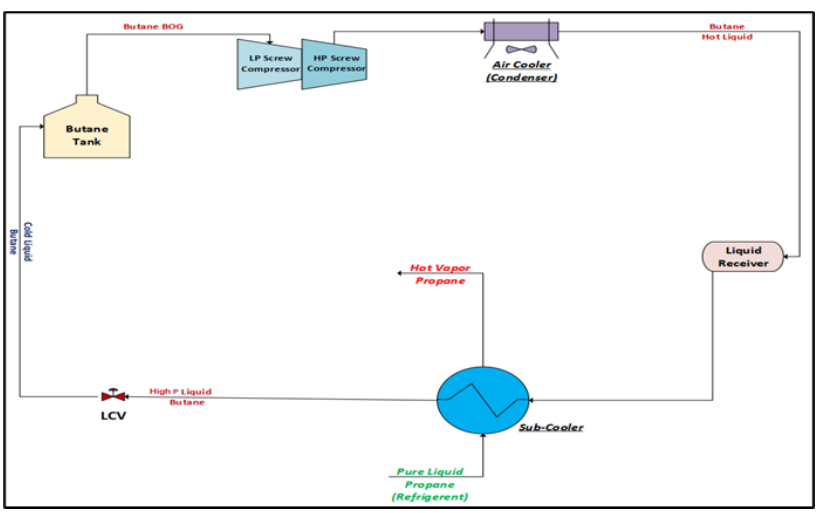

Figure 1. Butane BOG re-liquefaction process PFD.

2.3. Pure propane refrigeration process description

The refrigeration process is a closed-loop system that used pure propane as a refrigerant in the BOG re-liquefaction process of butane. The refrigerant, which is boiled in the sub-cooler, is converted into vapor phase. The pure propane vapors (0.1 barg and -40°C) after leaving the sub-cooler pass through a suction drum to remove liquid droplets. A stream of saturated refrigerant vapor flows from the horizontal suction drum into the low-pressure suction port of screw compressor. Another stream of saturated refrigerant vapor (3.85 barg and 0.8°C) flows from the upper of two vertical flash economizers into the intermediate pressure part. The compressor increases the vapor stream pressure. The refrigerant vapor from the compressor outlet is condensed in the air-cooler condenser. The maximum temperature of inlet air for the condenser is 45°C.

The condensed refrigerant then flows into two refrigerant liquid receivers. Some of the refrigerant liquid receiver outlet stream is bypassed through the filter dryer where moisture is captured. The mainstream of liquid refrigerant flows out of the refrigerant liquid receiver into two liquid control valves to maintain the quantity of the flow and break down the pressure and temperature of the stream, then to the two-flash economizer. The outlet liquid from the bottom of the flash economizer passed through another liquid control valve for more breakdown of temperature and pressure (-38°C and 0.2 barg). Finally, liquid refrigerant then flowed into the shell side of the sub-cooler to cool down the hot liquid butane (tube side) as per Figure 2.

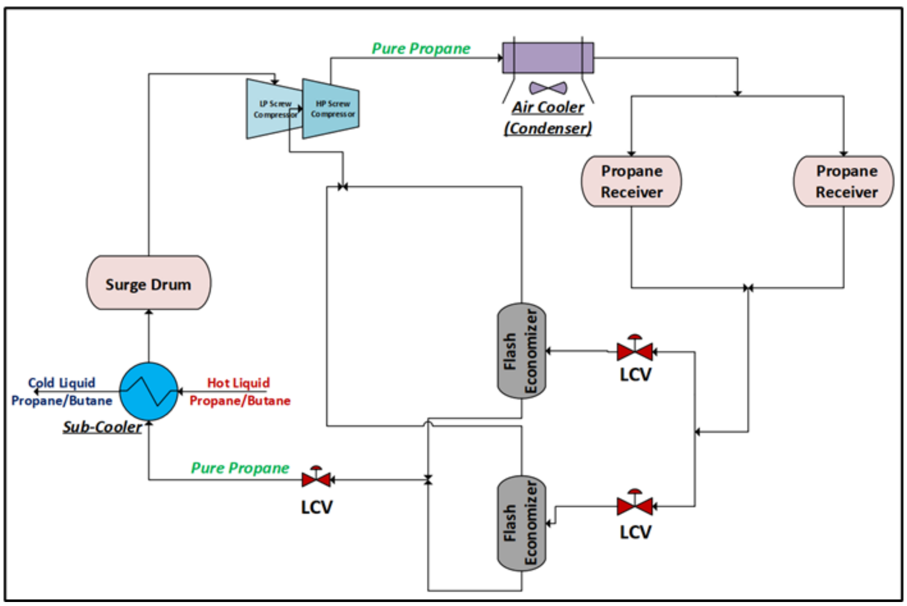

Figure 2. Pure propane refrigeration closed system.

The refrigerated screw compressors consisted of mechanical parts which need a lubrication system for cooling purposes to control the operating temperature of the compressor. Also, it prevents overheating and protects components from thermal damage, the lubrication system has not appeared on the PFD but enrolling in the plant. Table 2 shows the pure propane operating condition which is directed to the sub-cooler (shell side) to cool down the hot liquid butane.

Table 2. Operating condition of the refrigerant.

Refrigerant to sub-cooler	
Inlet temperature, °C	- 38
Inlet pressure, barg	0.2
Molar flow, kmol/h	157.59

2.4. Management of change (MOC)

The existing re-liquefaction process uses a closed refrigeration cycle to decrease the hot liquid temperature of butane. While functional, this has potential limitations in terms of efficiency, energy consumption, and capacity. To overcome these possible defects, the enhancement which is described as MOC would be a trial for executing a more efficient and potentially cost-effective method by the following steps:

1. Removal of the existing propane refrigeration system from the butane BOG re-liquefaction system.
2. Adding an economizer heat exchanger, which is located after the liquid receiver, with a splitting two pipelines as inlets.
3. The first pipeline inlet to the economizer has a throttling valve to breakdown the pressure and temperature of the inlet stream, which works as a cooling flow and is directed to the shell side of the economizer heat exchanger.
4. The second pipeline inlet is a regular pipeline, and the stream (butane) is directed to the tube side of the economizer heat exchanger for being cooled.
5. The formed vapors from the shell side of the economizer will be directed back to the new vapor recovery screw compressor for pressurizing the stream and recovered again to the main process.
6. Adding a screw compressor to pressurize the vapors that comes out from the economizer and recycle it again to the 2nd BOG screw compressor.

A heat exchanger economizer with two pipelines functioning as substitutes for the pure propane refrigeration loop. The second pipeline inlet is a regular pipeline and is directed to the tube side of the heat exchanger for cooling, whereas the first pipeline stream to the economizer has a throttling valve for reducing the pressure and temperature of the inlet stream, which functions as a cooling flow and directs to the shell side of the heat exchanger. The new butane PFD re-liquefaction process is described as illustrated in Figure 3.

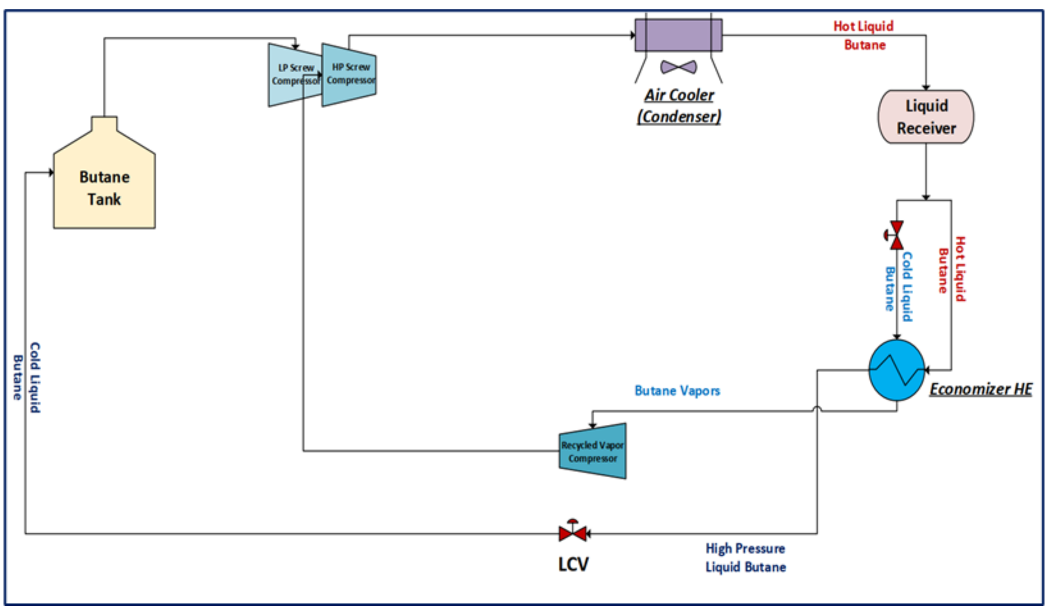

Figure 3. Butane BOG re-liquefaction process flow diagram.

2.5. Simulation basis and steps

The simulation of the BOG re-liquefaction process is simulated through two software [17], Aspen HYSYS and UniSim Design R460.1. The Peng-Robinson (PR) equation of state (EOS) could be suitable for the model. The simulation is divided into two main sections as the following: Re-liquefaction process of butane BOG; and Refrigeration closed system of pure propane as a refrigerant.

2.5.1. Butane feed composition and parameters

Table 3 presents the composition of the butane stream, detailing the mole percentages of its key components. The mixture primarily consists of n-butane (52.37%) and i-butane (37.79%), along with smaller amounts of propane, i-pentane, and n-pentane, making it essential for analyzing re-liquefaction performance. Table 4 describes the operating conditions for butane BOG that flows inside the pipeline into the BOG screw compressor suction.

Table 3. Butane BOG composition.

Component	Composition	Butane
Ethane	Mole %	0.00
Propane	Mole %	9.496
i-Butane	Mole %	37.793
n-Butane	Mole %	52.366
i-Pentane	Mole %	0.208
n-Pentane	Mole %	0.136
Total	Mole %	100

Table 4. Butane BOG operating condition.

Butane BOG stream	
Inlet temperature, °C	- 0.7
Inlet pressure, barg	0.02
Mass flow, kg/h	469

2.5.2. Simulation of the re-liquefaction process for butane BOG (without refrigeration system)

During the storage of liquid butane in the storage tank, the external temperature difference, transportation, and loading processes all affect the temperature and pressure of liquid butane, resulting in an unknown amount of butane vapors. Simulation of re-liquefaction butane BOG process is applied by using Aspen HYSYS as illustrated in Figure 4.

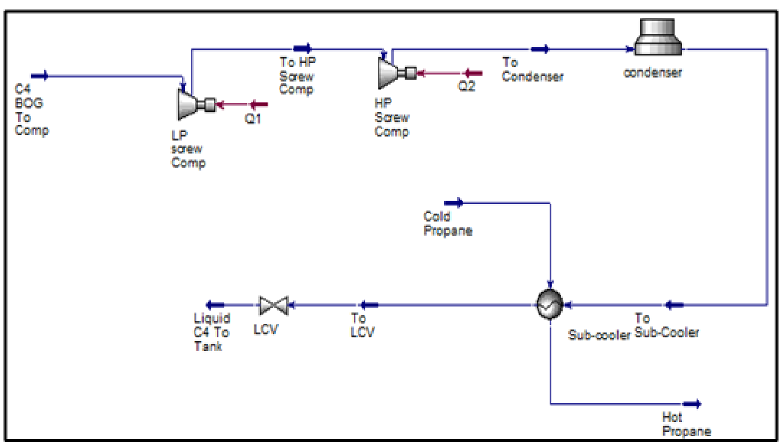

Figure 4. Simulation of the re-liquefaction process for butane BOG.

2.5.3. Simulation of the pure propane refrigeration closed system

Compressors, expansion valve, and heat exchanger may all be more accurately simulated when the refrigeration process of pure propane is modeled. Through virtual experimentation, this method makes it possible to assess alternate refrigeration cycles and their effects on system performance, dependability, and environmental sustainability. Also provide a clear comparison of the positive and negative aspects of propane refrigeration. A simulation of the pure propane refrigeration process is utilized to emphasize the energy usage, operating expenses, and utilized area. Figure 5 will present the simulation of the refrigeration system of pure propane using Aspen HYSYS software.

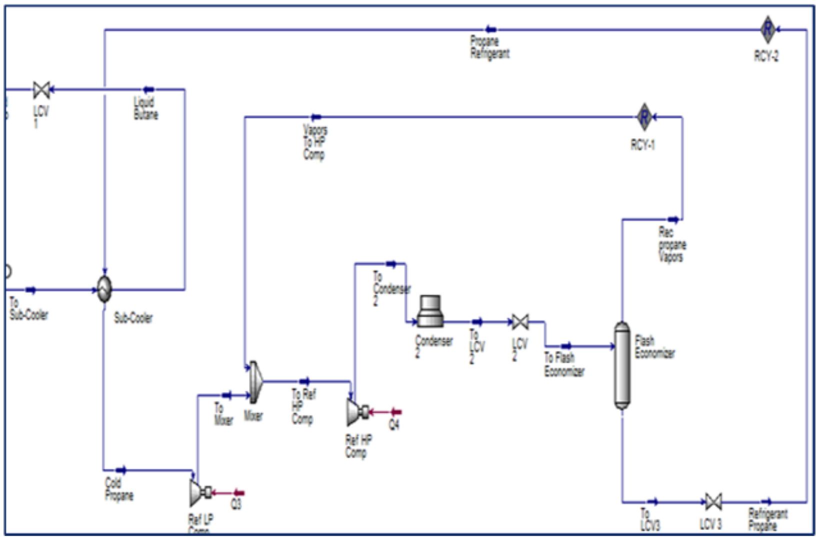

Figure 5. Simulation of the refrigeration closed system by Aspen HYSYS.

2.5.4. Simulating the modified re-liquefaction process of butane BOG

To restore the BOG to its liquid condition, the re-liquefaction process usually involves compressing gas to raise its temperature and pressure, then cooling and condensation. This process can be provided more efficiently by the addition of an economizer heat exchanger, which gathers as well as utilizes waste heat. System design, operating conditions, and control techniques are optimized by carefully simulating and analyzing critical parameters such as pressure, temperature, flow rates, and heat transfer coefficients. Furthermore, by using simulations, several factors can be evaluated, such as energy consumption and re-liquefaction performance which might be affected by equipment sizing, process adjustments, and ambient conditions. The composition of butane BOG is mentioned in Table 3. Figures 6 and 7 show the complete process simulation for butane BOG re-liquefaction after adding the economizer heat exchanger instead of the refrigerated closed loop of pure propane.

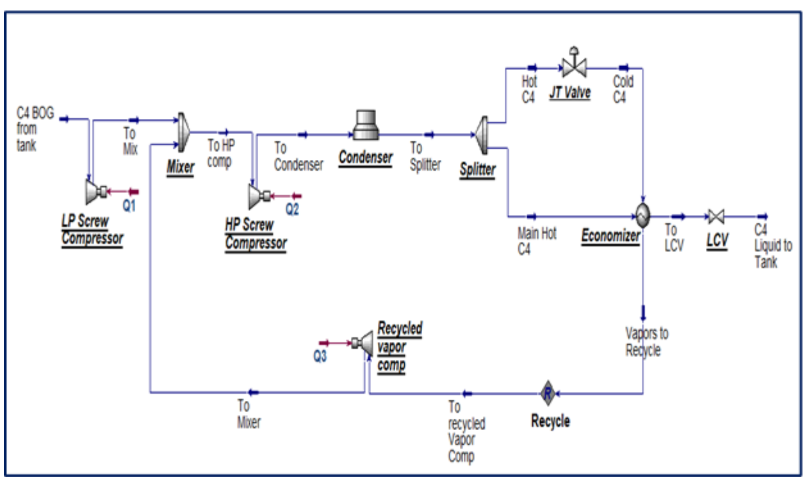

Figure 6. Simulation of the modified butane BOG (Aspen HYSYS).

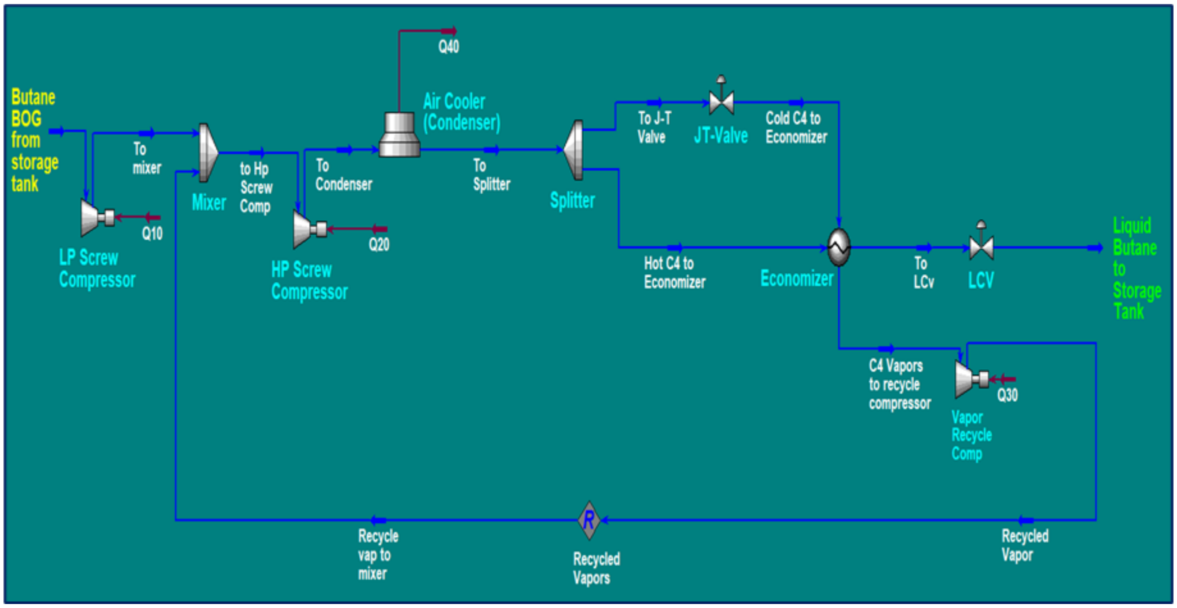

Figure 7. Simulation of the modified butane BOG (UniSim Design).

3. Results and discussion

3.1. A comparison between the actual and modified operating parameters

Table 5 describes the comparison for the butane BOG operating conditions before and after the modification which could prove if the modification resulted conditions can be applied.

Table 5. Comparison of butane operating conditions.

Equipment	Parameter	Aspen HYSYS		UniSim		unit
		Existing	Modified	Existing	Modified	
BOG screw compressor	Outlet temperature	73.5	70.64	74	71.8	°C
	Outlet pressure	6.8	6.8	6.8	6.8	barg
	Molar flow rate	8.2	12.88	8.2	13.29	kgmole/h
Condenser outlet	Outlet temperature	55	55	55	55	°C
	Outlet pressure	6.6	6.5	6.6	6.5	barg
	Molar flow rate	8.2	12.88	8.2	13.29	kgmole/h
	Vapor fraction	0	0	0	0	-
LCV outlet	Outlet temperature	-9	- 8.7	-8.8	- 8.8	°C
	Outlet pressure	0.1	0.1	0.1	0.1	barg
	Molar flow rate	8.2	8.246	8.2	8.242	kgmole/h
	Vapor fraction	0.04	0.058	0.042	0.054	-

The final parameters of the stream after the LCV will be exposed to minor losses in temperature and pressure according to heat ingress to pipeline and friction losses. The difference in temperature will be approximately equal 5°C.

BOG screw compressor outlet stream: The temperature and pressure values are the same in the existing result and also the 2 software results, the only difference is the molar flow rate, and this is due to combination of the recycled vapors with the butane BOG feed.

Condenser outlet stream: There is a total phase change from vapor to liquid in this stream for all conditions so, the vapor fraction is equal 0. The rest parameters are the same except molar flow rate for the modified case.

LCV outlet stream: There is no difference between the modification results and the existing values.

In summary, the operating condition of the butane modification results are the same as the butane existing results which reflect that the modification has no problem with the operating condition point and can be applied to the process in stability.

3.2. Splitting ratio of mainstream for butane mainstream

The splitter, which is located after the condenser, is the heart of the modified re-liquefaction process, as it controls the quantities of butane that will be separated and enter the economizer (hot for tube side and cold for shell side). Numerous trials are done to determine the optimal ratio that will produce the best results for both the method and operating conditions that are closest to the real operating conditions. Table 6 will show the trials of changing the splitting ratio and the most optimum value that will lead to the best condition of the butane re-liquefaction process based on Figure 8 and Figure 9.

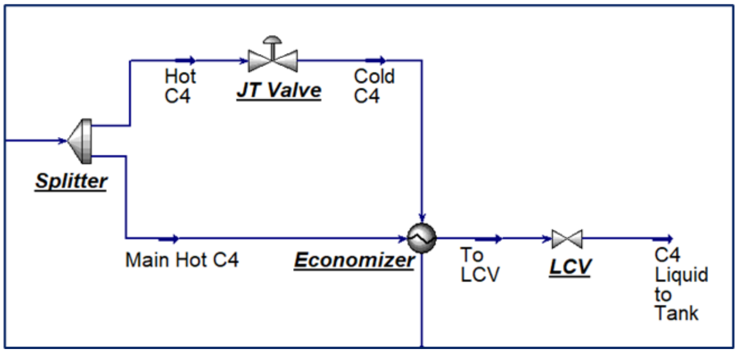

Figure 8. Splitting of butane mainstream using Aspen HYSYS.

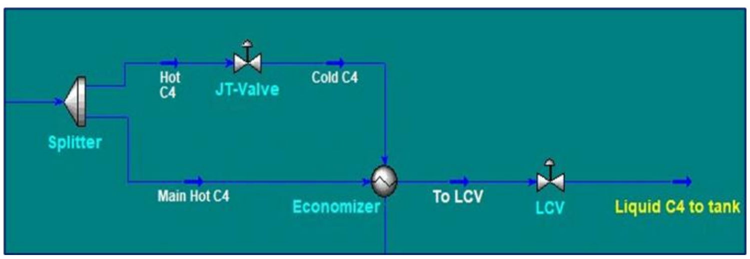

Figure 9. Splitting of butane mainstream using UniSim Design.

Figures 8 and 9 present the location of the splitter as per the simulation of Aspen HYSYS & UniSim Design software models, respectively. As shown in Table 6 the trials are done from 10 % to 100 % but after 37 % for Hot C_4 and 63 % for Main hot C_3, the economizer heat exchanger has a problem called temperature cross, so the trials will end at the 37%.

Table 6. Splitting ratio of mainstream of butane re-liquefaction process

Stream	Hot C4	Main hot C4	Temperature of economizer outlet stream to LCV		Economizer Heat Exchanger		Vapor fraction of LCV outlet stream	
Splitting Percent %	Percentage		Aspen HYSYS	UniSim	Aspen HYSYS	UniSim	Aspen HYSYS	UniSim
	10 %	90 %	45.7°C	53°C	√	√	0.35	0.33
	20 %	80 %	32.8°C	32°C	√	√	0.25	0.24
	30 %	70 %	15.4°C	11°C	√	√	0.14	0.13
	35 %	65 %	4.13°C	3°C	√	√	0.08	0.07
	36 %	64 %	1.6°C	1.1°C	√	√	0.064	0.06
	37%	63%	-2°C	-2°C	√	√	0.0432	0.043
	40%	60%	-10°C	-11°C	X	X	0	0
	45%	55%	-27.7°C	-29°C	X	X	0	0
	50%	50%	-49.5°C	-50.3°C	X	X	0	0

From Table 6, it's noted that the first 4 rows of percentages (from 10 to 35%) highlight that the resulting stream temperature is far away from the butane storage temperature in the existing process, so these rows are out of the optimization consideration. The last 3 rows (percentages from 40 to 50%) resulted in pressure that is very low (under tank operating pressure). The percentage 36 % of Hot C_4 and 64 % of Main hot C_4 resulted in temperature equal to 1.6°C and this value is slightly above the butane storage tank temperature, so it will not be the optimum. The percentage of splitting is optimum at 37 % of Hot C_4 and 63 % of the Main hot C_4 as its temperature is approximately equal to the butane storage temperature, and also the resulted pressure after LCV is approximately the same as the storage tank pressure. The quantity of Hot C_4 that will flow through the throttling valve should be enough to handle the main hot C_4 required temperature [17].

The optimization ratio is chosen based on the following:

- The outlet stream after the economizer should have a temperature closest to the butane storage temperature (nearly -1°C).
- The vapor fraction of the outlet stream of LCV is nearly the same as the butane existing process value in Table 6.
- The economizer heat exchanger condition is accepted in simulation cases (no temperature cross).

Figure 10 presents the optimum point for the butane re-liquefaction process with two curves, one using Aspen HYSYS results and the other using UniSim Design results. Also Figure 6 shows the optimum point does not exceed the butane tank design temperature (-48°C); also, it's the closest point to the butane storage temperature (-1°C). The reason for not choosing the points after -2°C is that the resulted pressure is very low and under the operating pressure of the butane storage tank. Based on the previous reasons, the selected point is the actual optimum and the modification is applicable since it has no impact on the primary process's requirements.

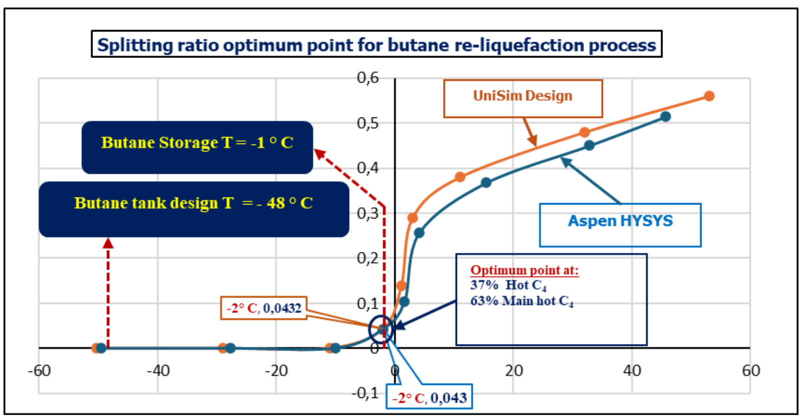

Figure 10. Optimum splitting point for the modified butane re-liquefaction process.

3.3. Power load

Power load can be measured to find areas where energy is being wasted or used excessively, which helps reduce the impact of energy use on the environment.

3.3.1. Power load of the existing butane BOG re-liquefaction process

Table 7 shows the calculated power load (total load) for the existing butane BOG re-liquefaction process without the refrigeration system of the pure propane; it means the power load calculation limit is the sub-cooler heat exchanger. As illustrated in section 2.2, there are two storage tanks of butane products with double compression systems: screw compressor system 1 and screw compressor system 2. Every system has online and standby equipment, but online status equipment is only included in the power load calculations. Table 7 results show that the total power load for the existing re-liquefaction process of butane BOG without refrigeration system is equal to 808 KW (Eq. 1)

Table 7. Power load of butane existing re-liquefaction process.

Equipment	Status Online/Standby	Consumed load (KW) (L)	Motor efficiency μ (E)	Total power load ($\frac{L}{E}$)
Butane BOG Compressors 1	Compressor 1 A (Online) Compressor 1 B (Standby)	250	78.2%	319.69
Butane BOG Compressors 2	Compressor 2 A (Online) Compressor 2 B (Standby)	250	78.2%	319.69
Lube oil pump motor of butane BOG compressor 1	Pump A (online) Pump B (standby) Pump C (Standby compressor) Pump D (standby compressor)	15.9	92.5%	17.19
Lube oil pump motor of butane BOG compressor 2	Pump A (online) Pump B (standby) Pump C (Standby compressor) Pump D (standby compressor)	15.9	92.5%	17.19
Motor space heater of butane BOG compressor 1	A (online) B (Standby)	0.025	100 %	0.025
Motor space heater of butane BOG compressor 2	A (online) B (Standby)	0.025	100 %	0.025
Oil separator heater 1	A (online) B (standby)	1.5	100 %	1.5
Oil separator heater 2	A (online) B (standby)	1.5	100 %	1.5
Condenser fan motor (VFD) 1	-	30.05	89.2 %	33.69
Condenser fan motor (VFD) 2	-	30.05	89.2 %	33.69
Condenser fan motor (M Feeder)1	-	30.05	93.9 %	32
Condenser fan motor (M Feeder) 2	-	30.05	93.9 %	32
Total loads		kW		808

3.3.2. Power load of the refrigeration system

This section analyzed and showed the power load of the refrigerated closed loop of pure propane, which is used for sub-cooling the butane BOG in the re-liquefaction process. The percentage 66.7% in Table 8 represents the consumed power load of the refrigeration system that used in the butane re-liquefaction process (the rest consumed power is used for another re-liquefaction process in the plant [17]). The calculation is described in Table 8. Based on Table 8 the electrical load of the refrigeration system in the existing butane re-liquefaction process = 582 KW (Eq. 2).

Table 8. Power load for refrigeration loop of pure propane.

Equipment	Status Online/Standby	Consumed load (KW) (L)	Motor efficiency μ (E)	power load ($\frac{L}{E}$)	Refrigeration power load used for butane re-liquefaction process
Ref compressor 1	Online	357	95.4 %	374.2	374.2 x 66.7%
Ref compressor 2	Online	357	95.4 %	374.2	374.2 x 66.7%
Ref compressor 3	Standby	-	-	-	-
Ref compressor 4	Standby	-	-	-	-
Lube oil pump motor 1	(A) Online	22.14	93.2 %	23.75	23.75 x 66.7%

Equipment	Status Online/Standby	Consumed load (KW) (L)	Motor efficiency μ (E)	power load $(\frac{L}{E})$	Refrigeration power load used for butane re-liquefaction process
	(B) Standby				
Motor space heater 1	(A) Online (B) Standby	0.025	100 %	0.025	0.025 x 66.7%
Lube oil pump motor 2	(A) Online (B) Standby	22.14	93.2 %	23.75	23.75 x 66.7%
Motor space heater 2	(A) Online (B) Standby	0.025	100 %	0.025	0.025 x 66.7%
Oil separator heater 1	-	1.5	100%	1.5	1.5 x 66.7%
Oil separator heater 2	-	1.5	100 %	1.5	1.5 x 66.7%
Condenser fan motor (VFD)	-	20	84.2 %	23.75	23.75 x 66.7%
Condenser fan motor (M Feeder)	-	37.07	93.8 %	39.52	39.52 x 66.7%
Oil cooler fan motor	-	8.73	91.3 %	9.56	9.56 x 66.7%
Total loads		kW			582

3.3.3. Power load of the modified butane BOG re-liquefaction process

The only new equipment in the modified butane re-liquefaction process is the recycle vapor screw compressor, its function is to compress the recycled gases from the economizer shell into the 2nd stage of the BOG screw compressor. Due to the unknown data of the compressor, assumptions will be applied to calculate the approximate power load of the new compressor. The flow rate of the butane vapors to the new screw compressor is equal 37% of the main feed stream.

1. The new screw compressor should have a standby compressor to be operated in case of upset conditions of the main compressor.
2. There are two tanks of butane, so the power load calculations will be doubled.

Based on the above 3 assumptions [18], the power load of butane modified re-liquefaction process will be assumed as the following: New compressor power load = 37% of BOG screw compressor power load. The overall calculation of the power load for the new compressor system in the butane modification re-liquefaction process is presented in Table 9. Table 9 results show that the power load for the new compression system in the modified butane BOG re-liquefaction process is equal to 249.3 KW (Eq. 3).

Table 9. Power load of modified butane re-liquefaction process.

Equipment	Status Online / Standby	Consumed load (KW), (L)	Motor efficiency μ, (E)	Total power load $(\frac{L}{E})$
Butane new compressors 1	A (online) B (standby)	250 x 37%	78.2%	118.28
Butane new compressors 2	A (online) B (standby)	250 x 37%	78.2%	118.28
Lube oil pump motor of butane new compressor 1	A (online) B (standby) C (Standby compressor) D (standby compressor)	15.9 x 37 %	92.5%	6.36
Lube oil pump motor of butane new compressor 2	A (online) B (standby) C (Standby compressor) D (standby compressor)	15.9 x 37 %	92.5%	6.36
Motor space heater of butane new compressor 1	A (online) B (standby)	0.025 x 37%	100 %	0.001
Motor space heater of butane new compressor 2	A (online) B (standby)	0.025 x 37%	100 %	0.001
Total loads		9,08		249.3

3.3.4. Power load saving percentage

Based on Tables 7, 8 and 9 total power saving is 24%. The result highlights a significant reduction in the power load consumption of the re-liquefaction process of butane BOG when replacing the refrigeration system of the refrigerant with an economizer; the power load consumption of the butane re-liquefaction process lowered from 1390 kW to 1057.3 kW**,** saves nearly 24 % of the electricity consumed, which reflects the importance of the enhancement.

4. Conclusion

The study's findings highlight how significant energy conservation is in the re-liquefaction process. Which is utilized to handle the problem that results from the temperature differential between the atmosphere and the liquid inside the butane tank. Also, it shows that the existing re-liquefaction process of butane BOG can be replaced with a new modification by splitting the inlet stream of the economizer into 2 streams, one acting as a cold stream after being broken down by the throttling valve (shell side) and the other as a hot stream (tube side). Also, it gives nearly identical operating parameters to the existing process, which means it can operate smoothly. By eliminating the propane refrigeration loop, the power consumed lowered by 24%. The resulted splitting ratio of the butane which represents 37 % for Hot C_4 and 63 % achieve the required storage temperature of the butane without exceeding the tank design temperature.

Also, the simulation results of the date shows there is no major difference between the existing process and the modified process. The proposed modification not only simplifies the re-liquefaction process but also reduces the complexity of the overall system. However, the potential drawback is the increase in operational time, as a portion of the split stream is recycled, which may slightly delay the overall process. Despite this, the advantages in terms of cost-effectiveness, energy efficiency, and system simplification affirm the feasibility and value of the proposed modification for industrial applications.

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