

An Exergy Study of a Liquefied Petroleum Gas Sweetening Unit of a Refinery Plant: A Real Starting Up Plant

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Abstract

A liquefied petroleum gas (LPG) is produced from a refinery plant that started its official production in 2020. The LPG is directed to the LPG absorber section where it is treated with lean amine (LA) to remove any H₂S traces before selling to the market. The LPG absorber section was simulated with HYSYS V.11. Then an exergy study was conducted on different equipment. While energy is transformed from a form to another, exergy is destructed in an irreversible process. The total exergy is equal to physical and chemical exergies. Physical exergy is calculated through HYSYS and chemical exergy is calculated through a series of equations embedded in excel. The LPG absorber showed the highest destruction rate of 62.36 kW and a percentage share more than 78% of total destruction. The total destruction rate is 79.52 kW. The overall efficiency of exergy is 99.98%. An actual case study about a problem that happened in the section after the starting up is explained. Contamination of the LPG in the product tank was found. The root causes and corrective actions were mentioned. The study was compared with two different exergy studies performed in the same refinery plant by the same authors. The comparison found some similar relations between equipment. The columns in the three studies showed the highest destruction rates with a percentage share of more than 78%. The pumps showed the lowest destruction rates in their units with a percentage share of less than 1%.

Keywords: Energy; Exergy; Liquefied petroleum gas; Refinery.

1. Introduction

Natural gas contains some acidic toxic compounds as hydrogen sulphide [1]. H₂S is an acidic toxic gas causing severe problems to health and equipment [2-3]. Sulphur Recovery plants (SRU) produce Sulphur from H₂S and prevent any acidic emissions against environmental regulations [4-8]. Recently most of the plants use the modified Claus process [9]. The aqueous amines as Methyl Diethanolamine (MDEA) and DEA (diethanolamine) are considered as chemical solvents [10].

Aqueous solutions of MDEA and DEA are openly used in the industrial treatment, especially for acid gas streams that contain H₂S and CO₂. MDEA has high selectivity for H₂S rather than CO₂, so in the presence of both acid gases, MDEA is used to absorb H₂S and desorb CO₂, while DEA is usually used if H₂S is present individually [11-14]. Optimum energy consumption is essential for community energy development [15].

Although energy is conserved in any process, another point of view for energy is called exergy, which can be destroyed by irreversible processes. Exergy is the work or power produced by the use of energy concerning the natural environment. Some exergy components such as kinetic and potential components are similar to those for energy. The exergy can also be broken down into chemical and physical exergy components. In comparison with the chemical and physical exergies, the lowest values for the kinetic and potential energies can be neglected. The chemical exergy is always higher than the physical exergy [16]. Chemical and

physical exergies are considered to be the maximum amounts of work that can be obtained from a substance. The difference between them is that for chemical exergy, the substance is changed from the environment state to the dead state only by exchange and heat transfer with the environment. For physical exergy, the substance is changed from its initial state to the environment state only by thermal interaction with the environment [17].

Some researchers concerned their studies about exergy. Ibrahim *et al.* [8] performed an exergy study on an MDEA scrubber unit used for sour gas sweetening. The exergy destruction rates, the destruction efficiency and the percentage share of the destruction of each equipment was calculated [18].

Ibrahim *et al.* performed an exergy study on an Amine regeneration unit used to regenerate the rich amine with H_2S to lean amine that is recycled again to the units for gas sweetening [19].

Literature survey did not find any exergy studies performed on liquified petroleum gas (LPG) sweetening unit. Therefore, an exergy study was performed for this unit. The exergy destruction rates, the destruction efficiency and the percentage share of the destruction of each equipment was calculated. A comparison was conducted between the results of this study and the results of the two previous studies performed by Ibrahim *et al.* [8]. The comparison elaborates some relations between equipment. The amine scrubber unit, the amine regeneration unit and the LPG sweetening unit are parts from a refinery plant that started its official production at 2020.

The refinery produces many strategic products. One of the products is LPG. The sour LPG to the LPG amine absorber section consists of the mixed stream of sour LPG produced from NHT unit and HCU unit. The sweet LPG has the following specifications: (10 wt-ppm H_2S , 10 wt-ppm free water and 1 wt-ppm mercaptan) as maximum limits.

2. LPG amine absorber section process description

The LPG amine absorber is designed to eliminate hydrogen sulfide (H_2S) in the sour LPG generated from naphtha hydrotreating unit (NHT) and hydrocracking unit (HCU). The sour LPG conditions are 18kg/cm²g and 40°C and contain 4 wt% of hydrogen sulfide. The combined sour LPG from NHT and HCU fed to the bottom of LPG amine absorber and flows upward thus H_2S will gradually be removed by contacting with downward lean amine stream. The LPG amine absorber is a liquid-liquid contactor with three packing beds. This absorber is designed to guarantee H_2S content in treated LPG to satisfy the specification in the Contract; maximum 10wtppm of H_2S in treated LPG. The LPG from the absorber is transferred to the Amine Separation Drum, where any carried over liquid amine is separated from liquid phase LPG and will be settled down into the boot. The LPG stream free of amine is then contacted with a caustic solution with (6.9wt% of NaOH) in the caustic wash drum to eliminate a trace of hydrogen sulfide. The sweet LPG treated with caustic in the caustic wash drum is further mixed with the wash water stream and sent to the water wash separator, where the maximum 3wt% of caustic solution carried - over is removed. The sweet LPG is then sent to LPG coalescer where a small amount of water entrained is eliminated. Then the sweet LPG is directed to a de-ethanizer Unit and then to LPG product tanks (TK-A, TK-B). The main purpose of de-ethanizer unit (DEU) is to produce LPG product which meets the required specifications while achieving overall C3 wt recovery more than 75%.

3. Materials and methods

3.1. Simulation step

LPG absorber section is simulated using Aspen HYSYS software V.11 and simulation output that describes the plant is shown in Figure 1 with the feed characteristics tabulated in Table 1

The simulation of the LPG absorber section contains some tips, that shall be carefully considered. Some equipment is not selected as the normal selection. Two packages are used in the same simulation and not one package. The simulation started with a package named "Acid Gas-Liquid Treating". This package is suitable for the components used as DEA and LPG components.

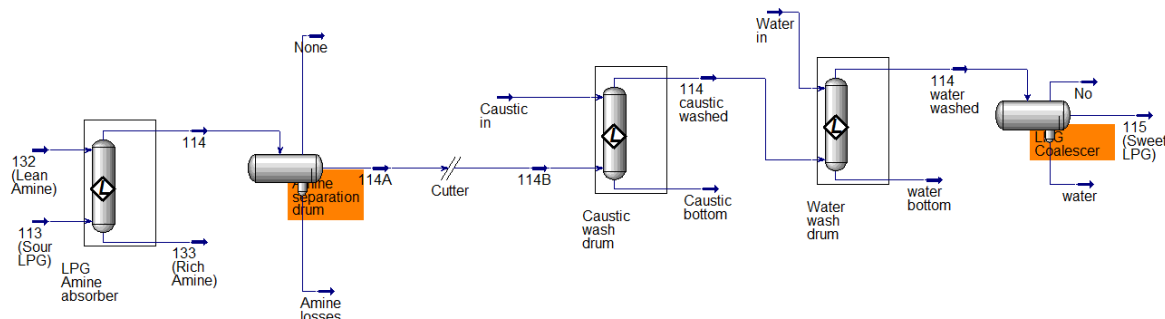


Figure 1. LPG absorber section

Table 1. Feed characteristics

Stream	Sour LPG to absorber	Lean amine to absorber
Stream number	113	132
Temperature	40	46
Pressure	18	26
Mass flow	16531	31270
Component	Total weight component fraction	
DEA	0.00	0.25
Water	0.00	0.75
H ₂ S	0.04	0.00
Ethane	0.02	0.00
Propane	0.37	0.00
i-butane	0.25	0.00
n-Butane	0.32	0.00

3.2. Simulation criteria

The LPG amine absorber is simulated as "liquid-liquid extractor" and not as normal absorber. The purpose is all components inlet and outlet from the LPG absorber are in the liquid phase. So, it cannot be simulated as a normal absorber that is suitable for the gas phase and liquid phase. The best practice to use suitable equipment without confusing is to see the HYSYS examples existing in the program. They approximately have examples from different units and industries. The amine separation drum is simulated with "Acid Gas-Liquid Treating" package as three-phase separator and not as normal two-phase separator. The purpose is two-phase separator is suitable to the separation of liquid existing in a gas phase while the inlet to the separator is liquid LPG. All the streams existing till stream 114A are simulated with the same package "Acid Gas-Liquid Treating". The caustic wash drum inlet streams are not able to be solved with the previous package. The package used is "Acid Gas – Caustic wash". This package exists from HYSYS V.11 and was not existing in the previous HYSYS versions. It is not possible to use two different packages without the usage of a cutter as shown in figure. Stream 114A is the same as stream 114B but stream 114B uses the "Acid Gas – Caustic wash" package. Stream (caustic in) uses also the same package. The equipment of (caustic wash drum) used the first selected package "liquid-liquid extractor". All streams and equipment after the caustic wash drum reused to the "Acid Gas-Liquid Treating" package. The Wash water drum is simulated as "liquid-liquid extractor" and not as normal absorber because all the inlet and

outlet components are liquids. The LPG coalescer is simulated as three-phase separator and not as a two-phase separator because no gas phase exists.

3.3. Validation step

Validation is done by comparing industrial data with simulation results. The two streams examples selected from the simulation are 133 (rich amine from absorber) and sweet LPG product as the purpose of the unit is the LPG sweetening.

3.4. Exergy calculations

The physical and chemical exergy values were calculated based on a sequence that used the following equations:

$$\text{Physical exergy} = (H - H_0) - T_0(S - S_0) \quad (1)$$

$$\text{Chemical exergy} = \sum \text{ex}^0_{\text{che}} + RT^0 \sum x_i \ln x_i \quad (2)$$

$$\text{Destruction exergy} = \sum m_i e_i - \sum m_e e_e \quad (3)$$

where x_i is the mole fraction of species "i" in the mixture, and ex^0_{che} is the standard chemical exergy found directly from tables or calculated through other methods.

The terms H , S , T , R , and 0 represent the enthalpy, entropy, temperature, global constant of gases, and standard condition, respectively. The chemical exergy was not ignored because its value was comparable to or higher than that of the physical exergy; therefore, the sum of the physical and chemical exergies was used as the total exergy.

$$E^{\text{ph}} = m \cdot e^{\text{ph}} \quad (4)$$

$$E^{\text{ch}} = m \cdot e^{\text{ch}} \quad (5)$$

The exergy of the material stream was also calculated by the summation of the physical and chemical exergy values for each stream.

$$E = E^{\text{ph}} + E^{\text{ch}} \quad (6)$$

The exergy efficiency of the system components was defined as the ratio of the outlet exergy value to the inlet exergy value for each component, where the exergy efficiency of the entire system represented the percentage of inlet exergy that was converted to the outlet in the system [17,18,19].

Table 2 represents the standard chemical exergy values for the components used in the study. The pentane has the highest value of 3461.30 kJ/mol, then butane with a value of 2804.20 kJ/mol, then NH_3 with a value of 337.90 kJ/mol. It is important to know that the standard chemical exergy value of $\text{H}_2\text{O}_{(\text{L})}$ is different than $\text{H}_2\text{O}_{(\text{V})}$. It is mandatory to check the actual status of water to select the proper value of ex^0_{che} .

Table 2. Standard chemical exergy values for the components used in the study

Components	Standard chemical exergy (kJ/mol)	Components	Standard chemical exergy (kJ/mol)
DEA	2718.10	Ethane	1495.00
Water _(L)	0.90	Propane	2152.80
H ₂	236.09	i-butane	2804.20
NH ₃	337.90	n-Butane	2804.20
H ₂ S	812.00	i-pentane	3461.30
CO ₂	19.48	Pentane	3461.30
N ₂	0.72	Hexane	4134.59
O ₂	3.97	NaOH	74.90
Methane	831.20		

3.5. Exergy destruction calculation equations for equipment

The exergy in, exergy out, and exergy destruction equations based on the equipment types in the studied unit are presented in Table 3.

Table 3. Exergy calculations

Equipment	Exergy in	Exergy Out	Exergy destruction
LPG Amine ab-sorber	$E_{132} + E_{113}$	$E_{114} + E_{133}$	$E_{132} + E_{113} - E_{114} - E_{133}$
Amine separation drum	E_{114}	$E_{114A} + E_{\text{Amine losses}}$	$E_{114} - E_{114A} - E_{\text{Amine losses}}$
Caustic wash drum	$E_{\text{caustic in}} + E_{114B}$	$E_{114-\text{caustic washed}} + E_{\text{caustic bottom}}$	$E_{\text{caustic in}} + E_{114B} - E_{114-\text{caustic washed}} - E_{\text{caustic bottom}}$
Water wash drum	$E_{\text{water-in}} + E_{114-\text{caustic washed}}$	$E_{114(\text{water washed})} + E_{\text{water bottom}}$	$E_{\text{water-in}} + E_{114-\text{caustic washed}} - E_{114-\text{water washed}} - E_{\text{water bottom}}$
LPG coalescer	$E_{114(\text{water washed})}$	$E_{115(\text{sweet LPG})} + E_{\text{water}}$	$E_{114(\text{water washed})} - E_{115(\text{sweet LPG})} - E_{\text{water}}$

4. Results and discussion

4.1. Validation results

The validation results are shown in Table 4 we can see clearly that industrial results and simulation results are almost closed. Authors experience in different simulations observed that the key factor in simulation is the suitable selection of package that gives the ability of high accuracy results. In this simulation, the highest deviation exists in the temperature of stream 133 with a deviation of 3.53%). Approximately no deviation exists in the composition of components. The (liquid-liquid extractor and Acid Gas-Liquid Treating) are the selected two packages for this case.

Table 4. Simulation validation

Stream	Rich Amine from LPG ab-sorber			Sweet LPG		
	133			115		
	Design	Simulation	Dev%	Design	Simulation	Dev%
Temperature	51.7	49.9	3.53	46.5	46.1	0.85
Pressure	17.6	17.6	0.00	13.5	13.5	0.00
Mass flow	31947.4	31950.8	-0.01	15849	15718.7	0.82
Component mass fraction						
DEA	0.25	0.24	0.19	0.00	0.00	0.00
Water	0.73	0.73	0.04	0.00	0.00	0.00
H ₂	0.00	0.00	0.00	0.00	0.00	0.00
NH ₃	0.00	0.00	0.00	0.00	0.00	0.00
H ₂ S	0.02	0.02	0.00	0.00	0.00	0.00
CO ₂	0.00	0.00	0.00	0.00	0.00	0.00
N ₂	0.00	0.00	0.00	0.00	0.00	0.00
O ₂	0.00	0.00	0.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00	0.00
Ethane	0.00	0.00	0.00	0.02	0.02	0.00
Propane	0.00	0.00	0.00	0.38	0.38	0.00
i-butane	0.00	0.00	0.00	0.26	0.26	0.00
n-Butane	0.00	0.00	0.00	0.33	0.34	-0.60
i-pentane	0.00	0.00	0.00	0.00	0.00	0.00
n-Pentane	0.00	0.00	0.00	0.00	0.00	0.00
Hexane	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00

4.2. Physical and chemical exergy calculations for streams

The physical and chemical exergy calculations for streams are calculated based on equations of section 3.4 (Exergy Calculations), HYSYS calculated molar flow rates, mass flow rates and mass exergy for streams are presented in Table 5.

Physical exergy, chemical exergy and total exergy calculations for streams are calculated based on equations in section 3.4 (Exergy Calculations) and gathered together in Table 6.

Table 5. HYSYS calculations for streams

Stream number	Molar flow (kmol/h)	Mass flow (kg/h)	Mass exergy (kJ/kg)
132 (Lean Amine)	1375.1	31270.0	6.9
113 (Sour LPG)	331.3	16531.0	85.8
114	311.4	15850.2	79.9
133	1395.0	31950.8	6.5
114A	311.4	15850.2	79.8
Amine losses	0.0	0.0	79.8
114B	311.4	15850.2	79.8
Caustic In	722.3	13525.0	4.5
114 (Caustic washed)	308.6	15723.4	79.5
Caustic bottom	725.2	13651.8	5.2
Water In	675.9	12176.5	4.9
114 (Caustic washed)	308.6	15723.4	79.5
114 (Water washed)	308.5	15718.7	79.2
Water bottom	676.0	12181.3	4.7
115 (Sweet LPG)	308.5	15718.7	79.1
Water	0.0	0.0	79.1

Table 6. Streams exergies

Stream number	E_{ph} (kW)	E_{ch} (kW)	E_{tot} (kW)	% share of E_{ph} in E_{tot}
132 (Lean Amine)	59.8	56541.0	56600.7	99.9
113 (Sour LPG)	394.0	217771.3	218165.4	99.8
114	351.8	213196.4	213548.2	99.8
133	58.1	61097.5	61155.5	99.9
114A	351.4	213196.4	213547.8	99.8
Amine losses	0.0	0.0	0.0	0.0
114B	351.4	211482.9	211834.4	99.8
Caustic In	16.9	589.2	606.1	97.2
114 (Caustic washed)	347.0	211482.9	211829.9	99.8
Caustic bottom	19.7	2290.4	2310.1	99.1
Water In	16.5	169.0	185.5	91.1
114 (Caustic washed)	347.0	211482.9	211829.9	99.8
114 (Water washed)	345.7	211416.2	211762.0	99.8
Water bottom	345.4	211416.2	211761.6	99.8
115 (Sweet LPG)	345.4	211416.2	211761.6	99.8
Water	0.0	0.0	0.0	0.0

4.3. Exergy destruction and exergy efficiency of equipment

Exergy destruction calculations of equipment are calculated based on the equations in Table 3 exergy efficiencies of equipment and percentage share of destruction are calculated based on section 3.4 Exergy Calculations and presented in Table 7.

The highest destruction rate is observed in LPG amine absorber with a value of 62.36 kW and a percentage share of 78.42% of total destruction, then Caustic wash drum with a value of 13.88 kW and a percentage share of 17.46% of total destruction. The percentage share of destruction is shown in Figure 2. The overall efficiency of exergy is 99.88%.

Table 7. Exergy destruction and exergy efficiency results

Equipment	Destructed energy (kW)	Percentage share	Exergy efficiency (%)
LPG amine absorber	62.36	78.42	99.98
Caustic wash drum	13.88	17.46	99.99
Water wash drum	2.51	3.16	100.00
Amine separation drum	0.39	0.49	100.00
LPG coalescer	0.38	0.48	100.00
Sum	79.52	100.00	99.98

4.4. High stream exergies and low stream exergies

It was observed from Table 6 that some exergies calculated for streams exceed others by significant values. We need to take 113 (sour LPG) stream and 132 (lean amine) as examples. The total exergy is the summation of the physical and chemical exergy. In most cases, the chemical exergy value is extremely higher than the physical exergy values. The composition of the components is the main influencer in E_{ch} calculated by the equation ($\sum x_i ex_{che}^0 + RT_0 \sum x_i \ln x_i$). 113 (Sour LPG) is composed of several components with high standard chemical exergies as (ethane, propane, i-butane, and n-butane) as shown in Table 8. stream 132 (Lean amine) is composed from 0.9 mole fraction of water that has low ex_{che}^0 of 0.90 kJ/mol. The values of exergies of stream 113 and stream 132 are 218165.4 kw and 56600.7 kw respectively.

Table 8. Stream 113 and 132 compositions

Components	Standard chemical exergy (kJ/mol)	113 (sour LPG)	132 (lean amine)
		Composition (mole fraction) x_i	Composition (mole fraction) x_i
DEA	2718.10	0.00	0.05
Water	0.90	0.00	0.94
H ₂	236.09	0.00	0.00
NH ₃	337.90	0.00	0.00
H ₂ S	812.00	0.06	0.00
CO ₂	19.48	0.00	0.00
N ₂	0.72	0.00	0.00
O ₂	3.97	0.00	0.00
Methane	831.20	0.00	0.00
Ethane	1495.00	0.03	0.00
Propane	2152.80	0.42	0.00
i-butane	2804.20	0.22	0.00
n-Butane	2804.20	0.27	0.00
i-pentane	3461.30	0.00	0.00
Pentane	3461.30	0.00	0.00
Hexane	4134.59	0.00	0.00
NaOH	74.90	0.00	0.00

The MDEA standard chemical exergy has extremely higher than water. ex_{che}^0 for (MDEA, and H₂O_L) are as follows (3392.50 KJ/kmol, and 0.90 KJ/kmol respectively). Consequently,

the Chemical exergy in 45% concentration is extremely higher than 22% concentration). The difference between both compositions in mole fraction with ex_{che}^0 is shown in Table 8.

4.5. Comparison between three units exergy calculations

Ibrahim *et.al.* [8] performed an exergy calculation on an amine scrubber unit using MDEA solvent on two different concentrations (45% and 22%) and performed another study on amine regeneration using DEA solvent on two different concentrations (25 and 20%) [18-19]. The two previous studies were compared with the current study. Table 9 shows columns values for the three units.

Table 9. Columns exergy destruction in three units

Columns (regenerator or absorber)				
Unit	Destructed energy (KW)	Total unit destruction (kW)	% share of destruction in its unit	Exergy efficiency
Scrubber unit (MDEA 45%)	1937.89	2404.85	80.58	99.36
Scrubber unit (MDEA 22%)	1494.27	1908.86	78.28	98.73
ARU unit (DEA 25%)	13459.73	16907.45	79.61	98.64
ARU unit (DEA 20%)	15571.65	18964.53	82.11	98.12
LPG	62.36	79.52	78.42	99.98

The percentage share of destruction for columns in the three studies represents the highest destruction rates with a value greater than 78% in all the units. The pumps showed the lowest percentage share of destruction in their units with values of less than 1% as shown in Table 10. The exergy destruction rate shall be related to exergy efficiency. The exergy destruction of LPG absorber is only 62.36 kW with an exergy efficiency of 99.98%, while the exergy destruction for regenerator DEA concentration 20% is 15571.65 kW with exergy efficiency 98.12%. It is not possible to compare only the two numbers (62.36 kW and 15571.65kW) by values without their exergy efficiency considerations. This will give the wrong indication.

Table 10. Pumps exergy destruction in two units

Pumps			
Unit	Destructed energy (KW)	Total unit destruction (kW)	% Share of destruction in its unit
Scrubber unit (MDEA 45%)	5.01	2404.85	0.11
Scrubber unit (MDEA 22%)	4.06	1908.86	0.11
ARU unit (DEA 25%)	198.41	16907.45	0.59
ARU unit (DEA 20%)	198.95	18964.53	0.53

4.6. LPG section troubleshooting case study

On 25th October 2020 at 7:31 AM, a fluctuation on LPG Tank TK-A level was detected. Also, DEU LPG product sample cylinder showed high contamination with liquid, when it was purged before analysis. As a result, LPG pumping out from the tank TKA to customer was stopped. Then, instrumentation team was called to inspect the problems related to the level transmitters in caustic and water wash drums.

4.6.1. Problem sequence

At 3:53 PM, the circulation water flow in wash water drum was stopped, the drum level control was manually opened letting the contaminated water to be flushed. Then, a clean condensate make-up was added, and the water circulation was re-established, seizing the problem of carryover from repeating.

At 4:20 PM, the produced LPG was transferred to LPG Tank TK-B, putting its calibration plan on hold. On 26th October, the contamination liquid level accumulated in LPG Tank TK-A started to be drained.

There is a persistent problem related to high fluctuations in feed rates to LPG absorber, affecting its operating performance badly. However, the problem of contamination was initiated by a malfunction of caustic wash drum level transmitter and wash water drum level transmitter.

System Applications Products (SAP) notifications were issued on 20th October, to check the malfunctioned transmitters as they did not match, awaiting maintenance proper action.

Firstly, the caustic wash drum level control valve was passing and manually isolated, coincidentally clean condensate make-up flow was in service for a long time, accordingly during the upset the drum level increased rapidly, leaving less residence time for caustic to be separated from LPG.

As a result of the above, the caustic solution was carried over from caustic wash drum to water wash drum, operating with malfunctioned level transmitters accordingly, the water level was not detected properly.

Then, a sudden increase was noticed in the coalescer drum boot level, indicating that a high load of caustic & water carried over from the upstream drums. This high load of carried over liquids could be handled neither in the coalescer drum nor in DEU feed surge drum boot level, and contamination liquids made its way to the LPG tank TK-A.

4.6.2. Corrective actions

To avoid reoccurrence of this incident, it is recommended to perform the following actions:

- Instrumentation to check the malfunctioned level transmitters in the LPG washing section and LPG feed surge drum boot.
- (pH indicator) need to be fixed to continuously monitor caustic solution pH.
- caustic wash drum control valve to be fixed to prevent the recurrence of caustic overflow to wash water drum.
- Instrumentation to tune the upstream NHT & HCU sour LPG control valves to decrease feed rate fluctuations to LPG absorber.

5. Conclusions

The LPG produced from a refinery plant is sweetened in an LPG absorber section unit. The refinery started its official production in 2020. The main calculations concern on exergy destruction, exergy efficiency and percentage share of the destruction of each equipment. The total exergy destruction was 79.52 kW. The highest destruction rate is observed in LPG amine absorber with a value of 62.36 kW and a percentage share of 78.42% of total destruction, then Caustic wash drum with a value of 13.88 kW and a percentage share of 17.46% of total destruction. The overall efficiency of exergy is 99.98%. The LPG was found contaminated with liquid in the product tank. The problem was investigated and it was found some problems in the level transmitters in the LPG sweetening unit. The problem was solved. The sequence that happened and the corrective actions were explained. Two exergy studies were performed before in the refinery by the same authors in an amine scrubber unit using MDEA solution and in a DEA amine regeneration unit. A comparison was performed between these two studies and the current study. Some equipment has a similar relationship. The columns showed the highest percentage share in the three studies with values of more than 78%. For Amine scrubber unit when the used MDEA amine concentration was 45 wt%, the percentage share was 80.58%, when the used MDEA amine concentration was 22 wt% the percentage share was

78.28%. For Amine regeneration unit when the used DEA amine concentration was 25 wt%, the percentage share was 79.61%, when the used DEA amine concentration was 22 wt% the percentage share was 82.11%. The LPG absorber percentage share is 78.42%. The pimps showed the lowest percentage share of values lower than 1%. The exergy destruction rate shall be related to exergy efficiency. The exergy destruction of LPG absorber is only 62.36 kW with an exergy efficiency of 99.98%, while the exergy destruction for regenerator DEA concentration 20% is 15571.65 kW with an exergy efficiency of 98.12%. It is not possible to compare only the two numbers (62.36 kW and 15571.65kW) by values without their exergies efficiencies considerations.

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List of abbreviations

DEA	diethanolamine
DEU	Deethanizer Unit
HCU	Hydrocracking Unit
LA	Lean Amine
LPG	Liquified Petroleum Gas
MDEA	methyl diethanolamine
NHT	Naphtha Hydrotreating Unit
P	Pump
RA	Rich Amine
SAP	System Applications Products
TK	Tank

Nomenclature

e	specific exergy)
E	exergy rate
ε	exergy efficiency
H	enthalpy
\dot{m}	mass rate
S	entropy
T	temperature
R	Gas constant

Subscripts

che	chemical
e	exit
i	Inlet, specie in a mixture
0	Standard conditions

Superscripts

ch	chemical
ph	physical
0	Standard conditions

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