Process Simulation and Exergy Analysis of a Mercaptan Oxidation Unit in a Latin American Refinery

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ABSTRACT: In this work, the mercaptan oxidation unit of an oil and gas refinery was simulated and assessed using exergy and parametric sensitivity analysis to identify opportunities for improvement from a technical and energy point of view. The process simulation was performed using Aspen HYSYS V10.1 to obtain extended mass and energy balances. The simulation results were validated with the data available in the literature. The effects of operating conditions on technical performance were analyzed via parametric analysis. The exergy analysis was applied to two case studies: the base case and the resulting case from technical improvements. The global exergy efficiency, irreversibilities, exergy of utilities, and efficiencies per stage were calculated to map process equipment with the highest losses of exergy. A comparison between both base and alternative cases was introduced in order to analyze increments in exergy efficiencies. An exergy efficiency of 84.21% was found for the base case, while for the alternative case after applying parametric sensitivity, it was calculated to be 81.95%. This decrease by 2.26% was attributed to the increase of irreversibilities and exergy of wastes to achieve a product with better quality standards.

1. INTRODUCTION

Minimizing climate changes and increasing the energy accessibility has become one of the main challenges of the last decades. There are some limitations for the oil and gas industries to increase energy efficiency because it is quite difficult to evaluate technical improvements of existing plants under continuous operation. In this context, the process simulation appears as an essential tool to analyze the performance of any units. Analyzing possible changes in operating parameters of the system offers several advantages as no real plant experimentation is needed, and consequently, the production capacity and product quality are not affected.

To manage energy resources more sustainably, it is imperative to improve the energetic efficiency of industrial processes such as units of oil and gas refineries. To this end, the application of computer-aided tools provides useful information in the assessment of energy performance of units. For example, the exergy analysis allows understanding how the energy is used, and where are the main losses of potential work. This is an effective method based to obtain a measurement of inefficiency sources in a system; thus, actions can be taken to reduce exergy loss of the system.

The Universal Oil Products (UOP) company developed the mercaptan oxidation (MEROX) technology by 1959 by the sweetening of crude oil distillates such as liquefied petroleum gas (LPG), naphthas, jet fuel, and gasoline, along with the extraction of mercaptans (RSH). This process is characterized by the catalytic oxidation of RSH and the recycling of caustic soda. The MEROX has become one of the most successful technologies in the oil and gas industry. This technology attempts to convert mercaptans into disulfides (RSSR) in the presence of caustic soda via oxidation in an aqueous environment. Such disulfides are easier to separate from the product because they form an oily phase lighter than water. It is considered as an efficient and economic alternative to treat petroleum fractions with sulfur content above the standards. The main reactions taking place in the MEROX unit are the following:

\[ \text{RSH} + \text{NaOH} \rightarrow \text{RSNa} + \text{H}_2\text{O} \]  

(R1)

\[ \text{RSH} + \frac{1}{4}\text{O}_2 + \frac{1}{2}\text{H}_2\text{O} \rightarrow \text{RSSR} + \text{NaOH} \]  

(R2)

According to previous works, the reaction of mercaptans oxidation is slow in the absence of a catalyst, especially for high-molecular weight compounds. This issue has motivated the search for modifications in operating conditions and reaction atmosphere at lab scale; for example, Leitão and Rodrigues studied the kinetics of n-butyl mercaptan during oxidation in air in an isobaric fixed bed reactor. They found an...
increase in the reaction rate with increasing temperatures, using a catalyst supported by activated carbon. Reza et al.\textsuperscript{12} also evaluated the kinetics of oxidation of ethyl, normal propyl, isopropyl, and isobutyl mercaptans in the presence of MEROX catalysts showing a first-order reaction.

To date, no contributions are found in the literature regarding the process simulation and exergy analysis of MEROX units in oil and gas industries, showing a knowledge gap to fulfill. This work addresses for the first time the evaluation of energetic performance of MEROX process using exergy analysis and parametric sensitivity analysis.

2. RESULTS AND DISCUSSION

2.1. Process Simulation. Figure 1a,b show the simulation of the mercaptans oxidation unit, where we used extended NRTL with SRK for the vapor phase as mentioned in the Methodology Section. The plant has the following feed streams: LPG with 107.753 lb/h at 100 °F and 219.7 psia, a 25% amine [diethanolamine (DEA)] solution with 46.123,99 lb/h at 129 °F and 354.7 psia, and a caustic soda solution with 716.8 lb/h at 90 °F and 200 psia.

A 10-stage absorber (D-3201) was used during process simulation, in which the LPG and lean amine contact to drag undesired compounds such as H\textsubscript{2}S in the amine stream. The top stream (016) is cooled in the heat exchanger E-3203 and then sent to D-2; there, the LPG is washed with water to
remove any remaining trace of amine. A caustic washing took place in the D-03A to remove mercaptans and the remaining H2S in the LPG stream. This stage was simulated with a component splitter. The treated LPG is fed into the caustic extractor D-03B, which was modeled as an eight-stage liquid−liquid extractor. In this equipment, most of the mercaptans and sulfur compounds can be removed using regenerated caustic soda from D-09. Then, the LPG stream is sent to the drum D-06, where carbonyl sulfide (COS) is removed using a monoethanolamine (MEA)−NaOH solution. The resulting stream goes through D-07 drum that was modeled as a component splitter where any traces of MEA−NaOH solution that could have been dragged by the LPG is removed.

Through the final stages of the process, the spent caustic soda is sent to the oxidizing drum D-3208 that was simulated as a conversion reactor. This type of reactor was selected owing to the unavailability of complete kinetics for all the reactions taking place for the oxidation of mercaptans with different molecular weights. A conversion reactor requires the conversion fraction for each reaction taking place, which is well-known from the literature and oil and gas companies. The reactor effluents go to the D-10 drum, simulated as a three-phase separator. In this drum, the air, disulfides, and regenerated soda are separated. The latter stream is sent to D-09 drum, where the lean soda is mixed with heavy naphtha to remove remaining disulfides. Finally, the regenerated soda is sent back to D-03A/B.

Table 1 summarizes the mass balance of main process streams for the MEROX unit. A comparison of simulation results with real data validated the modeling of this process via Aspen Plus software. This process data provided by the software is useful to quantify the energy performance through computer-aided exergy analysis.

### 2.2. Parametric Sensitivity Analysis

#### 2.2.1. LPG Feed and Air Effects on the Disulfides at the Oxidizing Drum Exit

Figure 2 shows the relationship between the feed flow of LPG and the quantity of disulfides in the oxidizing drum D-3208. There was an increase in the disulfide flow rate as the LPG feed and air increased.
feed rate increased because of the higher amount of mercaptans entering being converted into disulfides; however, this trend is observed up to 106,500 lb/h of LPG; after this value, there is a decrease assigned to the insufficiency in the air entering the reactor to maintain the conversion rate for the increased LPG feed.

Air is supplied to provide the oxygen to the oxidizing drum where conversion of mercaptans into disulfides takes place, the latter being less harmful to the environment and soluble in hydrocarbons. Despite the conversion methods proposed for MEROX in the open literature, the oxidation with molecular oxygen at room temperature and in presence of an aqueous base is the most common technology, in which the mercaptide ion reacts with oxygen; thus, free radicals are generated and then dimerized to obtain disulfides.

Figure 3 shows the airflow versus disulfide flow at the oxidizing drum’s exit, a behavior that matches the one explained above, where it is shown that the increment in the presence of air contributes to the fast conversion of mercaptans to disulfides.

2.2.2. LPG Flow Effect on the COS Flow at the Sedimentation Drum’s Exit. Figure 4 depicts the effect of the LPG feed flow on the COS flow at the sedimentation drum’s exit, where an increasing linear tendency is observed as the feed flow rises and its concentration remains constant.

2.2.3. DEA Fraction Effect on Absorbed H2S. Figure 5 illustrates the relationship between the DEA fraction and absorbed H2S, which shows that the absorbed H2S rises as the amine’s fraction does because the efficiency of the operation increases based on how chemical absorption reactions of these processes are carried out.

2.3. Exergy Analysis. Exergy analysis was carried out for the base case and the alternative case. The parametric sensitivity analysis showed that the most critical variable was the amine fraction because it is possible to remove higher amounts of sulfur compounds from the LPG feed stream when it increases, which leads to a better-quality product.

As mentioned in Section 4.1, the physical exergies were calculated during the simulation, and the chemical exergies of the different compounds that are involved in the process were gathered from the literature as shown in Table 2.

Table 2. Chemical Exergies of Compounds Involved in the Process

| components     | molecular weight (kg/kmol) | chemical exergy (kJ/mol) |
|----------------|----------------------------|--------------------------|
| H2O (liquid)   | 18                         | 0.9                      |
| H2O (vapor)    | 18                         | 9.5                      |
| H2S            | 34.08                      | 812                      |
| n-pentane      | 72.15                      | 3461.3                   |
| n-butane       | 58.12                      | 2804.2                   |
| propane        | 44.17                      | 2152.8                   |
| propene        | 42.08                      | 2002.7                   |
| N2             | 28.01                      | 0.72                     |
| O2             | 32                         | 3.97                     |
| NaOH           | 40                         | 74.9                     |

The chemical exergies that were not found in literature were calculated using eq 1.

\[
E_i = \Delta G_{F_0} + \sum_i N_i \epsilon_i
\]

where \(E_i\) is the total chemical exergy of a compound, \(\Delta G_{F_0}\) is the standard Gibbs energy for formation of the substance, \(N_i\) is the number of atoms in element \(i\), and \(\epsilon_i\) is the standard chemical exergy of each elemental compound.

Chemical exergies calculated using eq 1 are shown in Table 3.

2.3.1. Base Case Exergy Analysis. Table 4 shows the results for chemical, physical, and total mass exergies for each stream of the process. Chemical exergies were calculated by adding the ones from the compounds involved in each stream, the
Table 3. Calculated Chemical Exergies

| components | molecular weight (kg/kmol) | chemical exergy (kJ/mol) |
|------------|---------------------------|-------------------------|
| i-butane   | 58.12                     | 4931.2                  |
| i-butene   | 58.12                     | 4347.7                  |
| E-disulphide | 122.2                    | 6193.8                  |
| COS        | 60.07                     | 1087.5                  |
| E-mercaptan | 62.12                     | 3412.4                  |
| DEAmine    | 105.1                     | 5550.4                  |
| MEAmine    | 3268.8                    | 61.1                    |
| i-pentane  | 72.15                     | 6009.6                  |
| n-decane   | 142.3                     | 11,419.6                |
| n-nonane   | 128.3                     | 10,007.5                |
| n-octane   | 114.2                     | 9258                    |
| n-heptane  | 100.2                     | 8177.24                 |

Table 4. Exergy of Main Streams (Base Case)

| stream     | chemical exergy (MJ/h) | physical exergy (MJ/h) | total mass exergy (MJ/h) |
|------------|------------------------|------------------------|--------------------------|
| 7          | 3,632,012.088          | 5396.352               | 3,637,408.440            |
| 56         | 276,611.774           | 3085.700               | 279,697.474              |
| 18         | 3,594,784.137         | 5109.156               | 3,599,893.293            |
| 58         | 312,656.524           | 2820.636               | 315,477.160              |
| AE         | 17,38,061             | 0.000                  | 17,38,061                |
| AE1        | 17,38,061             | 14.000                 | 17,52,061                |
| 320        | 2.985                 | 1.467                  | 4.452                    |
| 92         | 5756.372              | 0.000                  | 5756.372                 |
| AE2        | 6.656                 | 0.000                  | 6.656                    |
| 28         | 3,582,713.306         | 4738.503               | 3,587,451.809            |
| 75         | 17,246.949           | 230.520                | 17,477.214               |
| 66         | 1574.113              | 60.920                 | 1635.033                 |
| AE3        | 6.656                 | 0.426                  | 7.082                    |
| solution   | 152,030.186          | 4002.759               | 156,032.945              |
| 38         | 3,611,143.618         | 4521.870               | 3,615,665.488            |
| to spent   | 964,000               | 92.230                 | 1056,230                 |
| soda       |                       |                       |                          |
| 81         | 73,987.317           | 493.860                | 74,481.177               |
| steam MP   | 54.149               | 41.198                 | 95.347                   |
| steam cond | 53.994               | 39.123                 | 93.117                   |
| 82         | 68,731.723           | 0.000                  | 68,731.723               |
| 82.1       | 4750.612             | 18.800                 | 4769.412                 |
| 111        | 14,939.555           | 2.518                  | 14,942.073               |
| 104        | 3.556                | 2.138                  | 5.694                    |
| drain      | 4748.751             | 0.000                  | 4748.751                 |
| 101        | 20,076.441           | 11.660                 | 20,088.101               |

Figure 6 shows the exergetic analysis per stage for the base case of the unit. The exergetic efficiencies of the absorption, extraction, prewash, and COS removal stages are above 90%. For the other stages, efficiency reached a value of 0% because these stages do not handle the principal product (LPG); this arrangement of the process contributed to the reduction of its global exergetic efficiency.19

The highest irreversibility percentages were observed in the stages of absorption and COS removal, with 49.4% and 20%, respectively; this destroyed exergy was associated to heat and work losses along with wastes; however, the waste exergy was found to be the highest in the absorption and disulphide separation stages with 317,229.22 MJ/h and 24,842.5 MJ/h, respectively.

Figure 7 illustrates the global exergy analysis of the unit. The exergy efficiency was calculated to be 84.21% with low irreversibilities in the process (645,932.49 MJ/h), where 53.3% corresponds to the total exergy of wastes (344,863.23 MJ/h). When comparing this quantity with the irreversibilities generated by utilities at the systems’ input (392.041 MJ/h), the latter was lower; thus, it would be convenient to try to improve this indicator.

2.3.2. Exergy Analysis of the Alternative Case. Table 5 displays the results for chemical, physical, and total mass exergies for each stream of the process. Chemical exergies were calculated by adding the ones from the compounds involved in each stream, the physical exergy was calculated by simulation, and the total mass exergy is the sum of the properties mentioned before.

Figure 8 shows the exergetic analysis per stage for the alternative case (best technical performance). For the alternative case, the exergetic efficiency was approximately 90% for the stages of absorption, extraction, prewash, and COS removal. On the other hand, the reactor and disulphide separation stages showed 0% for their exergetic efficiencies; hence, there was no significant differences between the base case and the alternative.

Figure 9 displays the global exergetic analysis for the alternative case. The global efficiency of the process was 81.95%, which indicates that there were few irreversibilities in the process (755,945.9 MJ/h), where the highest quantity was from the waste exergy (65%); therefore, the irreversibilities of wastes were higher than the exergy of industrial utilities, so it would be convenient to improve this indicator. Despite this, a process can be considered efficient from an energetic point of view when it has a global exergy efficiency greater than 59%.5
The amine fraction used in the absorption stage has a direct effect on the quantity of sulfur and acid compounds that can be absorbed, and when the fraction of amines is higher, the performance of this operation increases.

By comparing the exergy analysis of both the case studies, a decrease in the exergetic efficiency of the absorption stage due to the higher quantity of undesired components that are removed by increasing the amine fraction was found, thus causing the net flow of wastes to rise; the above can be evidenced because for the base case, waste exergy is 317,229.22 MJ/h, and for the alternative case, it is 466,789.05 MJ/h. This increase causes the exergetic efficiency of the absorption stage to drop from 91.9 to 89.31%.

### 3. CONCLUSIONS

This work contributed to the current body of knowledge about the energetic performance of units in the oil and gas refineries. For the first time, the process simulation of a MEROX unit was conducted, and further energy analysis was applied to identify possible improvements. The parametric sensitivity analysis also revealed that the amine fraction in the feed of the absorber was the most influential variable in the process; this is because it had the biggest impact on its overall performance by causing an increase in irreversibility contribution of the absorption stage from 49.39 to 56.8% of the total, which was the highest one among all the stages of the unit, thus reducing the contribution of the others. Based on the exergy analysis and after comparing both cases, the absorption, extraction, prewash, and COS removal stages had high exergetic efficiencies for each case; however, the absorption stage showed the highest decrease from 91.9 to 89.3%. As a larger quantity of impurities was removed, the exergy of wastes increased from 317,229.22 to 466,789.05 MJ/h while trying to improve the technical performance of the plant. It was also found that the global exergetic efficiency drops from 84.21 to 81.95% between the base and alternative cases; the above indicates that technical improvements may have direct impact on its exergetic performance because the higher the purity of products, the more waste generation and consequently, the exergy of wastes. Finally, we concluded that this process can be considered efficient; however, further studies should be done in order to determine if other configurations for the plant can contribute to the increase of global exergetic efficiency.

### 4. MATERIAL AND METHODS

#### 4.1. Methodology

For the modeling of the mercaptans oxidation plant, process data were gathered by consulting scientific literature and experienced personnel in this matter. Then, process simulation was carried out using Aspen HYSYS V 10. The fluid package selected for this task was extended NRTL with SRK for the vapor phase because of its accuracy in predicting physical properties and solubilities in systems that have the presence of H$_2$S and mercaptans in amine aqueous solutions. Simulation results were validated by comparing them with process data previously collected. Parametric sensitivity analysis was applied to determine the best technical performance of the unit (alternative case). Exergy analysis was applied to both the base and alternative case. Chemical and physical exergies were calculated and gathered from the literature (see Section 2.3). The global exergetic efficiency per stage was calculated to compare both process performances from energy point of view.

### Table 5. Exergy of Main Streams (Alternative Case)

| stream | chemical exergy (MJ/h) | physical exergy (MJ/h) | total mass exergy (MJ/h) |
|--------|------------------------|------------------------|-------------------------|
| 7      | 3,631,920.14           | 5396.35                | 3,637,316.49            |
| 56     | 375,791.13             | 3085.70                | 378,876.83              |
| 18     | 3,583,830.62           | 4,807.44                | 3,588,638.06            |
| 58     | 462,712.83             | 2278.69                | 464,991.52              |
| AE     | 1797.52                | 0.00                   | 1797.52                 |
| AE1    | 1797.52                | 0.00                   | 1797.52                 |
| 320    | 2.99                   | 0.00                   | 2.99                    |
| 92     | 5840.24                | 844.00                 | 6684.24                 |
| AE2    | 6.66                   | 0.00                   | 6.66                    |
| 28     | 3,572,302.76           | 4725.50                | 3,577,028.27            |
| 75     | 17,517.88              | 234.52                 | 17,752.40               |
| 66     | 1574.11                | 60.92                  | 1635.03                 |
| AE3    | 6.66                   | 0.43                   | 7.09                    |
| Solution | 152,030.19           | 152,030.19             | 304,060.37              |
| 38     | 3,601,431.75           | 4509.22                | 3,605,940.97            |
| To spent soda | 959.80        | 91.85                 | 1051.65                 |
| 81     | 73,915.71              | 502.13                 | 74,417.84               |
| Steam MP | 54.15                | 41.20                  | 95.35                   |
| Steam cond | 53.99                | 39.12                  | 93.12                   |
| 82     | 68,659.04              | 16.30                  | 68,825.34               |
| 82.1   | 4780.35                | 38.21                  | 4818.56                 |
| 111    | 14,939.55              | 2.52                   | 14,942.07               |
| 104    | 3.62                   | 0.00                   | 3.62                    |
| Drain  | 4,748.75               | 0.00                   | 4748.75                 |
| 101    | 19,998.25              | 11.74                  | 20,009.99               |

#### Figure 8. Exergetic analysis per stage for the alternative case.

#### Figure 9. Global exergy analysis for the alternative case.
4.2. Process Simulation. The gathered information was entered in the software Aspen HYSYS v10.1 to model the performance of the system by process simulation. First, the compounds involved in the process were entered using the software’s database along with the fluid package selected for this purpose, so the energy requirements and physical properties of these compounds could be calculated.

Then, the equipment was chosen from the simulation palette following the best representation of the real process. All the data related to the streams, such as temperature, pressure, mass and mole flows, processing capacity, and so forth, were entered into the simulation environment. Finally, a detailed model of the plant was obtained including heat and material balances.

4.3. Process Description. As shown in Figure 10, the LPG enters the unit through an absorber. Here, it comes in contact with a lean amine solution to remove undesired compounds; the rich amine comes out through the bottom of the absorber, and the sweetened LPG from the top. Then, the hydrocarbon passes through a heat exchanger to be cooled with cooling water. The cooled LPG stream is mixed with water, which helps to remove traces of amine dragged by the LPG.

The mixture enters a washing tank, where the water and LPG are separated; the water exits through the bottom of the tank and joins the amine stream coming from the absorber and leaves the unit. The LPG stream leaving the washing tank from the top is mixed with dilute caustic soda and water; then, the mixture enters a tank, where the LPG is treated to remove any H2S left (caustic prewashing); the spent soda leaves the unit. The LPG stream leaving the washing tank from the top is mixed with dilute caustic soda and water; then, the mixture enters a COS sedimentation tank in which the operation mentioned above is carried out; the solvents coming out from the top is mixed with dilute caustic soda and water; then, the mixture enters a tank, where the LPG is treated to remove any H2S left (caustic prewashing); the spent soda leaves the unit. The LPG stream leaving the washing tank from the top is mixed with dilute caustic soda and water; then, the mixture enters a COS sedimentation tank in which the operation mentioned above is carried out; the solvents coming out from the bottom of the tank are recirculated to its entrance, where they mix with the LPG, and the COS-free hydrocarbon leaves the unit as the principal product.

The rich caustic soda that leaves the extractor is mixed with fresh caustic soda and passes through a heat exchanger, where it is heated using low-pressure steam, and then, the stream is mixed with air and disulphides which later enter an oxidizing drum, where the caustic soda reacts, and the mercaptans in it are converted to disulphides; the stream with soda and disulphides exits the reactor from the top. Afterward, this stream is sent to the disulphide separator to split the spent air, disulphides, and regenerated soda into three different streams; the first one exists through the chimney of the separator and leaves the units; the second one passes through a filter to remove soda traces that may be dragged by the disulphides; then, the disulphides leave the plant as a waste; the third one is the regenerated soda or lean caustic soda, which is mixed with heavy naphtha in order to remove any amount of mercaptans or disulphides that remained in the soda after the separation process. The mixture enters a sedimentation drum, where the mercaptans and disulphides are separated and recirculated to the entrance of the oxidizing drum. The lean caustic soda that is settled at the bottom of the drum is recirculated to the extraction process.

4.4. Parametric Sensitivity Analysis. In this section, a technical analysis of the process was conducted via parametric sensitivity analysis. Several case studies were considered to determine how the behavior of the unit may vary upon changing the operating conditions. An alternative case was selected according to the best technical performance observed.

4.5. Exergy Analysis. The following concepts and definitions were compiled from the work of Martínez et al. and Toghyani and Rahimi. Exergy is based on the second law of thermodynamics, which gives an approach to analyze and compare the energetic behavior of complex systems. By employing them, it is possible to calculate different energetic parameters from processes such as total irreversibilities, global and staged energetic efficiency, wastes, industrial services, heat, work, mass, chemically and physically associated exergies from streams. Among the advantages that this type of analysis brings, it is found that: it allows to determine the most efficient
way to employ energy resources; it can make full energetic analysis and contribute to the design of a process because it integrates the principles of mass and energy conservation along with the second law of thermodynamics.

For an energetics analysis in the steady state, the destroyed exergy is related to mass, heat-associated, and work-associated exergies, as shown in eq 2.

$$ \text{Ex}_{\text{destroyed}} = \text{Ex}_{\text{net-mass}} + \text{Ex}_{\text{net-heat}} + \text{Ex}_{\text{net-work}} $$

(2)

$$ \text{Ex}_{\text{work}} = W $$

(3)

$$ \text{Ex}_{\text{heat}} = \sum_i \left( 1 - \frac{T_i}{T} \right) Q_i $$

(4)

Equation 3 shows that the exergy associated to work in a constant volume system is the same work of it. Regarding heat-associated exergy, it is calculated based on Carnot’s efficiency as shown in eq 4. On the other hand, the total exergy input of a process is related to the exergies from the streams that enter the process and industrial utilities as shown in eq 5, while the total exergy output of a system is defined by the principal product and the waste streams (eq 6).

$$ \text{Ex}_{\text{total-in}} = \sum \text{Ex}_{\text{mass-in}} + \sum \text{Ex}_{\text{utilities-in}} $$

(5)

$$ \text{Ex}_{\text{total-out}} = \sum \text{Ex}_{\text{products-out}} + \sum \text{Ex}_{\text{wastes-out}} $$

(6)

$$ \text{Ex}_{\text{destroyed}} = \sum \text{Ex}_{\text{total-in}} - \sum \text{Ex}_{\text{products-out}} $$

(7)

By subtracting the total exergy of the products from the total input exergy, the destroyed exergy is obtained as shown in eq 7. Finally, the exergetic efficiency of a process can be calculated based on the destroyed exergy, the total input exergy through eq 8, and the total irreversibility percentage through eq 9.

$$ \eta_{\text{exergy}} = 1 - \left( \frac{\text{Ex}_{\text{destroyed}}}{\text{Ex}_{\text{total-in}}} \right) $$

(8)

$$ \% \text{Ex}_{\text{destroyed}}.i = \left( \frac{\text{Ex}_{\text{destroyed}}.i}{\text{Ex}_{\text{total-destroyed}}} \right) \times 100\% $$

(9)

4.6. Comparison of the Base Case and Alternative Case. After conducting the analysis previously mentioned, the base case and alternative case (best technical performance) were compared to study the contributions of operating condition changes that enhance or affect the exergy performance of the mercaptans oxidation unit.

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