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Exergy Study of Sour Water Stripper Unit of Delayed Coker Unit in a Refinery plant: A Real Start-Up Plant

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Abstract

Process sour water produced from refinery contains some hazardous pollutants as (H_2S and NH_3). Sour water stripper units remove both compounds from water. The two stripped pollutants are sent to Sulphur recovery unit to produce Sulphur and prevent any acidic emissions against environmental regulations. The sour water stripper unit serving the delayed Coker unit was simulated with Aspen HYSYS V.11 and 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 exergy destruction rates, the destruction efficiency and the percentage share of the destruction of each equipment was calculated. The total unit destruction rate was 2996.25 kW. The stripper showed the highest destruction rate 2592.23 kW and a percentage share of 86.52 % of total destruction. The overall efficiency of exergy is 81.58%. A comparison was conducted between the exergy results of this study with two other exergy studies performed in the same refinery plant. The columns in the three studies showed the highest destruction rates exceeding 78% of the total destruction of each unit. The air coolers showed the second-highest destruction rates in their units with a percentage share exceeding 7% of total destruction. The pumps showed the lowest destruction rates with values of less than 1% of the total destruction of each unit.

Keywords: Diethanolamine; Energy; Exergy; Methyl diethanolamine; Sour water stripper; Sulphur recovery unit

1. Introduction

process sour water produced from refinery plants contains some hazardous contaminants. H_2S and Ammonia are considered as main pollutants in sour water [1,2,3]. Strippers are designed to remove H_2S and NH_3 from sour water [4, 5, 6]. Hydrogen Sulphide is a hazardous toxic, corrosive pollutant produced by the refinery industry. It produces acid rain causing severe damages to equipment and also for human health [7,8]. Hydrogen Sulphide is used as feed to sulphur recovery plants (SRU) to produce elemental Sulphur [9,10]. The main purpose of SRU plants is to prevent H_2S emissions against environmental regulations in the world [11,12,13]. The modified Claus process is the most used one to produce Sulphur [14]. H2S is usually removed by an Amine scrubber unit that follows the modified Claus process [15]. The CO_2/ H_2S removal Amine unit normally consists of much similar equipment as (exchangers, coolers, lean Amine (LA) / rich Amine (RA) heat exchanger, an absorber, a stripper and pumps). The acid gases contact with Amine solution in absorber where H_2S is absorbed in the Amine solution. The sweet gases exist at the top of the

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absorber. Then the rich amine that exits the bottom is regenerated in the stripper and recycled again within the process [16]. Aqueous solutions of MDEA and DEA are openly used in industrial treatment, especially for acid gas streams that contain H_2S and CO_2. MDEA has high selectivity for H_2S rather than CO_2, so in the presence of both acid gases, MDEA is used to absorb H_2S and desorb CO_2, while DEA is usually used if H_2S is present individually. Consequently, if the sour gas contains both CO_2 and H_2S and it is required to absorb only H_2S in the amine solvent and not CO_2, the MDEA solvent will be the suitable solvent. If the process requires that the solvent absorbs both CO_2 and H_2S, the suitable solvent will be the DEA. in the case of SRU plants the MDEA solvent is used to absorb H_2S and desorb CO_2. MDEA is regenerated and the stripped H_2S is recycled again to the SRU feed [15, 17-20]. The world's fastest expanding population lead to a dramatic increase in energy consumption. Optimum energy consumption is substantial for community development. Currently, optimum energy consumption is an essential indicator of the community development level from an energy point of view. Therefore, energy optimization and preventing its losses in various industries are very important. Higher energy consumption in chemical processes increases both operation and production cost and also decreases system efficiency [21,22]. While energy is conserved in any chemical processes, exergy is destroyed irreversibly. Exergy is the work or power that we can use from an energy amount concerning the natural environment. The total exergy components are potential, kinetic, chemical and physical exergy. Potential and kinetic exergy is neglected due to their lower values if compared with physical and chemical exergy [14]. The chemical exergy is defined as the maximum amount of work obtained when the substance is got from an environmental state to a dead state. The process exchange of substances and heat transfer is only with the environment. The physical exergy definition is also considered as the maximum amount of work, but when the stream the substance is got from its initial state to the state of environment by physical processes. Physical exergy involves only a thermal interaction with the environment [22]. (Rostami and Tavan; Hashemi, et al.; Zarei) performed exergy studies on SRU plants considering overall exergy of the SRU, the difference between individual sections and exergy study on individual equipment [14,23,24]. Authors found articles related to energy optimization and cost-saving of Sour Water Stripper (SWS) units [2,4] but did not find any articles relating to exergy studies. Therefore, a decision was taken to perform an exergy study for an SWS unit. The refinery plant has two ARU units to regenerate amine for gas sweetening. ARU No.1 regenerate the DEA to be used in the gas sweetening of all the refinery plants. ARU No. 2 is used especially for regenerating the DEA used in the DCU. Ibrahim et al. performed an exergy study for ARU No.1[25]. Also, they conducted an exergy study for an MDEA scrubber unit of an SRU plant [26]. The current SWS No.2 study results were compared with ARU NO.1 results to conclude the relationships between similar equipment. A refinery plant in the middle east has two SWS units to treat all the refinery sour water. The Sour Water Stripping Unit – No.1 will process the sour water coming from Vacuum Distillation Unit (VDU), Naphtha Hydrotreating Unit (NHT), Diesel Hydrotreating Unit (DHT) and Hydrocracking Unit (HCU). The function of the SWS unit No.1 is to remove hydrogen sulfide and ammonia from the sour water streams. Some of the stripped water will be used as wash water for DHT and HCU, process water for Delayed Coker Unit (Unit 22) and rest will be sent to Waste Water Treatment Unit. The SWS Unit No.2 will process the sour water coming from Delayed Coker Unit (DCU) and Sulphur Recovery Units (SRU). The function of the SWS unit No.2 is to remove hydrogen sulfide and ammonia from sour water. The sour water generated from the Delayed Coker Unit contains not only hydrogen sulfide and ammonia but also a small amount of phenolic compound, which requires the sour water from the Delayed Coker Unit to be processed separately in SWS No.2. This exergy study is concerned about SWS No.2. The unit was simulated with HYSYS software V.11. After model validation, exergy analysis (chemical and physical) is conducted and local irreversibility in equipment, distribution of destructed exergy between devices is compared, exergy efficiency of different equipment is calculated. The exergy is new studies in plants to determine which equipment have the highest destruction rates to be an initial point in future studies for using this destructed energy. The study is compared by another two studies performed in the same refinery plant by Ibrahim et. al. Some relations appear between the same equipment and it was clear about which equipment have the highest exergy destruction. Exergy studies have recently been based on by researchers to assess the destroyed energy from various process fields and to try to find the best ways to avoid this loss in irreversible processes. This will be an excellent potential challenge for using and conserving energy. Ibrahim et al. optimized the energy consumption of the same refinery facility. The study saved 1,537,206.38 $/year by reducing steam consumption on four different units, including the SWS2 unit, which is included in the exergy study in this article. The annual savings from SWS2 is $/year. The SWS2's two energy and exergy studies enable readers to distinguish between energy and exergy concepts [27].

2. Materials and methods

This section describes the simulation step, the simulation sections, the simulation criteria, the validation step and the exergy calculations.

2.1. Simulation Step

SWS unit is simulated using Aspen HYSYS software V.11 with the feed characteristics tabulated in

Table 1.The output from the simulation is shown in Figure 1 and can be considered as a PFD for the plant.

Table 1. Feed characteristics

Stream description	**Rich Amine**
Temperature	87
Pressure	6.3
Mass flow	39000
Total Weight Comp. Fraction	
H_2O	0.991
NH_3	0.003
H_2S	0.006
Phenol	0.000
CO_2	0.000
H_2	0.000

2.2. Simulation Sections

The SWS unit is designed to treat process water contaminated with Hydrogen Sulphide (H_2S) and Ammonia (NH_3) from DCU. The sour water is heated in E1 (Feed/Bottom Exchanger) and then H_2S and NH_3 are stripped from the water in the stripper. The hydrogen sulfide and ammonia are stripped from the sour water as it flows down through the stripper. The H_2S content and NH_3 content in sour water from the stripper's bottom are specified as Maximum 10 wt.-ppm and Maximum 50 wt.-ppm, respectively. Sour Water Stripper Reboiler supplies heat to the stripper to strip the hydrogen sulfide and ammonia from the sour water at a lower level than the specification described above. The stripped water is cooled in E1, then in the air cooler. The stripped water outlet is diverted to Waste Water Treatment (WWT) for further processing.

A pump around is used to cool the overhead of the tower instead of the condenser to meet the design of the tower. Figure 2 shows the pump around system from the column environment simulation.

2.3. Simulation Criteria

The fluid package used in the simulation is “Peng Robinson”. This package is suitable for components feed. A wrong selection of the fluid package deviated the results. The stripper is simulated as a distillation tower. A distillation tower requires also some information to solve as (number of trays, the connection for inlet and outlet streams, bottom pressure, top pressure, bottom temperature, top temperature), the column solve according to some specifications as flow rates or top and bottom component fractions. Some modifications are created to the column to meet the pump around criteria. E1 and E2 are simulated as normal heat exchangers. It requires some values of cold and hot side streams as the flow rates of streams, temperature and pressure drop. P is selected as a pump.

2.4. Validation Step

Validation was performed by comparing the industrial data with the simulation results. The feed stream is input to HYSYS while the stripped water stream and the acid gas to SRU stream are outlet calculations from HYSYS. The outlet calculations shall be validated by the existing data in the plant documents as Process Flow Diagram (PFD) and (heat and material balance) documents. If the deviation between both is reasonable, then we can use the calculated values from the simulation. The two stream examples selected from the simulation were 225 (stripped water) and 211 (acid gas to SRU) because the aim of the unit was amine regeneration.

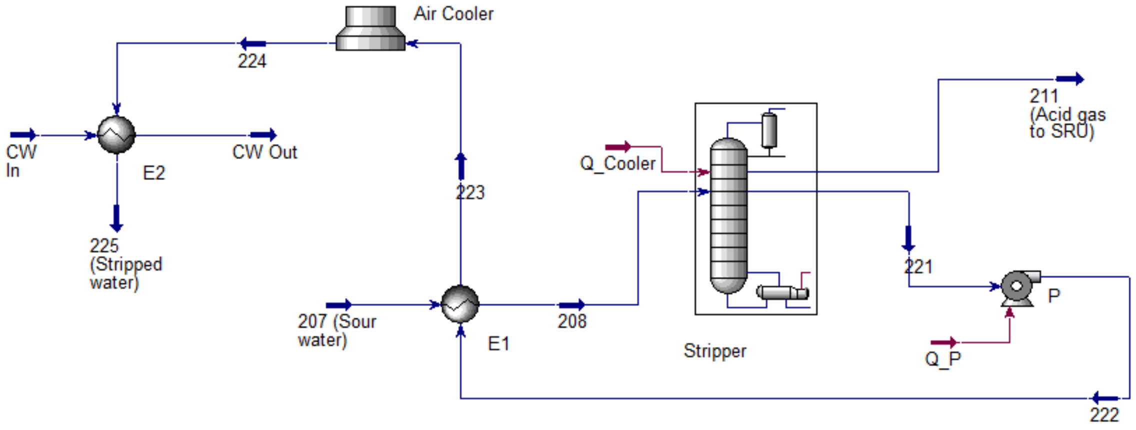

Figure 1. Sour water stripper unit

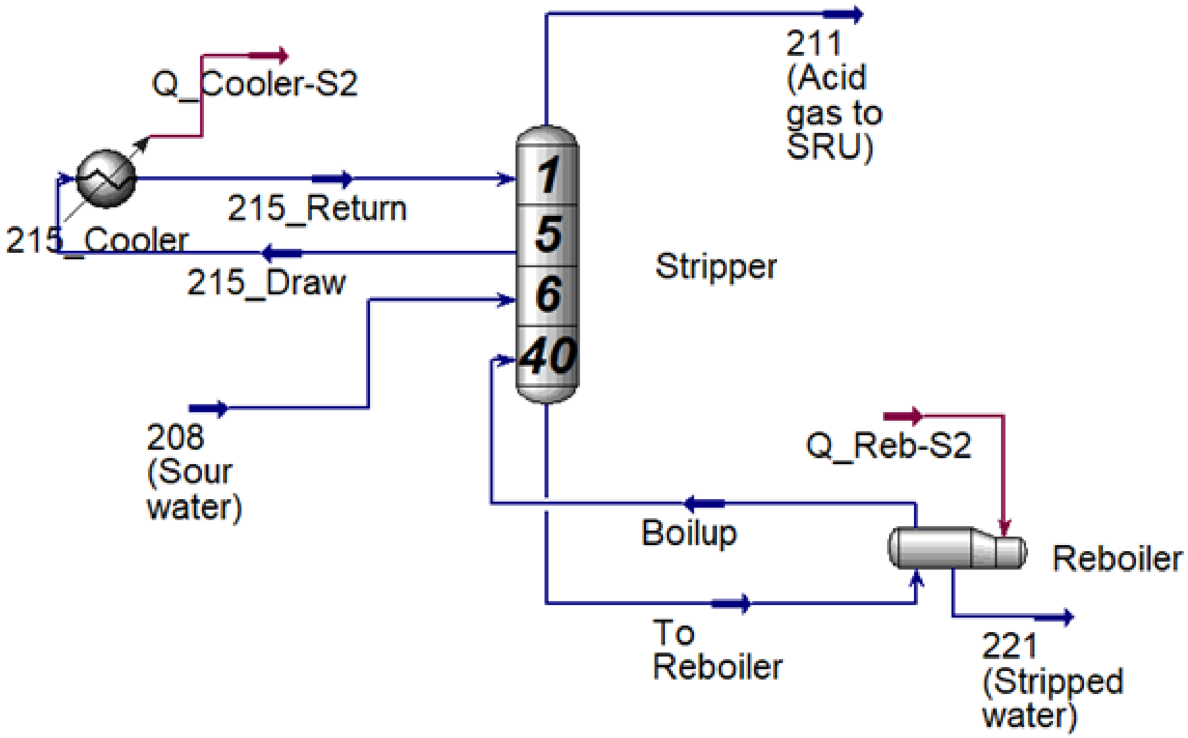

Figure 2. Sour water stripper simulation from column environment

2.5. Exergy Calculations

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

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

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

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

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.

$$E^{ph} = \dot{m}\, e^{ph} \quad (4)$$

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

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

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

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. [14, 23, 28].

Table 2 represents the standard chemical exergy values for the components used in the study. The phenol has the highest value of 3126.20 kJ/mol, then H_2S with a value of 812.00 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 $H_2O_{(L)}$is different from $H_2O_{(V)}$. 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 [28]

Components	**ex^0_{che} (KJ/mol)**
$H_2O_{(L)}$	0.90
$H_2O_{(V)}$	9.50
NH_3	337.90
H_2S	812.00
Phenol	3126.20
CO_2	19.48
H_2	236.09

2.6. 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.

2.7. Software program solving equations

2.7.1. Material balance equations

The general material balance equation is as follows:

$$input - output + generation - consumption = accumulation \quad (7)$$

In the case of steady-state conditions, no accumulation exists, the equation is written as:

$$input + generation = output + consumption \quad (8)$$

2.7.2. Material balance assumptions

The plant runs on steady-state conditions, in the case of the non-reactive system as our SWS unit no generation or consumption in the system.

2.7.3. Material Balance equations used in Plant

The reactive systems follow equation (8). A continuous non-reactive system follows the following equation:

$$input = output \quad (9)$$

otherwise the equation is written as follows:

$$\sum_{input} m^{\cdot}_i = \sum_{output} m^{\cdot}_i \quad (10)$$

2.7.4. Energy Balance Equations

The overall energy balance equation is as follows:

$$\Delta H^{\cdot} + \Delta E^{\cdot}_k + \Delta E^{\cdot}_p = Q^{\cdot} - W^{\cdot}_s \quad (11)$$

The enthalpy difference is calculated based on the following equation

$$\Delta H^{\cdot} = \sum_{output} m^{\cdot}_i \hat{H}_i - \sum_{input} m^{\cdot}_i \hat{H}_i \quad (12)$$

The kinetic energy is calculated based on the following equation:

$$\Delta E^{\cdot}_k = \sum_{output} m^{\cdot}_i v^2/2 - \sum_{input} m^{\cdot}_i v^2/2 \quad (13)$$

The potential energy is calculated based on the following equation:

$$\Delta E^{\cdot}_p = \sum_{output} m^{\cdot}_i g z_j - \sum_{input} m^{\cdot}_i g z_j \quad (14)$$

Table 3. Exergy calculations

Equipment	**Exergy in**	**Exergy Out**	**Exergy destruction**
E1	$E_{207} + E_{222}$	$E_{208} + E_{223}$	$E_{207} + E_{222} - E_{208} - E_{223}$
Stripper	$E_{208} + Q_{Reboiler}$	$E_{211} + E_{221} + Q_{Cooler}$	$E_{208} + Q_{Reboiler} - E_{211} - E_{221} - Q_{Cooler}$
P	$E_{221} + Q_P$	E_{222}	$E_{221} + Q_P - E_{222}$
Air Cooler	E_{223}	E_{224}	$E_{223} - E_{224}$

E2	$E_{223} + E_{CW\ in}$	$E_{225} + E_{CW\ out}$	$E_{223} + E_{CW\ in} - E_{225} - E_{CW\ out}$

2.7.5. Energy balance assumptions

The plant contains much equipment, so we have to use assumptions according to each equipment.

- If no temperature change or phase change or chemical reaction, no big change in pressure from inlet to outlet. Then $\Delta H = 0$ (mechanical energy balance is more useful in this case)
- If (temperature change or phase change or chemical reaction occur), $\Delta H^{\cdot} \neq 0$,($\Delta E^{\cdot}{}_{k}$, $\Delta E^{\cdot}{}_{p}$) can be neglected.
- If no great vertical distances between the inlets and the outlets, $\Delta E^{\cdot}{}_{p} = 0$
- If the system and its surrounding are at the same temperature or if the system is perfectly insulated then $Q^{\cdot} = 0$ and the process is adiabatic
- If the energy is not transmitted across the system boundary by a moving part, an electric current, or radiation $W^{\cdot}{}_{s} = 0$

2.7.6. Plant equipment energy balance equations

The equation used for pumps is:

$$\Delta H^{\cdot} = W^{\cdot}{}_{s} \qquad (15)$$

The equation used for pump around cooler and reboiler is:

$$\Delta H^{\cdot} = Q^{\cdot} \qquad (16)$$

The equation used for mixers:

$$\Delta H^{\cdot} = 0 \qquad (17)$$

Felder et al. displayed material and energy balance equations for different process and equipment, he also indicated the assumptions of each case [29]

2.8. Detailed equipment equations

2.8.1. Distillation (Stripper)

A distillation column (Stipper) can be described using several material and energy balance equations. Figure 3 shows a typical distillation column. The overall material balance can be found as follows:

$$F = D + B \qquad (18)$$

where F, D, and B are the feed, distillate, and bottom rates, respectively (kg/h). The component material balance can be found as follows:

$$F\, x_f = D\, x_D + B\, x_B \qquad (19)$$

where x_f, x_D, and x_B are the distillate compositions in the feed, distillate, and residue, respectively.

The overall heat balance can be found as follows:

$$F h_f + Q_r = D\, h_d + W\, h_B + Q_c \qquad (20)$$

where Q_r and Q_c are the reboiler duty and condenser duty, respectively, and h_f, h_d, and h_B are the specific enthalpies (J/kg) for the feed, distillate, and residue, respectively.

$$Q_c = V\, \lambda_{mix} = (m\, c_p\, \Delta T)_{water} \qquad (21)$$

Here, c_p is the sensible heat (J/kg °C).

$$V = L + D \qquad (22)$$

Here, V and L are the rates of the vapor at the top plate and liquid flow returning to the top plate (kg/h), respectively.

$$Q_r = m_{steam}\, \lambda_{steam} \qquad (23)$$

Here, λ_{mix} and λ_{steam} are the latent heat of vaporization (J/kg) values for the overhead mixture and reboiler steam, respectively [31].

2.8.2. Heat Exchanger Equations

The material balance equations were presented in equation (10). The general equation for the heat transfer across a surface is as follows:

$$Q = U\, A\, \Delta T_{lm} \qquad (24)$$

where Q, U, A, and ΔT_m are the heat transfer per unit time (W), overall heat transfer coefficient (W/m^2 °C), area of heat transfer (m^2), and log mean temperature difference (°C), respectively. The log mean temperature difference was calculated using the following equation:

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\frac{(T_1 - t_2)}{(T_2 - t_1)}}, \qquad (25)$$

where T_1 is the hot-fluid inlet temperature, T_2 is the hot-fluid outlet temperature, t_1 is the cold fluid inlet temperature, and t_2 is the cold fluid outlet temperature.

2.8.3. Pump Equation

The total energy required can be calculated from the following equation:

$$g\Delta z + \frac{\Delta P}{\rho} - \frac{\Delta P_f}{\rho} - W = 0 \quad , \qquad (26)$$

where W is the work done (J/kg), Δz is the elevation difference between z_1 and z_2 (m); ΔP is the system pressure difference between P_1 and P_2 (N/m^2); ΔP_f is the pressure drop due to friction, including miscellaneous losses and equipment losses (N/m^2); ρ is the liquid density (kg/m^3); and g is the acceleration due to gravity (m/s^2) [31].

3. Results and Discussion

3.1. 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. Approximately no deviation exists in the validation. The (Peng Robinson) is the selected one for this case.

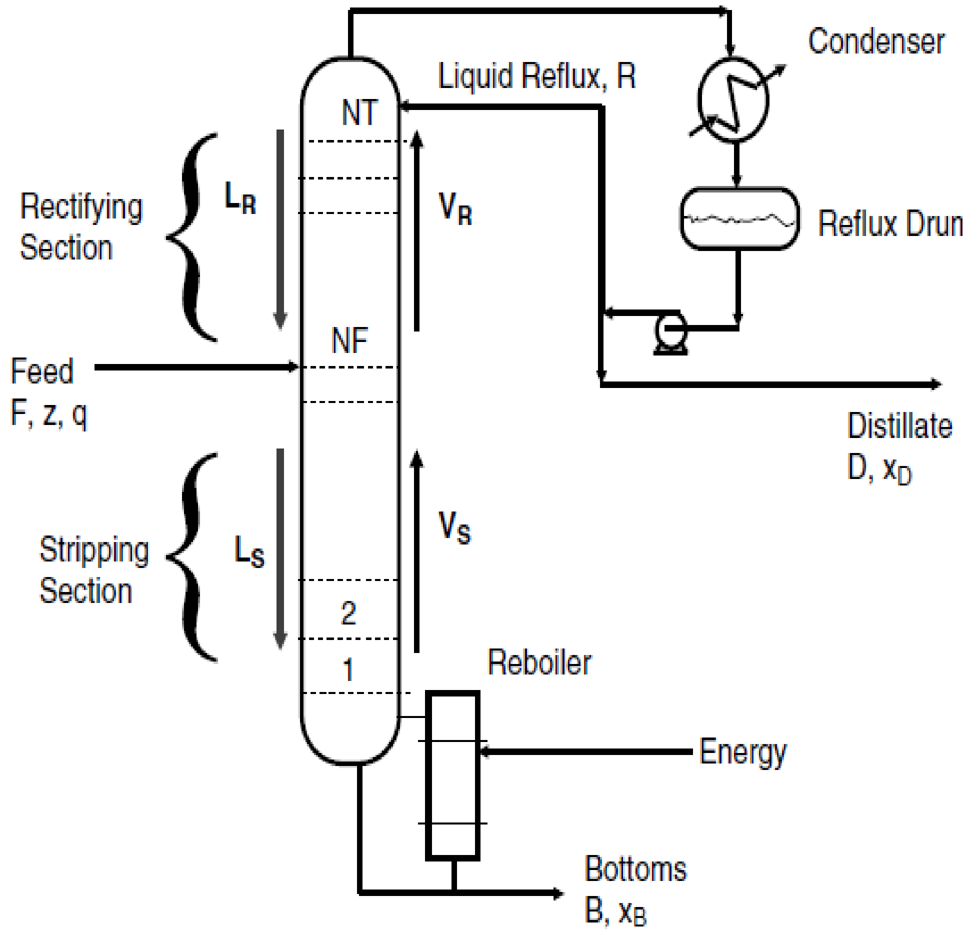

Figure 3. Tray distillation [29]

Table 4. Simulation validation

• **Stream**	• **211 (Acid gas to SRU)**			• **225 (Stripped water)**		
• Property	• Design	• Simulation	• Deviation %	• Design	• Simulation	• Deviation %
• Temperature (ºC)	• 92	• 90	• 2.00	• 40.0	• 40.1	• -0.26
• Pressure (kg/cm^{2}g)	• 1	• 1	• 0.00	• 5.3	• 5.3	• 0.00
• Mass flow (kg/h)	• 493.40	• 493.26	• 0.03	• 38506.6	• 38506.7	• 0.00
• **Component**	• **Total Weight Comp. Fraction**					
• H_2O	• 0.26	• 0.26	• 0.00	• 99.99	• 99.99	• 0.00
• NH_3	• 0.23	• 0.23	• 0.00	• 0.00	• 0.00	• 0.00
• H_2S	• 0.50	• 0.50	• 0.00	• 0.00	• 0.00	• 0.00
• Phenol	• 0.00	• 0.00	• 0.00	• 0.00	• 0.00	• 0.00
• CO_2	• 0.00	• 0.00	• 0.00	• 0.00	• 0.00	• 0.00
• H_2	• 0.00	• 0.00	• 0.00	• 0.00	• 0.00	• 0.00

●

3.2. Exergy calculations

3.2.1. Physical and Chemical Exergy Calculations for Streams

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

Table 5. HYSYS calculations for streams

Stream number	Molar flow (kmol/h)	Mass flow (kg/h)	mass exergy (KJ/kg)
207	2158.63	39000.00	6.30
208	2158.63	39000.00	25.79
221	2137.41	38506.74	61.48
222	2137.41	38506.74	62.33
211	21.23	493.26	149.57
223	2137.41	38506.74	29.16
224	2137.41	38506.74	8.91
225	2137.41	38506.74	2.21
CW-In	5345.52	96300.00	1.02
CW-Out	5345.52	96300.00	2.09

The physical exergy, chemical exergy, and total exergy for the streams were calculated using the equations in section Exergy Calculations) and listed in Table 6.

Table 6. Stream exergies.

Stream number	E_{ph} (kW)	E_{ch} (kW)	E_{tot} (kW)	% share of E_{ch} in E_{tot}
207	68.24	2764.26	2832.50	97.59
208	279.35	2764.26	3043.61	90.82
221	657.57	551.72	1209.29	45.62
222	666.71	551.72	1218.43	45.28
211	20.49	2278.45	2298.94	99.11
223	311.94	551.72	863.66	63.88
224	95.26	551.84	647.11	85.28
225	23.63	551.72	575.35	95.89
CW-In	27.25	1336.38	1363.63	98.00
CW-Out	56.04	1336.38	1392.42	95.98

Table 3. Usually, the chemical exergy magnitude is higher than that for the physical exergy in most streams as shown in Table 6.

Table 3, exergy efficiencies of equipment and percentage share of destruction are calculated based on section (Exergy Calculations) and presented in Table 7 .

Table 7. Exergy destruction and exergy efficiency results

Equipment	**Destructed energy (KW)**	**Percentage share**	**Exergy Efficiency (%)**
Stripper	2592.23	86.52	56.87
Air Cooler	216.55	7.23	74.93
E1	143.66	4.79	96.45
E2	42.98	1.43	97.86
P	0.83	0.03	99.93
Sum	2996.25	100.00	81.58

The total exergy of some streams is higher than other streams. For example, E_{tot} for stream 211 is 2298.94 kW while E_{tot} for stream 225 is 575.35 kW. The purpose is described below: The total exergy was the summation of the physical and chemical exergy values. Usually, the chemical exergy value is extremely higher than the physical exergy values, so it is the main influencer of E_{tot} values. The composition of the components had the main effect on the E_{ch} value calculated using the equation $\sum x_i ex^0_{che} + RT_0 \sum x_i \ln x_i$. The ex^0_{che} values of components are the main influencer of the E_{ch} value. Stream 211 is composed of 0.503 wt.-Fr. H_2S, 0.232 NH_3 and the remaining is water. Stream 225 is approximately 100% water. The H_2S standard chemical exergy and the NH_3 standard chemical exergies were much higher than that of water. The ex^0_{che} values for H_2S, NH_3 and H_2O_L are 812.00 kJ/mol, 337.90, and 0.90 KJ/kmol respectively. Consequently, the chemical exergy at of stream 211 was much higher than that of stream 225, consequently, E_{tot} for stream 211 is higher than E_{tot} for stream 225.

The values for Q_P, Q_Reboiler, and Q_Cooler were 9.97, 2967 and 999.8 kW respectively. These values were used in the destruction calculations for the equipment, as listed in

3.2.2. Exergy Destruction and Exergy Efficiency of Equipment

Exergy destruction calculations of equipment are calculated based on the equations in

The highest destruction rate is observed in Stripper with a value of 2592.23 kW and a percentage share of 86.52% of total destruction, then Air Cooler with a value of 216.55 kW and a percentage share of 7.23% of total destruction. The percentage share of destruction is shown in Figure 4. The overall efficiency of exergy is 81.58%.

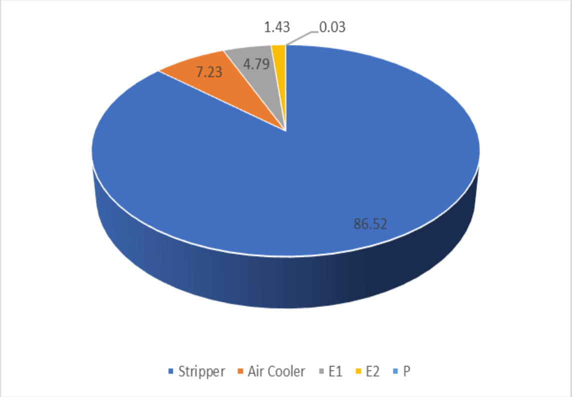

Figure 4. Percentage share of equipment

3.3. Exergy results comparison with ARU1 study

Ibrahim et al. performed an exergy study of the Amine scrubber unit of the SRU plant on different equipment. MDEA is used in this unit. The study was conducted on two different concentrations (45% and 22%) by weight [26]. Also, they performed an exergy study of one of the two ARU units of the plant. DEA is regenerated in this unit. The DEA concentration decreased from the design concentration of 25 wt.% to 20% wt.% due to system losses. The design concentration value of the amine is set by the licensor of the process to guarantee that the amine will perform efficiently for H_2S gas sweetening. The decrease in this concentration due to any purposes may lead also to other severe problems. System losses in general for amine may happen due to many purposes explained in section Purposes of amines losses). The study was conducted on two different concentrations (25% and 20%) by weight [25]. A comparison was conducted between the similar equipment of the current study and the previous two studies to conclude the similar relationships between equipment.

3.3.1. Purposes of amines losses

The amine concentration decreasing in plants is due to system losses. The concentration of the Amine may decrease in the start-up especially due to three possible purposes: (Amine degradation, foaming and flooding). In the degradation phenomena, Amines are transformed into undesirable products that are not able to recover with normal regeneration. Amines can be degraded for many purposes. One of these purposes is the make-up water used to prepare the Amine solution. Other purposes are (Suspended solids, non-volatile contaminants, lower and higher molecular weight hydrocarbon, additives and antifoaming agents, corrosion inhibitor, make-up water and water impurities, inorganic and organic acids. Before the starting-up of any plant flushing and cleaning procedures as degreasing shall be done. In many cases, it is not done properly. Undesirable compounds are present especially in the start-up in case of any defect that happens in the cleaning of the unit. Consequently, many of these contaminants exist in the system causing Amine degradation. Foaming is one of several Amine degradation problems. Foaming takes a part of the Amine to exit from the top of the tower instead of going to its normal way from the bottom causing MDEA loss and decreasing in concentration. Other degradation problems are: (reduction solution capacity and plant performance, corrosion effect of degradation products, capital/material of construction issues, the environmental effect of degradation products and fouling effect of degradation products. The third purpose of the decrease in concentration is the flooding phenomena that happens in high sour gas feed flow rates that also takes a part of the DEA or MDEA to exit with the sweet gas from the top. In the starting-up period, foaming and flooding phenomena were observed in the plant absorbers several times [25,32].

3.3.2. Laboratory analysis deviation in DEA

Heat stable salts (HSS) are considered a part of degradation products [32]. Lean Amine solutions are generally not corrosive because they have low conductivity and high pH. However, an excessive accumulation of Heat Stable Salts (bicine, oxalate, formate and acetate salts) above 2% can significantly increase corrosion rates in the hot lean amine as per API 571. It was observed high HSS exceeding 3% in the ARU unit in parallel to the decreasing concentration.

3.3.3. Columns comparison

It was observed that the main highest exergy destruction in the three units was in the columns (Regenerators and stripper).

Table 8 shows the tower values in the three units and the percentage share of these values in total unit destructions.

Table 8. Comparison between columns destructions in three units

Columns (Regenerator or stripper)			
Unit	**Destructed energy (KW)**	**Total unit destruction (kW)**	**% share of destruction in its unit**
MDEA 45%	1937.89	2404.85	80.58
MDEA 22%	1494.27	1908.86	78.28
ARU 25%	13459.73	16907.45	79.61
ARU 20%	15571.65	18964.53	82.11
SWS	2592.23	2996.25	86.52

It was observed that the columns in the three units have the highest destruction rate. All destruction rate values of the columns exceed 78% of the total destruction of the units.

3.3.4. Air coolers comparison

The air coolers exist in ARU and SWS. The air coolers in their units have the second-highest destruction rates and percentage shares in destruction as shown in Table 9. The destruction values exceed 7% in the two units.

Table 9. Comparison between columns destructions in two units

Air cooler			
Unit	**Destructed energy (KW)**	**Total unit destruction (kW)**	**% share of destruction in its unit**
ARU (DEA Conc. 25%)	2096.65	16907.45	12.40
ARU (DEA Conc. 20%)	2034.29	18964.53	10.73
SWS	216.55	2996.25	7.23

3.3.5. Pumps comparison

The pumps in the three units have the lowest percentage share in the destruction of the units.

Table 10 shows a comparison between pumps destructions in three units. The pumps have a contribution low than 1% in three units.

Table 10. Comparison between pumps destructions in three units

pumps			
Unit	**Destructed energy (KW)**	**Total unit destruction (kW)**	**% Share of destruction in its unit**
ARU (DEA Conc. 25%) [25]	198.41	16907.45	0.59
ARU (DEA Conc. 20%) [25]	198.95	18964.53	0.53
SWS	0.83	2996.25	0.03

4. Conclusions

A sour water stripper unit treating the sour water of the delayed Coker unit was simulated with HYSYS V.11. The units are a part of a refinery plant that started its official production in 2020. The main calculations concern exergy destruction, exergy efficiency and percentage share of the destruction of each equipment. The total exergy destruction was 2996.25 kW. The highest destruction rate is observed in stripper with a value of 2592.23 kW and a percentage share of 86.52% of total destruction, then air cooler with a value of 216.55 kW and a percentage share of 7.23% of total destruction. The overall efficiency of exergy is 81.58%. The total exergy is the summation of chemical and physical exergies. Usually, the chemical exergy magnitude is higher than the physical exergy. In most streams of the unit, Ech represents the highest percentage share of Etot. For example, for stream 207. Ech represents 97.59% of Etot of this stream. The exergy efficiency of equipment shall be considered with their destructed values. The stripper has the highest destruction rate and also the lowest exergy efficiency. The air cooler has a destruction rate higher than E1 but has a lower exergy efficiency than E1. The destruction values for the air cooler and E1 are 216.55 kw and 143.66 kW respectively, while their exergy efficiencies are 74.93% and 96.45% respectively. The SWS exergy study results were compared by the study of two other units in the same refinery plant (the amine scrubber unit of SRU and an amine regenerator unit). It was observed that the main highest exergy destruction in the three units was in the columns (Regenerators and stripper) with a percentage share values exceeding 78% of total destruction of each unit. The air coolers existing in SWS and ARU unit slowest the second-highest destruction rates with values exceeding 7% of the total destruction of their units. The pumps in the three units have the lowest percentage share in the destruction of the units with a contribution low than 1% of the total destruction in the three units.

5. Conflicts of interest

"There are no conflicts to declare".

6. Formatting of funding sources

List funding sources in a standard way to facilitate compliance to funder's requirements.

7. Acknowledgments

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

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9. List of abbreviations

ARU	Amine Regeneration Unit
CW	Cooling Water
DEA	diethanolamine
DCU	Delayed Cooker Unit
DHT	Diesel Hydrotreating
E	Exchanger
Fr.	Fraction
HCU	Hydrocracking Unit
HSS	Heat Stable Salts
LA	Lean Amine
MDEA	methyl diethanolamine
Naphtha Hydrotreating Unit	NHT
No	Number
P	Pump
PFD	Process Flow Diagram
RA	Rich Amine
SRU	Sulphur Recovery Unit
SWS	Sour Water Stripper
VDU	Vacuum Distillation Unit
WWT	Waste Water Treatment

10. Nomenclature

Symbol	Description	Unit
A	Area of heat transfer	m^2
B	Bottom feed rate	kg/h
c_p	Sensible heat	J/kg °C
D	Distillate rate	kg/h
e	Specific exergy	kJ/kmol
e^{ch}	Specific physical exergy	kJ/kmol
e^{ph}	Specific physical exergy	kJ/kmol
ex^0_{che}	Standard chemical exergy	kJ/kmol
E	Exergy rate	kW
$\dot{E}_k$	Kinetic energy	kW
$\dot{E}_p$	Potential energy	kW
E^{ch}	Chemical exergy	kW
E^{ph}	Physical exergy	kW
ε	Exergy efficiency	-
F	Distillation feed rate	kg/h
g	Gravitational Acceleration constant	m/s^2
H	Enthalpy	kJ/kg
$\dot{H}$	Enthalpy rate	kW
$\hat{H}$	Specific enthalpy	kJ/mol
h_d	Specific enthalpy in distillate	J/kg
h_f	Specific enthalpy in feed	J/kg
h_B	Specific enthalpy in bottom	J/kg
L	Rate of the liquid flow return returning to the top plate	kg/h
$\dot{m}$	Mass rate	kg/h
P	pressure	Kg/cm^2g
P_f	pressure due to friction	N/m^2
$\dot{Q}$	Heat duty	J/h
Q_c	Condenser duty	J/h
Q_r	Reboiler duty	J/h
S	Entropy	kJ/kg
R	Gas constant = 8.314	kJ/kmol ºK
T	Temperature	°C
T_1	hot fluid temperature inlet	°C
T_2	hot fluid temperature outlet	°C
t_1	cold fluid temperature inlet	°C
t_2	cold fluid temperature outlet	°C
T_{lm}	log mean temperature	°C
U	overall heat transfer coefficient	W/m^2 °C
V	Rate of the vapor at the top plate	kg/h
v	velocity	m^2/s
W	Work done	J/kg
$\dot{W}_s$	Shaft work	kW
x_d	Distillate composition in top	mass fr.
x_f	Distillate composition in feed	mass fr.
x_B	Distillate composition in bottom	mass fr.
z	elevation	m

11. Greek letter

Δ	The difference between inlet and outlet	-
λ_{mix}	Latent heat of vaporization for overhead mixture	J/kg
λ_{steam}	Latent heat of vaporization for reboiler steam	J/kg
ρ	Liquid density	kg/m^3

12. Subscripts

c	Condenser
che	Chemical
d	Distillate
e	Exit
f	Feed, friction
i	Inlet, specie in a mixture
k	Kinetic
lm	Log mean
p	Potential
r	Reboiler
s	Shaft
w	Residue
0	Standard conditions

13. Superscripts

ch	Chemical
ph	Physical
0	Standard conditions