Petroleum and Coal

Article Open Access

Exergy Study of Amine Scrubber Unit of a Sulphur Recovery Plant using Methyl Diethanolamine: A Real Starting up Plant

Ahmed Y. Ibrahim [1], Fatma H. Ashour [1], Mamdouh A. Gadalla [2,3]*

[1] *Department of Chemical Engineering, Cairo University, Giza 12613, Egypt*
[2] *Department of Chemical Engineering, Port Said University, 42526, Port Fouad, Egypt*
[3] *Department of Chemical Engineering, The British University in Egypt, Misr-Ismalia Road, El-Shorouk City, 11837, Cairo, Egypt*

Received December 21, 2020; Accepted January 26, 2021

Abstract

Sulphur recovery plants use methyl diethanolamine (MDEA) solutions for gas sweetening. The MDEA role is to absorb H_2S and desorb CO_2 from sour gas. The unit used to do this role is called Amine scrubber unit. The amine unit of an SRU plant in a middle east refinery plant that started its official production in 2020 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 MDEA concentration used is 45 wt.%. The exergy destruction rates, the destruction efficiency and the percentage share of destruction of each equipment was calculated. The regenerator showed the highest destruction rate 1937.89 kW and a percentage share of 80.58 % of total destruction. The overall efficiency of exergy is 99.88%. The MDEA concentration decreased from 45% design value to 22% due to system losses in the start-up. so, a case study was conducted to test the effect of this decrease on H_2S concentration in sweet gas. No effect was found by this decrease. An exergy study was conducted in MDEA 22%. The equipment destruction distribution did not change. The total destruction loss decreased by 495.99 kW. A comparison was conducted between both cases.

***Keywords**: Amine unit; Energy; Exergy; MDEA; Sulfur Recovery unit.*

1. Introduction

Hydrogen sulfide produced from refinery industry is considered as a hazardous pollutant, it is toxic, corrosive, and has acidic nature. It causes severe damage to equipment due to its corrosivity and may cause human death [1-2]. Sulphur Recovery Unit plants recover elemental sulphur from harmful H_2S [3-4], to prevent any acidic gas emissions violating environmental regulations [5-7]. Recently, most of the plants use the modified Claus process for sulphur recovery [8]. H_2S is usually removed by an amine scrubber unit that follows the modified Claus process [6]. The CO_2/H_2S removal amine unit normally consists in a number of 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 exit the top of the absorber. Then the rich amine that exits the bottom is regenerated in the stripper and recycled again within the process [9]. so, the selection of an excessively effective chemical solvent, the nominated which can achieve the favorable requirements, i.e., high absorption capacity, high chemical and thermal stability, rapid reaction kinetics, large savings of regeneration energy, is one of the most pivotal points solvents in the chemical absorption [6]. The aqueous solvents of alkanolamine used in scrubbers' units, such as DEA (diethanolamine), MDEA (methyl diethanolamine), have been presented for industrial chemical absorbents [10], but these amine solvents demand high energy for their regeneration [11]. Aqueous solutions of MDEA and DEA are openly used in the industrial treatment, especially for acid gas streams that contains 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 [12-15]. The world's rapidly extending in population and mounting industrialization lead to dramatically increasing the energy consumption [16]. MDEA is widely used as a chemical absorbent for its lower energy requirement [17-18]. Optimum energy consumption is substantial for community development. Currently, from the energy point of view, the optimization of energy consumption is counted as one of the important indicators in evaluating the community development level. Therefore, energy optimization and preventing its losses in different industries is very essential. High energy consumption, chemical processes, increase both production and operation cost and consequently decrease system efficiency [19]. Some researchers focused on using renewable energy resources to compensate for the high decrease in energy demands. Al Tanjil *et al.* proved the effectiveness of peat as an alternative energy source in Bangladesh [20]. Energy is conserved in any process, another energy point of view of energy is called exergy consider that exergy is destroyed due to irreversible processes.

Exergy is the work or power we can use from an energy with the respect of the natural environment. Some exergy components as kinetic and potential are similar to the energy, chemical and physical exergies are another exergy component. We can neglect both kinetic and potential energy to their lowest values in comparing with chemical and physical exergy. Always chemical exergy value is higher than physical exergy [21]. Chemical exergy and physical exergy are considered as the maximum amount of work we can obtain from a substance. The difference between them is that for chemical exergy the substance is obtained from the environment sate to the dead state by exchange and heat transfer only with the environment. While for physical exergy the substance is obtained from its initial state to the environment state by only thermal interaction with the environment [22]. Authors [19,21,23] performed exergy studies on SRU plants considering overall exergy of the SRU, the difference between individual sections and exergy study on individual equipment). The literature study showed no remarkable study of energy and exergy analysis of amine scrubber units. Mohamadi-Baghmolaei *et al.* [9] did an exergy study on different compositions of a mixture of DEA and MDEA), they studied also on the blended mixture the CO_2 emissions of the exit sweet gas. No studies were indicated related to the individual MDEA solution and the effect of the decrease of the original concentration due to operational problems.

Therefore, an industrial amine scrubber unit is simulated with Aspen HYSYS V.11 and the results of simulation are compared to industry data. The amine unit is used for sweetening the tail gas of an SRU plant that started its official production in 2020. The tail gas contains H_2S and CO_2, The amine scrubber unit employees the selective H_2S solvent MDEA in order to maximize hydrogen sulfide absorption rather than CO_2. MDEA concentration in the solvent solution is 45% by weight. 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 concentration of MDEA decreased to around 22% due to system losses. The same exergy study also is conducted on MDEA solution with concentration 22% to see the changes happened to different exergy calculations.

2. Materials and methods

2.1. Simulation step

Amine unit of the SRU plant, is simulated using Aspen HYSYS SW V.11 and simulation output that describes the plant is shown in Fig.1 with the feed characteristics tabulated in Table 1.

2.2. Simulation sections

The H_2S absorption step is accomplished using a formulated lean amine solution, MDEA based at 45% weight concentration. The rich amine solution, leaving the bottom of the Absorber is pumped by means of the rich amine pump P1 to the regenerator, where it is regenerated. The regenerated lean amine is cooled in the lean/rich amine exchanger, pumped by means of lean amine pump P2 to the lean amine cooler E2 and finally routed back to the absorber.

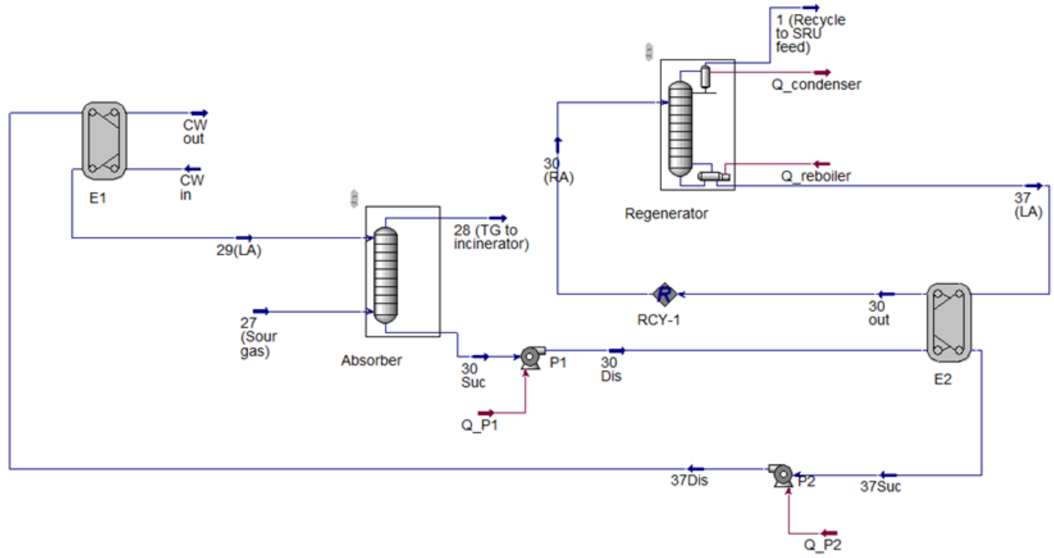


Fig.1. Amine scrubber unit

Table 1. Feed characteristics

Stream description		Sour gas	Lean Amine
Temperature	°C	38	40
Pressure	kg/cm² g	0.06	5
Flow	kg/h	26847	81194
Component		mass fraction	
H_2		0.002	0.000
H_2O		0.042	0.550
CO		0.000	0.000
N_2		0.924	0.000
O_2		0.000	0.000
CO_2		0.006	0.000
H_2S		0.025	0.001
MDEA		0.000	0.450

2.3. Simulation criteria

The fluid package used in the simulation is chemical solvent. This package is suitable for components feed. A wrong selection of the fluid package deviated totally the results. The absorber is selected as absorber from HYSYS, the simulation of the absorber requires entering the number of trays, bottom pressure, top pressure, the connection for inlet and outlet streams. The regenerator 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. E1 and E2 are simulated as plate heat exchangers. It requires some values of cold and hot side streams as the flow rates of streams, temperature and pressure drop. P1 and P2 are selected as pumps. A recycle operation must be used in HYSYS for recycling streams. RCY-1 is used between streams 30 out and 30 (RA).

2.4. Validation step

Validation is done by comparing industrial data with simulation results. The two streams examples selected from the simulation are 28 (tail gas to incinerator) and regenerated lean amine, because the aim of the unit is the sweetening of the sour gas and the Amine regeneration.

2.5. Exergy calculations

The physical and chemical exergy are calculated based on a sequence that uses the equations:

Physical exergy = $(H - H_0) - T_0(S - S_0)$ [23] (1)

Chemical exergy = $\sum x_i ex^0_{che} + RT_0 \sum x_i \ln x_i$ [23] (2)

Destruction exergy = $\sum m_i e_i - \sum m_e e_e$ [21] (3)

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

The terms of H, S, T, R and 0 stand for enthalpy, entropy, temperature, global constant of gases and standard condition, respectively. We did not ignore chemical exergy because its value is comparable and higher than physical exergy; therefore, the sum of physical and chemical exergy is used as total exergy.

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

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

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

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

Exergy efficiency of system components is defined as the ratio between the outlet exergy value to the inlet exergy value for each component, and exergy efficiency in the whole system represents the percentage of inlet exergy that is converted to the outlet in the system [19-23].

2.6. Exergy destruction calculations equations of equipment

Exergy in, Exergy out, and exergy destruction equations based on equipment types in the studied unit have been presented in Table 2.

Table 2. Exergy calculation

Equipment	Exergy in	Exergy out	Exergy destruction
E1 (LA cooler)	$E_{37\ Dis} + E_{CW\ in}$	$E_{29(LA)} + E_{CW\ out}$	$E_{37\ Dis} + E_{CW\ in} - E_{29(LA)} - E_{CW\ out}$
Absorber	$E_{29(LA)} + E_{27(TG)}$	$E_{28} + E_{30\ Suc}$	$E_{29(LA)} + E_{27(TG)} - E_{28} - E_{30\ Suc}$
P1 (RA pump)	$E_{30\ Suc} + Q_{P1}$	$E_{30\ Dis}$	$E_{30\ Suc} + Q_{P1} - E_{30\ Dis}$
P2 (LA pump)	$E_{37\ Suc} + Q_{P2}$	E_{37Dis}	$E_{37\ Suc} + Q_{P2} - E_{37Dis}$
LA-RA exchanger	$E_{30\ Dis} + E_{37(LA)}$	$E_{30\ out} + E_{37\ Suc}$	$E_{30\ Dis} + E_{37(LA)} - E_{30\ out} - E_{37\ Suc}$
Regenerator	$E_{30(RA)} + Q_{Reb}$	$E_1 + E_{37(LA)} + Q_{Cond}$	$E_{30(RA)} + Q_{Reb} - E_1 - E_{37(LA)} - Q_{Cond}$

3. Results and discussion

3.1. Validation results

The validation results are shown in Table 3, we can see clearly that industrial results and simulation results are almost closely.

Table 3. Simulation validation

Stream		37 (A)			28		
Property	Unit	Design	Simulation	Dev	Design	Simulation	Dev
Temperature	ºC	127.00	125.80	0.94	40.00	40.12	-0.12
Pressure	bar	1.20	1.20	0.00	0.03	0.03	0.00
Mass flow	kg/h	81288.00	81240.45	0.06	26116.00	26123.69	-7.69
Component mass fraction							
H_2		0.00	0.00	-	0.00	0.00	-
H_2O		0.55	0.55	-	0.04	0.04	-
CO		0.00	0.00	-	0.00	0.00	-
N_2		0.00	0.00	-	0.95	0.95	-
O_2		0.00	0.00	-	0.00	0.00	-
CO_2		0.00	0.00	-	0.00	0.00	-
H_2S		0.00	0.00	-	0.00	0.00	-
MDEA		0.45	0.45	-	0.00	0.00	-

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 mass flow of stream 28 with a deviation of (-7.69%). Approximately no deviation exists in the composition of components. The (chemical solvent package) is the selected one for this case.

3.2. MDEA 45% concentration calculations

3.2.1. Physical and chemical exergy calculations for streams

The physical and chemical exergy calculations for streams are calculated based on equations of section 2.3 Exergy Calculations, HYSYS calculated molar flow rates, mass flow rates and mass exergy for streams are presented in Table 4.

Table 4. HYSYS calculations for streams

Stream number	mass exergy (KJ/kg)	Molar flow (Kmol/h)	Mass flow (kg/h)
27	6.64	1001.29	26847.00
28	4.28	980.51	26134.75
29	1.96	2785.26	81194.01
30 Suc	2.06	2806.04	81906.26
30 Dis	2.44	2806.04	81906.26
30 Out	28.01	2806.04	81906.26
30 (RA)	28.01	2808.42	81948.33
37 (LA)	50.82	2785.26	81194.01
1B	48.25	23.16	754.31
37 (Suc)	12.35	2785.26	81194.01
37 (Dis)	12.75	2785.26	81194.01
CW in	0.88	17934.05	323087.00
CW out	1.95	17934.05	323087.00

Physical exergy, chemical exergy and total exergy calculations for streams are calculated based on equations in section 2.5 Exergy Calculations) and gathered together in Table 5.

Table 5. Streams exergies

Stream number	E_{ph} (kW)	E_{ch} (kW)	E_{tot} (kW)	Percentage share of E_{ph} in E_{tot}
27	49.54	6415.44	6464.98	99.23
28	31.10	2031.01	2062.10	98.49
29	44.13	289040.84	289084.97	99.98
30 Suc	46.95	293412.49	293459.44	99.98
30 Dis	55.53	293412.49	293468.03	99.98
30 Out	637.17	293412.49	294049.67	99.78
30 (RA)	637.50	293401.57	294039.08	99.78
37 (LA)	1146.30	289040.84	290187.14	99.60
1B	10.11	4441.15	4451.26	99.77
37 (Suc)	278.61	289040.84	289319.44	99.90
37 (Dis)	287.47	289040.84	289328.31	99.90
CW in	79.09	4483.51	4562.61	98.27
CW out	174.93	4483.51	4658.45	96.24

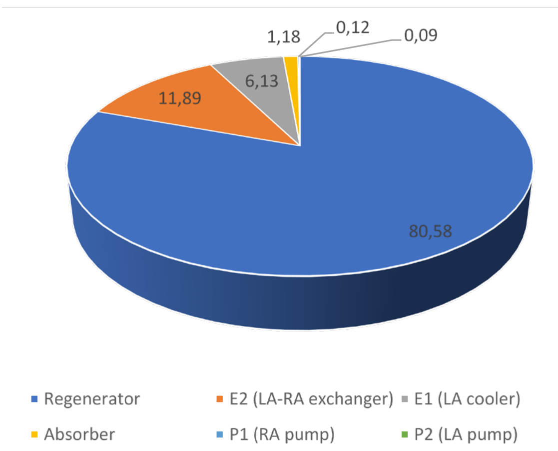
The values for (Q_P1, Q_P2, Q_Reboiler and Q_Condenser) are (11.36, 11.1, 6758.91 and 4221.71) kW respectively. These values are used in the destruction calculations for equipment based on Table 2. Usually, the chemical exergy magnitude is higher than the physical exergy. The percentage share of destruction of chemical exergy exceeds 96% in all streams.

3.2.2. Exergy destruction and exergy efficiency of equipment

Exergy destruction calculations of equipment are calculated based on the equations in Table 2, exergy efficiencies of equipment and percentage share of destruction are calculated based on section (2.5 Exergy Calculations) and presented in Table 6.

Table 5. Exergy destruction and exergy efficiency results

Equipment	Destructed energy (KW)	Percentage share	Exergy efficiency (%)
Regenerator	1937.89	80.58	99.356
E2 (LA-RA exchanger)	286.05	11.89	99.951
E1 (LA cooler)	147.50	6.13	99.950
Absorber	28.40	1.18	99.990
P1 (RA pump)	2.77	0.12	99.999
P2 (LA pump)	2.24	0.09	99.999
(Sum/Sum/Overall efficiency)	2404.85	100.00	99.88



The highest destruction rate is observed in Regenerator with a value of 1937.89 kW and a percentage share of 80.58 % of total destruction, then E2 with a value of 286.05 kW and a percentage share of 11.89 % of total destruction. The percentage share of destruction is shown in Figure. 2. The overall efficiency of exergy is 99.88%.

Figure. 2. Percentage share of equipment

3.3. MDEA 22% concentration calculations

3.3.1. Physical and chemical exergy calculations for streams

The physical and chemical exergy calculations for streams are calculated based on equations of section 2.3 Exergy calculations, HYSYS calculated molar flow rates, mass flow rates and mass exergy for streams are presented in Table 7.

Table 7. HYSYS calculations for streams

Stream number	mass exergy (kJ/kg)	Molar flow (kmol/h)	Mass flow (kg/h)
27	6.64	1001.29	26847.00
28	5.41	994.24	26385.79
29	2.12	2790.69	61840.20
30 Suc	1.67	2797.74	62301.40
30 Dis	2.05	2797.74	62301.40
30 Out	27.57	2797.74	62301.40
30 (RA)	30.79	2808.42	62417.22
37 (LA)	54.37	2790.69	61840.20
1B	48.43	17.73	577.02
37 (Suc)	13.58	2790.69	61840.20
37 (Dis)	13.98	2790.69	61840.20
CW in	0.88	17934.05	323087.00
CW out	1.73	17934.05	323087.00

The values for (Q_P1, Q_P2, Q_Reboiler and Q_Condenser) used for exergy calculations are (8.77, 8.59, 5193.06 and 3226.21) kW respectively. Physical exergy, chemical exergy and total exergy calculations for streams are calculated based on equations in section (2.5 Exergy Calculations) and gathered together in Table 8.

Table 8. Streams exergies

Stream number	E_{ph} (kW)	E_{ch} (kW)	E_{tot} (kW)	Percentage share of E_{ph} in E_{tot}
27	49.54	6415.44	6464.98	99.23
28	39.62	2074.09	2113.70	98.13
29	36.46	108160.32	108196.78	99.97
30 Suc	28.94	112495.42	112524.36	99.97
30 Dis	35.43	112495.42	112530.85	99.97
30 Out	477.19	112495.42	112972.61	99.58
30 (RA)	533.88	111492.82	112026.70	99.52
37 (LA)	934.00	108160.32	109094.32	99.14
1B	7.76	3397.20	3404.96	99.77
37 (Suc)	233.26	108160.32	108393.58	99.78
37 (Dis)	240.07	108160.32	108400.39	99.78
CW in	79.09	4483.51	4562.61	98.27
CW out	154.85	4483.51	4638.37	96.66

The exergy calculations of streams in MDEA concentration 22% are similar to MDEA 45%. chemical exergy values are higher than the physical exergy values. The percentage share of destruction of chemical exergy exceeds 96% in all streams.

3.3.2. Exergy destruction and exergy efficiency of equipment

Exergy destruction calculations of equipment are calculated based on the equations in Table 2, exergy efficiencies of equipment and percentage share of destruction are calculated based on (2.5 Exergy Calculations) and presented in Table 9.

Table 9. Exergy destruction and exergy efficiency results

Equipment	Destructed energy (KW)	Percentage share	Exergy efficiency (%)
Regenerator	1494.27	78.28	98.725
E2 (LA-RA exchanger)	258.98	13.57	99.883
E1 (LA cooler)	127.85	6.70	99.887
Absorber	23.70	1.24	99.979
P1 (RA pump)	2.28	0.12	99.998
P2 (LA pump)	1.78	0.09	99.998
Sum	1908.86	100.00	99.76

The highest destruction rate is observed in regenerator with a value of 1494.27kW and a percentage share of 78.28% of total destruction, then E2 with a value of 258.98 kW and a percentage share of 13.57% of total destruction. The percentage share of destruction is shown in Table 9. The overall efficiency of exergy is 99.76%. Destruction efficacy shall be compared with the destructed rate. Although the regenerator has destruction energy higher than E2, its efficacy is lower than E2.

3.3.3. A Case study for actual MDEA concentration

The refinery and SRU plant started its official operation in 2020, and faced actual problems. The actual operational MDEA concentration of the plant decreased from the original design 45% concentration by weight to 22% concentration due to system losses. A study was done on the simulation absorber to check the H_2S concentration in sweet gas, the H_2S concentration is not affected at 22% concentration only a little increase in weight percent from 0.0002 to 0.0003, and it was found that the value of H_2S concentration will be 0.0008 wt.% at 16%

MDEA concentration, which indicates a significant increase. The value of H_2S concentration will be 0.0016 wt.% at 15% MDEA concentration. Figure 3 show the relation between MDEA concentration wt. % and H_2S wt. % out of sweet gas from absorber.

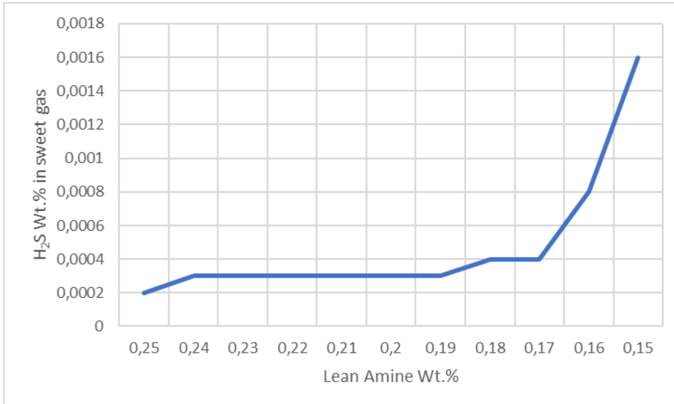


Figure 3. Lean MDEA *wt.*% versus H_2S *wt.* % in sweet gas from absorber

3.4. Comparison between MDEA 45% concentration and MDEA 22% concentration

The comparison between MDEA 45% concentration and MDEA 22% concentration is shown in table. The total destructed exergy in MDEA 45% concentration exceeds MDEA 22% concentration by 495.99 kW. The main contributor for this increase is the regenerator. 45% concentration destructed value is higher than 22% concentration by 443.62 kW. destructed exergy of all equipment by 45% is higher than 22% by small values as shown in Table 10.

Table10. Comparison between destructed values of MDEA 45% concentration and 22% concentration

Concentration Equipment	45 wt.% Destructed energy (kW)	22 Wt.% Destructed energy (kW)	Difference
Regenerator	1937.89	1494.27	443.62
E2 (LA-RA exchanger)	286.05	258.98	27.08
E1 (LA cooler)	147.50	127.85	19.64
Absorber	28.40	23.70	4.71
P1 (RA pump)	2.77	2.28	0.49
P2 (LA pump)	2.24	1.78	0.45
Sum	2404.85	1908.86	495.99

We need to identify the main purpose of the difference in destructed values in the regenerator. The destructed exergy in the regenerator is calculated from the equation ($E_{30(RA)}+Q_{Reb}$ - E_1-$E_{37(LA)}$-Q_{Cond}) as mentioned in Table 2. The reboiler duty regenerator 45% exceeds 22% by 1565.85 kW, while the condenser duty increased by a value of 995.49 kw. The difference between the two values is 570.35 kW which is approximately the value exceeded in total destruction between both cases (495.99 kW). We are talking here about the main contributor because some other small values may increase or decrease. Table 11 shows the streams related to regenerator destruction calculations.

Table 6. Regenerator streams

Stream		Conc	E_{ph}	E_{ch}	E_{tot}
Inlet	30 (RA)	45%	637.50	293401.57	294039.08
		22%	533.88	111492.82	112026.70
	Diff		103.63	181908.75	182012.38
	Q_Reboiler	45%	6758.91		
		22%	5193.06		
	Diff		1565.85		

Stream		Conc	E_{ph}	E_{ch}	E_{tot}
Outlet	1B	45%	10.11	4441.15	4451.26
		22%	7.76	3397.20	3404.96
	Diff		2.35	1043.95	1046.29
	37 (LA)	45%	1146.30	289040.84	290187.14
		22%	934.00	108160.32	109094.32
	Diff		212.30	180880.52	181092.82
	Q_Condenser	45%	4221.71		
		22%	3226.21		
	Diff		995.49		

It was observed from Table 11 that some exergies calculated for streams in 45 % concentration exceed 22% concentration by significant values. We need to take 30 (RA) stream as an example. E_{tot} of the stream in 45% is higher than E_{tot} 22% by 182012.38 kW. The total exergy is the summation of the physical and chemical exergy. Eph in 45% is higher than 22% by only 103.63 kW. So, it is not the main contributor. E_{ch} in 45% concentration is higher than 22% concentration by 181908.75 kW. E_{ch} is the influencer of this difference. The composition of the components is the main influencer in E_{ch} calculated by the equation ($\sum x_i ex^0_{che} + RT_0 \sum x_i \ln x_i$). The MDEA standard chemical exergy has extremely higher than water. ex^0_{che} for (MDEA, and H_2O_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^0_{che} is shown in Table 12.

Table 7. Standard chemical exergy values and mole fraction of MDEA

MDEA concentration Components	ex^0_{che} (KJ/kmol)	45 Wt.% Mole fr.	22 Wt.% Mole fr.
H_2	236.09	0.00	0.00
H_2O	0.90	0.88	0.95
CO	274.71	0.00	0.00
N_2	0.72	0.00	0.00
O_2	3.97	0.00	0.00
CO_2	19.48	0.00	0.00
H_2S	812.00	0.01	0.01
MDEA	3392.50	0.11	0.04

4. Summary and conclusions

An amine scrubber unit uses MDEA 45% concentration for gas sweetening in an SRU plant. The SRU plant is a part of a refining plant in the middle east that started its official production in 2020. The amine scrubber unit was simulated with HYSYS V.11 to make an exergy study on original MDEA 45 wt. % concentration. The main calculations concern on exergy destruction, exergy efficiency and percentage share of the destruction of each equipment. The highest destruction rate is observed in regenerator with a value of 1937.89 kW and a percentage share of 80.58 % of total destruction, then E2 with a value of 286.05 kW and a percentage share of 11.89 % of total destruction. The overall efficiency of exergy is 99.88. The total exergy destruction was 2404.85 kW. The MDEA concentration decreased to 22 wt. % due to start-up problems. A case study was conducted on the actual situation to check if sweet gas outlet from absorber will be affected by high H_2S concentration. No effect appeared from the H_2S concentration point of view. at 22% concentration only a little increase in weight percent from 0.0002 to 0.0003, and it was found that the significant increase in H_2S concentration with a value of 0.0008 wt.% will be at 16% MDEA concentration. An exergy study was conducted at 22 MDEA wt.% concentration, it was found the same percentage share distribution for equipment. It was indicated that the highest destruction rate is in regenerator with a value of 1494.27 kW and a percentage share of 78.28 % of total destruction. the second-highest one was also E2 with a value of 258.98 kW and a percentage share of 13.57% of total destruction. The overall exergy efficiency is 99.76 %. The comparison between both cases showed a decrease in destruction by 495.99 kW. The purpose of this difference was found approximately in the regenerator having a higher value in MDEA 45% concentration by 443.62 kW. The total exergy is the summation of chemical and physical exergies. The chemical exergy calculations of all streams in MDEA concentration 45% and MDEA concentration 22% showed a percentage share exceeding 99% of the total exergy values of each stream. The exergy efficiency of equipment should be considered with their destructed values. The regenerator has the highest destruction value by 443.62 kW in MDEA concentration 45%, but it has a lower exergy efficiency than MDEA 22%concentration. For regenerator, the exergy efficiency values are 99.356 % and 98.725 kW in MDEA 45% and 22% concentration respectively.

Acknowledgment

The authors would like to thank the refinery company team for the availability of data and information of the study and also the process engineering team for contributing with ideas.

List of abbreviations

CW	*Cooling Water*	*P*	*Pump*
Cond	*Condenser*	*RA*	*Rich Amine*
DEA	*diethanolamine*	*Reb*	*Reboiler*
Dis	*Discharge*	*SRE*	*Sulfur Recovery Efficiency*
E	*Exchanger*	*SRU*	*Sulphur Recovery Unit*
Eq	*Equation*	*Suc*	*Suction*
LA	*Lean Amine*	*TG*	*Tail Gas*
MDEA	*methyl diethanolamine*	*Wt.*	*Weight*

Nomenclature

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

References

[1] Khatami A, Heidari Y, Safadoost A, Aleghafouri,A, Davoudi M. The activity loss modeling of catalytic reactor of sulfur recovery unit in South Pars Gas Complex (SPGC) 3rd refinery based on percolation theory. Journal of Natural Gas Science and Engineering, 2016;28, 723-736.

[2] Abdolahi-Mansoorkhani H, Seddighi S. H_2S and CO_2 Capture from Gaseous Fuels using Nano-particle Membrane. Energy, 2019; 168, 847-857.

[3] Mahmoodi B, Hosseini SH, Ahmadin G, Raj A. CFD simulation of reactor furnace of sulfur recovery units by considering kinetics of acid gas (H_2S and CO_2) destruction. Applied Thermal Engineering, 2017; 123, 699-710.

[4] Abdoli P, Hosseini SA, Mujeebu MA. Effect of Preheating Inlet Air and Acid Gas on the Performance of Sulfur Recovery Unit—CFD Simulation and Validation. Forschung im Ingenieurwesen, 2019; 83(1), 81-89.

[5] Lavery CB, Marrugo-Hernandez JJ, Sui R, Dowling NI, Marriott RA. The effect of methanol in the first catalytic converter of the Claus sulfur recovery unit. Fuel, 2019; 238, 385-393.

[6] Sui R, Lavery CB, Li D, Deering CE, Chou N, Dowling NI, Marriott RA. Improving low-temperature CS2 conversion for the Claus process by using La (III)-doped nanofibrous TiO_2 xerogel. Applied Catalysis B: Environmental, 2019; 241, 217-226.

[7] Ibrahim S, Rahman RK, Raj A. Effects of H_2O in the feed of sulfur recovery unit on sulfur production and aromatics emission from Claus furnace. Industrial & Engineering Chemistry Research, 2017; 56(41), 11713-11725.

[8] Kazempour H, Pourfayaz F, Mehrpooya M. Modeling and multi-optimization of thermal section of Claus process based on kinetic model. Journal of Natural Gas Science and Engineering, 2017;38, 235-244.
[9] Mohamadi-Baghmolaei M, Hajizadeh A, Zahedizadeh P, Azin R, Zendehboudi S. Evaluation of Hybridized Performance of Amine Scrubbing Plant Based on Exergy Energy, Environmental, and Economic Prospects: A Gas Sweetening Plant Case Study. Energy, 2020; 31, 118715.
[10] Pashaei H, Ghaemi A. CO_2 absorption into aqueous diethanolamine solution with nano heavy metal oxide particles using stirrer bubble column: Hydrodynamics and mass transfer. Journal of Environmental Chemical Engineering, 2020; 8, 104110.
[11] Aghel B, Sahraie S, Heidaryan E. Carbon dioxide desorption from aqueous solutions of monoethanolamine and diethanolamine in a microchannel reactor, Separation and Purification Technology, 2019; 237, 116390.
[12] Rinker EB, Oelschlager DW, Colussi A, Sandall AT. Viscosity, Density, and Surface Tension of Binary Mixtures of Water and N-Methyldiethanolamine and Water and Diethanolamine and Tertiary Mixtures of These Amines with Water over the Temperature Range 20-100ºC, J. Chem. Eng., 1994; 39, 392-395.
[13] Concepción EI, Moreau A, Martín MC, Vega-Maza D, Segovia JJ. Density and viscosity of aqueous solutions of Methyldiethanolamine (MDEA) + Diethanolamine (DEA) at high pressures. The Journal of Chemical Thermodynamics, 2020; 148, 106141.
[14] Pal P, AbuKashabeh A, Al-Asheh S, Banat F. Role of aqueous methyldiethanolamine (MDEA) as solvent in natural gas sweetening unit and process contaminants with probable reaction pathway. Journal of Natural Gas Science and Engineering, 2015; 24, 124-131
[15] Shunji K, Xizhou S, Wenze Y. Investigation of CO_2 desorption kinetics in MDEA and MDEA+DEA rich amine solutions with thermo-gravimetric analysis method. International Journal of Greenhouse Gas Control, 2020; 95, 102947.
[16] Mores P, Scenna N, Mussati S. CO_2 capture using monoethanolamine (MEA) aqueous solution: Modeling and optimization of the solvent regeneration and CO_2 desorption process. Energy, 2012; 45, 1042-1058.
[17] Yang H, Xu Z, Fan M, Gupta R, Slimane RB, Bland AE, Wright I. Progress in carbon dioxide separation and capture: A review. Journal of Environmental Sciences, 2008; 20, 14–27.
[18] Wang M, Joe, AS, Ramshaw C, Eimer D, Musa NM. Process intensification for post-combustion CO2 capture with chemical absorption: A critical review. Applied Energy, 2015; 158, 275–291.
[19] Hashemi M, Pourfayaz F, Mehrpooya M. Energy, exergy, exergoeconomic and sensitivity analyses of modified Claus process in a gas refinery sulfur recovery unit. Journal of Cleaner Production, 2019; 220, 1071-1087.
[20] Al Tanjil H, Akter S. Characterization of Peat for Identifying the Effectiveness as Energy Source by Proximate Analysis. Pet Coal, 2020; 62(1): 63-70.
[21] Rostam, A, Tavan Y. A survey on exergy, energy and environmental analysis of sulfur recovery unit in case of five intensified configurations. Chemical Papers, 2019; 73, 1529–1539.
[22] Kotas TJ. The exergy method of thermal plant analysis, Butterworths 1985.
[23] Zarei S. Exergetic, energetic and life cycle assessments of the modified Claus process. Energy, 2019; 191, 116584.

To whom correspondence should be addressed: Ahmed Y. Ibrahim, Department of Chemical Engineering, Cairo University, Giza 12613, Egypt, E-mail: yehiawe@hotmail.com