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SIMULATION AND OPTIMIZATION OF NATURAL GAS SWEETENING PLANT WITH HYSYS 8.8

ABSTRACT

Computer-aid engineering programs are the best approach to understand the behavior and effect of variables of a power plant operation with each other and improve the efficiency before capital investment. In this study, a commercial natural gas sweetening plant of Iraq investigated and simulated with aid of HYSYS 8.8. For finding optimum circulation rate and precise amine solution. Ten cases of a simulation studied, Five cases on investigating diethanolamine (DEA) solution, and five cases on methyl diethanolamine (MDEA) solution. The first five cases start with a concentration of 20% DEA up to 45% DEA with a 5% difference. And the next five cases concentrations are the same but with the MDEA solution. Each concentration was run with five different circulation rates which starts with 175 m^3/h up to 325 m^3/h with 25 m^3/h differences. The result showed, with increasing circulation rate for DEA and MDEA in all concentrations, the concentration of CO_2 in the sweet gas decreased drastically. The water loss and hydrocarbons loss percentage increased with increasing circulation rate in all concentrations of amine solutions, except the DEA behaved differently compare to MDEA regarding water loss. Higher DEA concentration showed lower water loss, but a low concentration of MDEA was better for decreasing the water loss. The final results showed the circulation rate of 200 and 250 m^3/h were the stable and optimum condition for MDEA amine, but for DEA amine the cost drastically increases with increasing the
circulation rate. Moreover, the optimum condition demonstrated with a circulation rate of 175 m3/h at 20% DEA and 25% DEA solution which equals 60.988 MMBtu/hr and 213 MMBtu/day, respectively.

1. Introduction

Natural gas (NG) is a prime and foremost source of energy, it is widely used for many different purposes. NG is obtained from deep underground from natural gas reservoirs, which many undesired impurities and hazardous chemicals. The most dangerous and effective undesired impurities are hydrogen sulfide and carbon dioxide. These contaminants create problems such as corrosion, freezing, plugging, erosion, health damage, and environmental hazards [1]. It is very important to make it fit market demand, environmentally safe, and to meet the gas pipeline specifications.

A gas reckoned as 'sour gas' when the H_2S and CO_2 concentration exceed 2% CO_2 and 4 ppm H_2S [2]. Therefore, the widely used sweetening method is the 'amine gas sweetening process', it is classified under the chemical absorption process which used for removing H_2S and CO_2 [3]. During the process, a solvent reacts with the acid gases to form organic compounds [4]. The most used solvents are alkanolamine. Amine solutions are weak organic bases, they react with acid gases at normal temperature and they can be deacidized in higher temperatures. In this study, we focus on the effect and simulation of diethanolamine (DEA) and Methyldiethanolamine (MDEA). DEA is a secondary amine and MDEA is a

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tertiary amine. The primary amines are more reactive than the secondary and the secondary amine than the tertiary amines [5]. The primary and secondary amines directly react with CO_2 and form carbamate and bicarbonate ion via hydrolysis, but the tertiary amine form only bicarbonate ion and protonated amine [6].

[2,5] secondary amines reaction with CO_2 and H_2S:

$$CO_2 + R_1R_2NH \leftrightarrow R_1R_2NH^+COO^-$$
$$R_1R_2NH_2^+ + HS^- \leftrightarrow R_1R_2NH_2.SH$$
$$R_1R_2NH + H_2S \leftrightarrow R_1R_2NH_2.SH$$

[2,5] Tertiary amines reaction with CO_2:

$$CO_2 + R_1R_2R_3N + H_2O \leftrightarrow R_1R_2R_3NH^+ + HCO_3^-$$
$$R_1R_2R_3NH^+ + HCO_3^- \leftrightarrow R_1R_2R_3NH.HCO_3$$

Amine gas sweetening process consist of some process units, like; absorber, regenerator, filter, amine flash tank, condenser, cooler, surge tank, separator, heat exchanger, and pumps (as appear in Figure 1). The sour gas enter absorber from the bottom and the amine solution from the top. The flow through the column is counter-current. And then after the reaction come to happen, rich amine solution from the bottom of the absorber goes to the seperator unit where any kind of vapor will be released from the streamline. Then the rich amine flow through the heat exchanger and then the rich amine goes to the top of the stripper column. Inside the striper, the rich solution moves downward in counter-current with the water steam generated by the reboiler. The acid gases and the steam leave the top of the stripper and enter a condenser, where the major portion of the steam is condensed and return to the reboiler. The acid gases are separated in a separator and sent to the flare. The lean amine goes back to the system, first to the heat exchanger, and then to absorber [7–9].

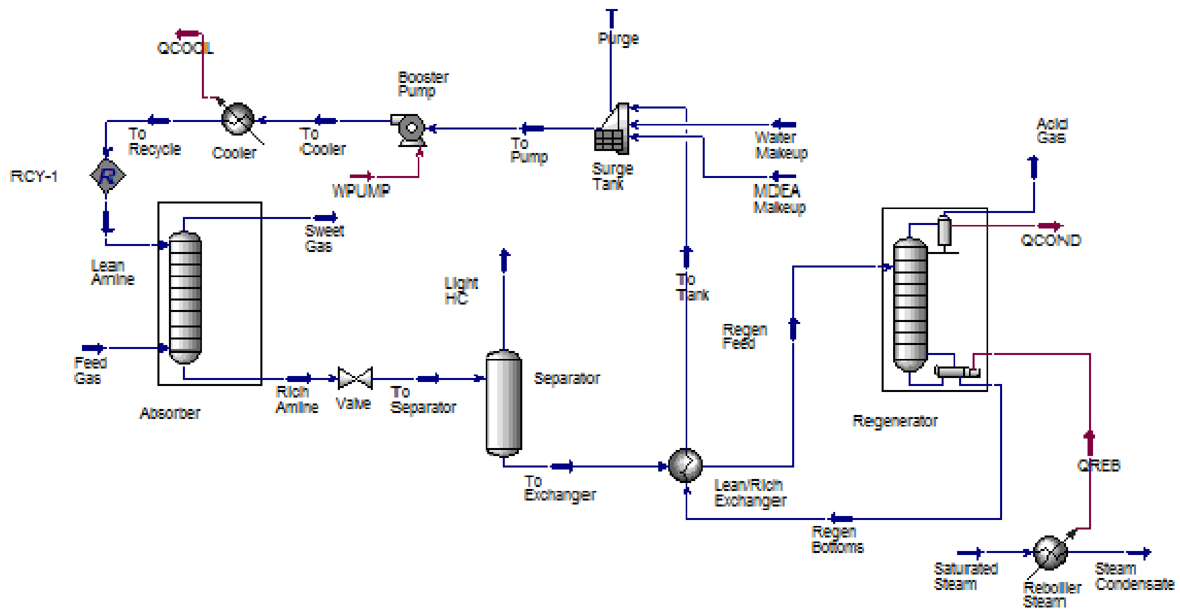

Figure.1 Schematic of amine unit.

The Iraqi Kurdistan region is an encounter with an extraordinary development by discovering a huge amount of oil and gas reservoirs through Investors. This study aims to do simulation and modification of the amine sweetening process of KAR group with the HYSYS V8.8 program. This operation runs with different parameters, each parameter plays a major role in energy consumption and the total cost of the operation. The major units that

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played role in the simulation were lean amine circulation flow rate and lean amine concentration. Two different amines are tested (MDEA and DEA).

2. Materials and methods

2.1. Materials

For running the simulation and finding the optimum condition, simulating software and the real data from the facility is required.

2.1.1. Aspen HYSYS V8.8

Aspen HYSYS is a comprehensive process modeling system used by the world's leading oil and gas producers, refineries, and engineering companies. It is used for optimization and simulation process and evaluating process performance under different circumstances [10]. The modeling of a process like an amine unit is so far easier and also more practical with the functionality of Aspen HYSYS version 8.8 and higher. "Acid Gas" property package has made this simulation easier. There are several main advantages of the 'Acid Gas' package of HYSYS. First, the built-in property packages in HYSYS provide accurate thermodynamic, physical, and transport property predictions for hydrocarbons, non-hydrocarbons, petrochemical, and chemical fluids. Second, this package contains the thermodynamic models developed by D.B. Robinson. Third, this program has more than 1600 components and 17000 binary coefficients and even if the component couldn't be found in HYSYS, you can create a fully defined hypothetical component. But fortunately, the equilibrium acid gas solubility and kinetic parameters for the aqueous alkanolamine solutions in contact with H_2S and CO_2 have integrated into this property package. Fourth, the amines package gives a precise stage efficiency model. The stage efficiency model calculates H_2S and CO_2 component stage efficiency based on the tray dimensions, internal tower condition, and status for both absorber and stripper [11].

2.1.2. Gas composition

The sour gas composition is the cornerstone of all calculations. The gas composition of the Khurmala amine gas sweetening plant was used for simulation [9]. The simulation consists of 8 cases. All the cases will be compared to each other to find the best case of working with the least energy consumption. For this work, we need the composition of the following components of input feed: N2, H2S, CO2, C1, C2, C3, i-C4, n-C4, i-C5, n-C5, C6, H2O, and MEA, DEA, and MDEA wt% (Table 1). The initial substances composition of the sour gas stream is taken from a previous study [9].

Table 1. Khurmala natural gas specifications for the sour gas to the absorber

Component	**Mole%**	**RMM**	**kmole/h**	**kg/h**	**Mole%**
H2S	5.38	34.076	288.03426	9815.056	5.372849
CO2	4.48	44.01	239.85009	10555.8	4.474045
N2	0.11	28.02	5.8891764	165.0147	0.109854
CH4	63.35	16.02	3391.6302	54333.92	63.26579
C2H6	13.9	30.07	744.17775	22377.42	13.88152
C3H8	6.03	44.09	322.83394	14233.75	6.021985
i-C4H10	1.36	58.123	72.811636	4232.031	1.358192
n-C4H10	2.44	58.123	130.63264	7592.761	2.436757
i-C5H12	1.03	72.15	55.144106	3978.647	1.028631
n-C5H14	0.73	72.15	39.082716	2819.818	0.72903
C6H14	1.19	86.177	63.710181	5490.352	1.188418

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H2O	-	18	7.1258541	128.2654	0.132922
Total	100		5360.9226	135722.8	100

Source: (Abdulrahman and Sebastine, 2013)

Throughout the simulation, some parameters are fixed which is taken from real-time running operation (Table 2).

Table 2. fixed parameters of amine unit simulation

Parameters	**Value**
Absorber - stages	20
Absorber Top Pressure	1090
Absorber Bottom Pressure	1094
Desorber - stages	20
Reboiler - temperature	117 oC
Desorber top pressure	2 bar
Desorber - Reflux ratio	0.35
Rich amine pump - inlet pressure	1091 Psi
Inlet gas pressure	1095 Psi
Inlet gas temperature	38 C
Inlet Gas Flow	172.2 m3/h
Seperator Delta P	14.7 Psi
Desorber Inlet Temperature	190 oF
Desorber top pressure	35 Psi
Desorber Bottom Pressure	38 psi
Condenser Temperature	7 oC
Reflux Ratio	0.3

2.2. Methods

In this project, the focus will be on the simulation of the acid gas removal process with high efficiency and using different amine solution. For gas sweetening several packages available. There are a lot of variables that affect the efficiency of the plant and energy consumption.
In this research, the main simulation variables are; DEA and MDEA Amines concentration with different weight percentages and different circulation rates. This simulation is consisting of some steps.

- Constitution of plan one-on-one
- Select a model property package
- Select all substances
- Define all the reactions inside the process
- Create and specify the feed stream
- Install and define the operational units of the process plan
- Create an 'analyzing list' and tables inside the program
- Test all the cases
- Comparing to each other and find out the best result

2.2.1. Modeling

modeling with HYSYS starts with opening a' new case'. Right after that, a new screen shows up which consists of 'Properties, Simulation, Safety analysis, and Energy analysis'. In the category of 'Properties'. first, we have to add and define the 'Components list'. Every component that exists in the entire process should be added. Then inside the 'Fluid package' section, the acid gas property package was selected. After package selection, the 'Reactions' section very important which should be defined and set very carefully. Any reactions that occur inside the whole process must be outlined.

The equipment and streams will be set and defined. The most significant equipments are absorber tower, separator, Lean/rich exchanger, regenerator (stripper), make-up mixer, cooler. Defining each equipment with more detail makes the simulation work with less error percentage and closer to reality. Absorber tower requires the specifications of two inlets, number of stages, and geometry dimensions. The separator requires inside pressure and the geometry of the vessel. The heat exchanger needs information upload regarding the shell and tube side geometry, the pressure drops for both sides and the condition of the stream goes to the regenerator. For regenerator parameters required reflux ratio with the pressure of reboiler and condenser, residual acid gas load in desorption process, bottom and top temperature, and pressure inside the tower. The concentration of amine adjusted inside the makeup mixer (purge tank) with adding water, the outlet concentration of amine solution required. Pressure through the simulation lines adjusted by installing pumps and set their outlet pressure.

2.2.2. Simulation cases

2.2.2.1. Case 1-5: MDEA case

The investigating cases from case 1 to case 5 will be analyzed on a process model of Figure 1. For these five cases, these data are being specified for them which only the amount of amine concentration is been changed. Each case tested between a circulation rate of 175 – 325 m^3/h (Table 3).

Table 3. case 1 to case 5.

Case No.	**Lean Amine Composition**
Case 1	20% MDEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h
Case 2	25% MDEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h
Case 3	30% MDEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h
Case 4	35 % MDEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h
Case 5	45% MDEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h

The next five cases will run under the same conditions as the first five cases, only the amine changes to DEA (Table 4).

Table 4. case 6 to case 10

Case No.	**Lean Amine Composition**
Case 6	20% DEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h
Case 7	25% DEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h
Case 8	30% DEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h
Case 9	35 % DEA, with best inlet temperature and best circulation

	rate between 175 – 325 m^3/h
Case 10	45% DEA, with best inlet temperature and best circulation rate between 175 – 325 m^3/h

Results and discussion

In various circulation rates, different individual amines are used in the simulation.

Amount of CO_2 in the sweet gas stream of the absorber column

The result showed MDEA is less reactive with CO_2 compare to DEA. The circulation rate has the same effect on both amines which the higher circulation rate results in more CO_2 removal. Almost all amines with all concentrations were giving an acceptable concentration of CO_2. All the results match with the required safety of pipelines specifications (Figure 2).

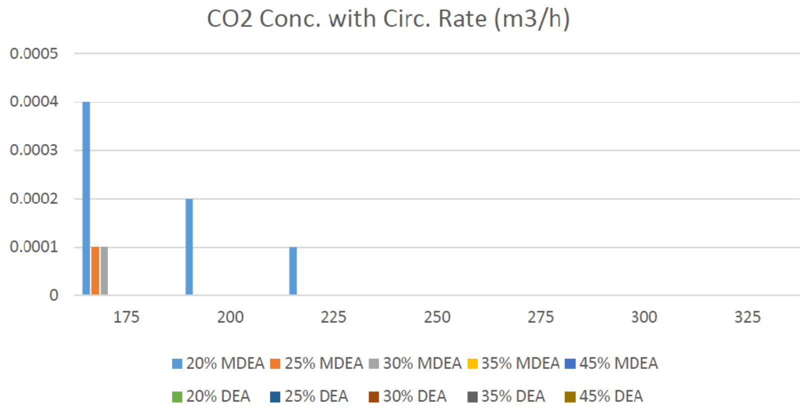

Figure 2. effect of a different percent of amines on CO2 concentration in sweet gas.

Amount of H_2S in the sweet gas stream of the absorber column

All amines concentrations with different circulation rates were showing zero H_2S amount in the sweat gas stream of the absorber column. This promises the removal of H_2S completely with all tested cases.

Wasted hydrocarbon inside acid gas (AG) streams

The best result for the loss of hydrocarbons demonstrated at 30%DEA, 20% DEA, 20%MDEA, and 30%MDEA, while with a higher circulation rate the higher hydrocarbon (HC) waste observed (Figure 3). Therefore, keeping both circulation rate and amine concentration in a rational range would give benefit to the plant productivity and energy loss which at a circulation rate of 225 and 250 m3/h seems an appropriate status.

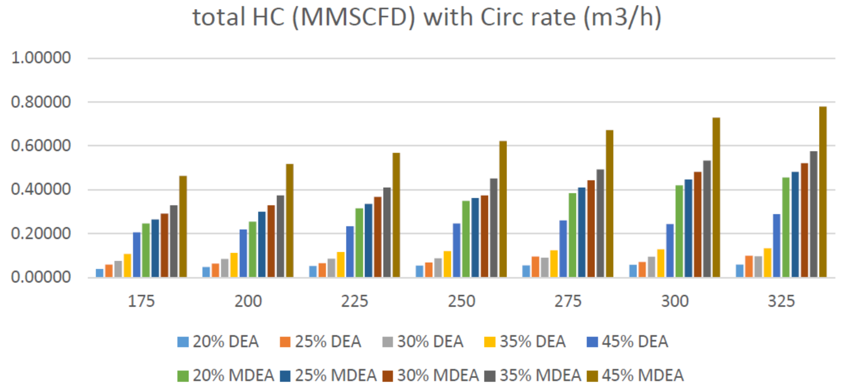

Figure 3. Total HC waste from light HC and AG streams.

Water losses in the process plant

There are three streams that water can escape through, and they are (sweet gas stream, the acid gas stream, and the light HC stream from the seperator). The result showed (increasing the circulation rate in all cases comes out with increasing water loss and also DEA saves more water than MDEA in the system (Figure 4). Moreover, the lowest water loss was observed at 45% DEA and 20% MDEA compare to all other amine concentrations in all different circulation rates. Besides, with increasing concentration of MDEA also water loss will increase but with increasing DEA concentration the water loss decrease.

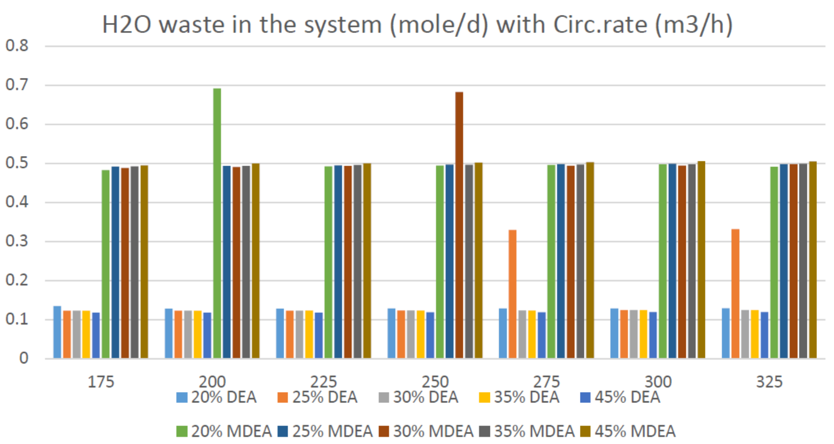

Figure 4. Effect of different percent of mixing amines on water loss.

Energy consumption

The condenser and the reboiler duty for regeneration are the foremost major points to be overseen in terms of energy consumption. After running the simulation, the results showed, the best circulation rates were 175 and 225 m^3/h with DEA based amine is always the least amount of condenser duty observed. The MDEA is always counting twice condenser duty compare to DEA (Figure 6). On the other hand, the Reboiler duty was showing the inverse of the condenser in which the duty of heating DEA is always higher with 20% (Figure 7). The circulation rate of 200 and 250 m^3/h shows a stable and not excessive amount of heat for MDEA amine because the amount of the change from 225 m^3/h gets so close to each other. DEA amine at a circulation rate of 175 m^3/h and 25% DEA the amount of energy saved is the highest which equals 60.988 MMBtu/hr (Figure 5). After simulating for one day, the daily energy-saving became 213 MMBtu/day.

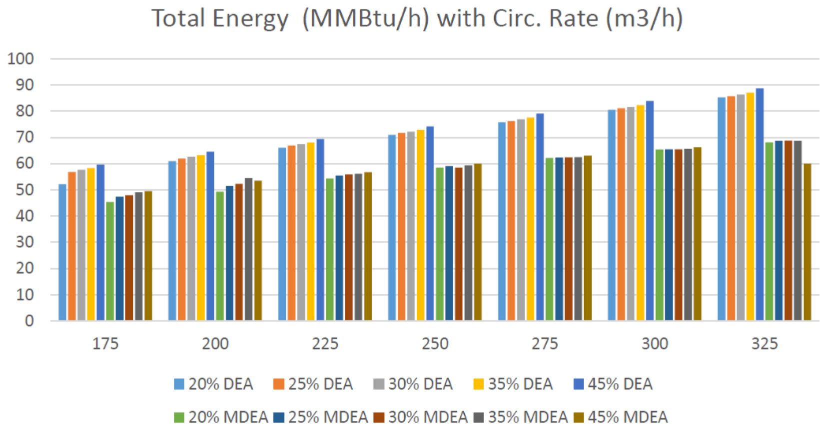

Figure 5. Total Energy required by Regenerator.

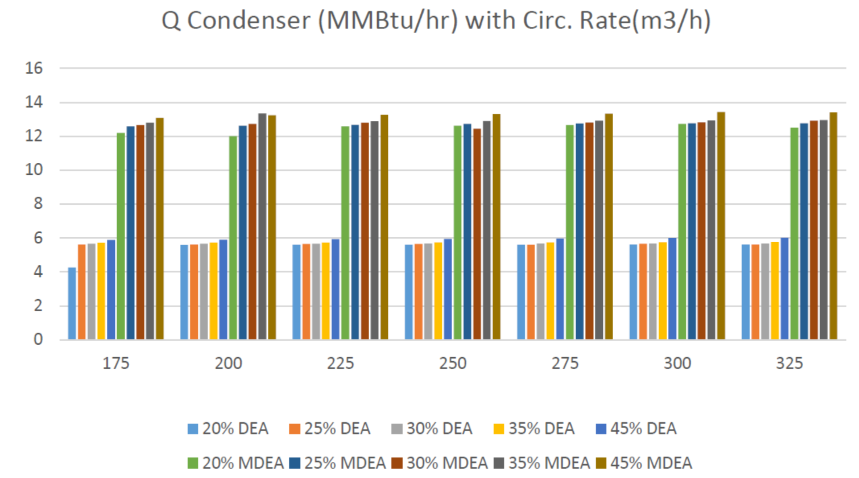

Figure 6. The required energy for the Condenser of Regenerator column.

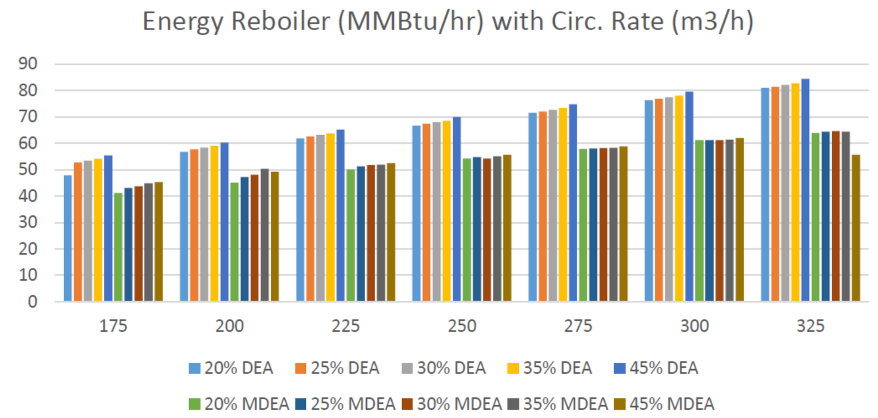

Figure 7. The required energy for the reboiler of the regenerator column.

Conclusion

In this study, different Amine concentrations, and two amines with different circulation rates were used for simulating an existing gas production facility. The target always must consider the amount of H_2S and CO_2 in the sweet gas which shall not be more than 4 PPM of H_2S and 2% of CO_2. For the simulation, HYSYS has been used with the property package of Acid Gas Package. The simulation runs with 10 cases, the first five cases with DEA, and the next five cases MDEA with different concentrations.

The results show that, with increasing circulation rate with any amine concentration of DEA and MDEA amine types, causes to decrease in the concentration of CO_2 in the sweet gas. According to this result, the optimal circulation rate is 200 m^3/h. and Also DEA works better than MDEA regarding removing CO_2.

The amount of H_2S mole fraction in sweet gas was 0.00000% with all different amine types with different concentrations and different circulation rates. All simulation cases showed a high performance with treating the amount of H_2S inside the sour gas. The total HC waste was recorded with 30% DEA, 20% DEA, 20% MDEA, and 30% MDEA. Although it is proven with increasing concentration and circulation rate, the loss of Hydrocarbons will increase. According to the final analysis, between 225 and 250 m^3/h would keep the process in an appropriate status for saving the maximum amount of hydrocarbons. The temperature of the rich amine stream, any ascending concentration of amines increases the temperature of the rich amine stream because the density increases also due to this the capacity of saving energy will increase. The MDEA with 20% and 25% were showing the best result between

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the circulation rate of 200 to 250 m^3/h. For water loss problem-solving, the circulation rate (between 200 and 225 m^3/h) with possible highest DEA (30-45% DEA) and lowest MDEA (20-30% MDEA) amine concentration was the best choice. In circulation rate of 175 m^3/h, 20% DEA, and 25% DEA the amount of energy saved was the highest average (60.988 MMBtu/hr). The saved energy consumption per day is approximately equal to 213 MMBtu.

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