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Economical and Environment-Friendly Utilization of the Eastern Desert Oil Fields Flare Gases

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Abstract

Natural gas's relevance has grown considerably because of recent key world events. One of the biggest challenges in processing raw natural gas is the presence of acid gases, particularly hydrogen sulfide, a highly toxic gas. This paper uses a proposed amine sweetening unit to treat sour gases with a high content of acid gases that exceed 12 wt% in Ras Gharib oil fields (Eastern Desert, Egypt). The present study aims to use these gases rather than transmitting them to flares as it is applied to the existing case with no benefit and significant environmental pollution. HYSYS (version 9) is used as a simulation software to study and simulate the introduced sweetening process using Monoethanolamine (MEA), Diethanolamine (DEA), and Methyl Diethanolamine (MDEA) as solvents to reach an acceptable limit of hydrogen sulfide at a reasonable cost. Furthermore, this paper summarizes a sensitivity study to optimize the operating parameters of the process considering optimum cost and energy consumption. The simulation results show that the sweetening unit applying MDEA is the preferable and cost-effective unit with a high-anticipated outcome that reaches 22 million USD annually. Additionally, the flared gas quantities are reduced by 85 wt% which reduces the pollution with an attractive environmental impact to the atmosphere.

Keywords: *Sweetening; Hydrogen sulfide; Monoethanolamine; Diethanolamine; Methyl diethanolamine; Sour gas.*

1. Introduction

As natural gas is an unavoidable fuel, it has become increasingly vital to treat it as the consumption and usage of NG have risen by approximately 22% over the past ten years, Therefore, due to tight environmental norms and laws, Natural gas processing becomes more intricate and important to develop a usable, clean fuel while also satisfying the energy needs [1].

Natural gas is a complicated blend of several hydrocarbon chains. In most cases, it comprises a significant amount of methane in addition to heavier hydrocarbons such as ethane, propane, butane, propane [2]. Nitrogen, water, and acid gases are examples of non-hydrocarbons that can be found in natural gas. Acid gases in untreated gases like carbon dioxide (CO_2) and hydrogen sulfide (H_2S) should be further processed, as Hydrogen sulfide is a highly corrosive and toxic substance, while carbon dioxide's main issues are reducing the heating value of natural gas and freezing at extremely low temperatures [3-4]. furthermore, it is expected that total CO_2 emissions will reach 37.2 Gt by 2035 due to the fuel combustion facilities according to World Energy Outlook.

The sweetening method is crucial in gas processing for the reasons described above to achieve sales gas specifications. The techniques used in gas sweetening procedures are diverse and can vary depending on a variety of factors. The basic approaches of natural gas sweetening can be divided into four groups described below [5].

1. Solvent absorption. Absorbers are widely used to remove acid gases with sulfur compounds present and in similar systems, where a chemical reaction or solubility properties can remove undesired compounds in a vapor stream and transfer them to the absorption material.

2. Solid adsorption: Because of the continual development of adsorbents, the usage of adsorption has improved in recent years. Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a high surface area solid (adsorbent) [6].

3. Permeation through a membrane is a technique that depends on the principle of selective permeation of one or more components. A pressure differential across the membrane is maintained to allow at least one of the gases in the feed mixture (the acid gas in the sweetening process) to selectively permeate through the membrane from the high-pressure side of the membrane to the low-pressure side. Membrane technology has been introduced to reduce the load on the amine process in the natural gas treatment plant, instead of expanding the amine acid gas facility [7].

4. Direct aonversion depends on the oxidation process to convert hydrogen sulfide to elemental sulfur. This process is used to treat gas streams containing high concentrations of H_2S [8].

Chemical absorption using an aqueous solution of a weak base is the method of sweetening that is used the most frequently because this method is efficient, compact, and can reach an acceptable limit of H_2S at a reasonable cost, besides being not sensitive to the inlet pressure. Another factor favoring chemical absorption is the treatment for both CO_2 and H_2S, as it can target both compounds in a single system. Besides that, the chemical absorption unit can be skid mounted system, making it easier to transport [9].

Alkanolamines are the most frequently accepted and utilized solvents available for removing acid gases from natural gas streams. Amines are chemical compounds formed by substituting an organic group for one or more hydrogen atoms in ammonia (NH_3) [10]. The amine that results can be primary, secondary, or tertiary depending on how many hydrogen atoms are replaced. Nevertheless, despite offering a high purity of CH_4 content in the sweet gas stream using an amine-based chemical absorption process, However, there is still a need to look at the significant energy requirement incurred during its regeneration process, which raises the overall cost and makes treating very sour gases a great challenge [11].

Primary amines have the general formula RNH_2, where R is the acrylic or alkano group. Examples of primary amines are monoethanolamine (MEA) and DiGlycolamine (DGA). MEA has the advantage of cost and low density. The main issue with primary amine is its high vapor pressure, which causes high vaporization losses. Reactions between primary amines and carbonyl sulfide or carbon disulfide result in irreversible reaction products which leads to even more losses [8-9]. Secondary amine diethanolamine (DEA) is less basic and reactive than MEA. It has a lower vapor pressure than MEA, resulting in lower evaporation losses; it can work at higher acid gas loadings, typically 0.35 to 0.7-mole acid gas/mole of amine; and the reactivation process requires less energy. Concentration ranges for DEA are 30 to 50 weight percent, and corrosion is the main limiting factor. Forming regenerable compounds with COS and CS_2 is another benefit of DEA [12].

MDEA is a tertiary amine used to sweeten natural gas streams, much like the other amines. MDEA can selectively extract H_2S in the presence of CO_2. H_2S concentrations can be reduced to those required by pipelines, while at the same time, 40-60% of the CO_2 flows untreated through the contactor. In most cases, amine solution strengths range from 40% to 50% MDEA by weight. Acid gas loading can range from 0.2 to 0.4 moles of acid gas per mole of MDEA. Higher allowable MDEA concentration and acid gas loading result in reduced circulation rates, reducing pump and regeneration requirements [13].

Regardless of the type of amine used, the fundamental amine sweetening procedure remains the same, as it consists of two basic steps: absorbing and regeneration. The absorbing process occurs in an absorber where the downflowing amine solution absorbs acid gases from the upflowing untreated gas to produce a sweetened gas stream. The regeneration process is based on increasing the temperature of the amine solution to reverse the chemical processes that occurred in the previous step and regenerate the amine that is recycled for reuse in the absorber [14-15]. A process flow diagram of an amine sweetening process is shown in Figure 1.

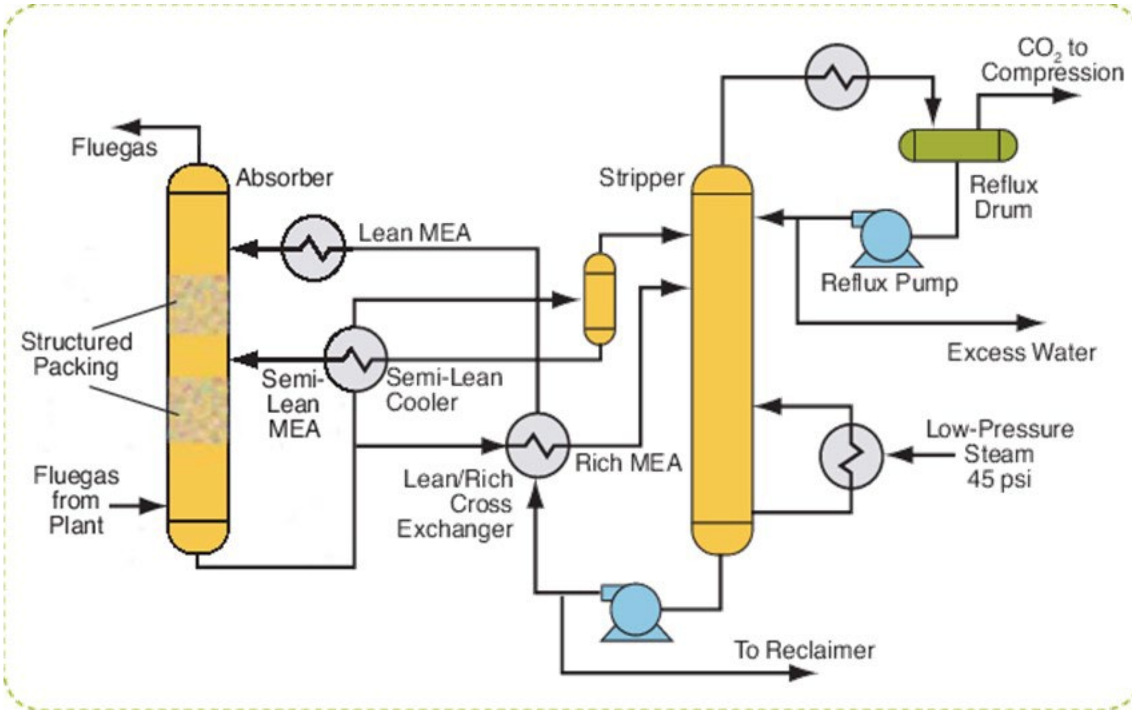

Figure 1. Process flow diagram of the amine unit(modified after [16]).

Numerous earlier publications have addressed the optimization and simulation of gas-sweetening processes. Simulation software is frequently utilized to obtain a robust model to study the effects of operating and design parameters on the efficiency of the process. For example, Abdulrahman and Sebastine [17] simulated a high acid gas content sweetening process using Aspen HYSYS. They studied the lean amine temperature effect on the performance of the absorption column. Tikadar *et al.* [18] examined the impact of lean amine and gas temperatures on other variables such as sweet gas H_2S content, sweet gas CO_2 content, and power consumption.

Muhammad and GadelHak [19] employed the Aspen HYSYS simulator to investigate the effects associated with the concentration of acid gas content in the gas feed on the overall cost of the unit. Zare Aliabad and Mirzaei [20] conducted research to study the absorption of acid gases into a solvent mixture consisting of DEA and MDEA. It was observed that packing height has a significant impact on CO_2 absorption but has little effect on the clean gas's H_2S concentration. All of these studies were conducted on large-scale gas sweetening plants.

This paper outlines a proposal for utilizing the flared gases associated with Ras Gharib oil fields (Elhamd, Gharib, and Fanar) which are burned with negative effects on the environment, as shown in Figure 2.

The purpose of this study is to perform an economic study summarizing the profitability, revenues, and economics along with the expected environmental impact of treating and processing about 15 MMSCFD of the sour gases produced in the Eastern Desert oil fields (Egypt). Unlike the current study, all of the previous studies focused on large-scale gas sweetening processes.

The novelty of the paper lies in discussing the ability to treat small amounts of gases with high acid content (reaching 10.5% H_2S) in an economical method and comply with the policy of the government to reduce the flared gases. Besides that, the previous research on acid gas removal has been focused only on evaluating systems to meet sweet gas criteria. This paper not only focuses on the sweet gas specifications but also studies the desired acid gas hydrogen sulfide content to meet sulfur recovery unit requirements which can be used as a future development for the acid gases.

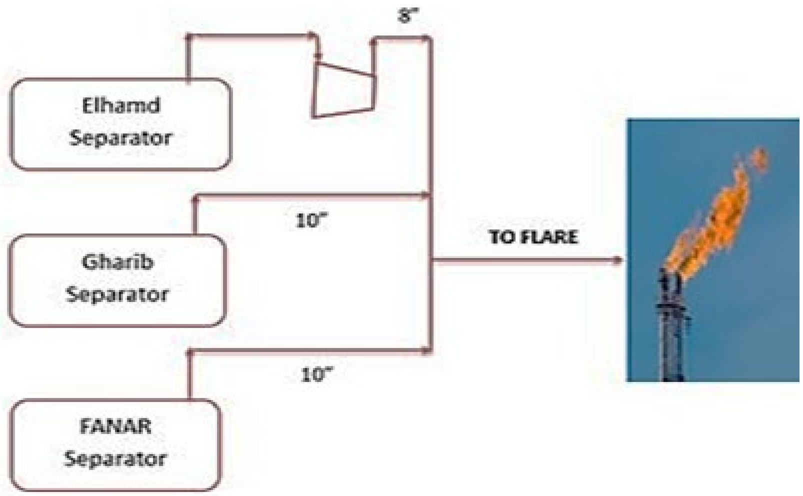

Figure 2. Flare gases path from Ras-Gharib oil fields.

The paper is aligned with the Zero Routine Flare initiative by 2030, as the paper studies a cost-effective and environmentally responsible manner to treat sour gases instead of flaring as the studies showed that CO_2 emissions associated with the burning of fossil fuels constitute up to 78% of the total emissions between 1970 and 2010 [21]. This research also presents a comparison between three types of amine solutions: monoethanol amine, diethanol amine, and methyl diethanol amine to select the optimum amine solution among them as well as the operational factors optimization of the proposed acid gas treating process were also studied in the present research paper by using Aspen HYSYS (version 9) with a fluid package known as the Amine package.

2. Methods

Sour gas streams with a high CO_2/H_2S ratio can be treated to produce on-spec gases. These gases shall not exceed a certain amount of hydrogen sulfide (usually 4 ppm), and/or carbon dioxide. This current work studies how to treat sour gases with high acid gas concentrations (over 12 wt%) in Ras Gharib oil fields (Eastern Desert, Egypt) by applying a proposed amine sweetening unit. Instead of sending these gasses to flares, as it is applied now, with no benefit and severe environmental pollution, the present study aims to have an economic return from these gases and make the investigated oil fields more environmentally friendly.

HYSYS is a common and reliable software that can provide results with a high degree of satisfaction and accuracy. HYSYS software (version 9) was used to study and simulate the introduced sweetening process using monoethanolamine, diethanolamine, and methyl diethanolamine as solvents, to obtain an acceptable level of hydrogen sulfide at an acceptable cost. The choice of the best solvent depends on the sweet gas H_2S content, corrosion analysis, and economic considerations. This simulation program is also beneficial for determining the optimal operational conditions of the investigated process to be run more affordably and efficiently.

3. Case study

This study discusses the utilization of 15 MMSCFD of the associated gases produced from El-Hamd, Gharib, and Fanar oil fields located in the Eastern Desert of Egypt by applying the proposed amine sweetening unit. In the current situation, the crude oil produced from previous fields is treated while most of the associated gases are directed to the flare. The analysis of each field was measured separately by a gas chromatograph which is also used to examine the mixed feed from the three fields; the gas chromatograph results are shown in Tables 1 and 2.

Table 1. Fanar Field, Gharib Field, and El-hamd Field associated gases compositions.

Component	Fanar Field	Gharib Field	El-Hamd Field
	Mol.%	Mol.%	Mol.%
Methane	47.138	50.305	61.371
Ethane	13.831	16.194	10.476
Propane	11.307	11.541	9.157
i-Butane	1.753	1.511	1.225
n-Butane	4.591	3.359	3.338
i-Pentane	1.502	0.871	0.973
n-Pentane	1.519	0.711	1.019
Hexanes	1.439	0.561	0.837
Benzene	0.004	0.006	0.006
Heptanes	0.408	0.131	0.217
Toluene	0.006	0.013	0.007
Octane	0.163	0.054	0.074
Ethylbenzene	0.002	0.004	0.001
p, m, o - xylene	0.005	0.009	0.005
Nonanes	0.036	0.015	0.015
Nitrogen	0.397	0.332	0.307
Carbon dioxide	4.297	3.258	2.173
Hydrogen sulfide	11.602	11.125	8.799
Total	100	100	100

The next step in the study is to simulate the proposed sweetening unit using HYSYS (Version 9) with an acid gas–chemical solvent fluid package [22-23]. The considered sweetening process is applied to treat the combined feed flare gases stream with the composition shown in Table 2 which includes high acid gas content. The operating conditions of the mixed raw gases were measured using local gauges and an orifice plate flow meter; The determined pressure, temperature, and flow rate of the sour gas feed are 1000 psia, 25°C, and 15 MMSCFD respectively. The amines used in the proposed sweetening unit are MEA, DEA, and MDEA. Table 3 shows the concentrations and pick-up rates for various amine solutions [9].

The considered sweetening processes contains an absorber with 20 trays to be used to absorb acid gases from the untreated sour gas stream at a pressure of 1000 psia, and a stripper with 20 trays operates at atmospheric pressure to be used to break the chemical reactions formed earlier and regenerate the amine for reuse.

Table 2. The combined feed flare gases stream composition.

Component	Mol.%	Component	Mol.%
Methane	51.97	Toluene	0.00
Ethane	13.52	Octane	0.00
Propane	10.86	Ethyl-Benzene	0.00
i-Butane	1.49	p, m, o - xylene	0.00
n-Butane	3.97	Nonanes	0.00
i-Pentane	1.35	Nitrogen	0.34
n-Pentane	1.31	Carbon dioxide	1.24
Hexanes	0.93	Hydrogen sulfide	10.45
Benzene	0.01	Water Vapor	1.81
Heptanes	0.75	Total	100

The circulation rate of each type of amine depends on the solution pick-up rate and the solution concentration for each type and it can be calculated using the data listed in Table 3. The calculated circulation rates for MEA, DEA, and MDEA solutions are 357, 250, and 179 GPM respectively.

As recommended, the temperature of the lean amine entering the absorber should be 7°C greater than the inlet sour gas temperature to prevent any condensation of heavy hydrocarbons in the feed sour gas. Simulation of the sweetening process with the calculated circulation rates will be performed for each type of amine to ensure that the sales gas is within the acceptable specs.

Moreover, this paper presents a sensitivity analysis for the key operational variables of the amine process; these operating conditions will be optimized for each type of amine to reach an acceptable limit of hydrogen sulfide with the lowest cost. Finally, an economic evaluation is performed to evaluate the economics of the proposed unit.

Table 3. Concentrations and pick-up rates for various amine solutions.

Type of amine solution	Amine solution concentration, wt%	Solution Pick-up rate	
		M^3 acid gas per liter of solution	Ft^3 acid gas per gal of solution
MEA	15 – 20	0.023 – 0.03	3 - 4
DEA	20 – 30	0.03 – 0.038	4 - 5
MDEA	40 – 60	0.038 – 0.050	5 - 7
DGA	50 – 70	0.038 – 0.053	5 - 7

4. Results and discussion

Our primary focus in this study is the utilization of flared gases through the application of the proposed sweetening unit. Amines are frequently used by the majority of natural gas sweetening facilities to extract H_2S and other sulfur compounds from the gas. There are several distinct amines; the most common ones are MEA, DEA, and MDEA solvents.

To select the best amine type, the proposed sweetening process is simulated using HYSYS (version 9) by applying the three types of amines. The program provides a robust thermodynamic package known as the Amine package, a unique package made specifically for simulating amine sweetening units.

The selection between the different types of amines is based on the H_2S content of sweet gas, corrosion analysis, and economic considerations. It should be noted that the investigated sweeting unit was optimized for each type of amine to determine the optimum operational conditions that can be used to achieve an acceptable limit of H_2S of the sweet gas at the lowest cost.

4.1. Sweetening process using MEA as a solvent

The sweetening plant with the application of MEA was simulated using the feed gas composition presented in Table 4 at the operating conditions mentioned earlier. The simulation results are shown in Figure 3. According to these results, it is noticed that at an amine flow rate of 357 GPM, 12.92 MMSCFD of sweet gas with about 0.24 ppm of H_2S is produced from the sweetening process. With a deeper analysis of the operation conditions, it's found that the lean amine temperature at the inlet of the absorber is 32°C which is higher than the sour feed gas temperature by 7°C as recommended, Table 4 shows the main operating conditions of the sweetening process using MEA solvent.

Table 4. The main condition of the MEA cycle.

CO_2 concentration in sweet gas, mol%	5e-007
H_2S concentration in sweet gas, ppm	0.2404
Rich amine loading	0.3505
Regenerator feed temperature, °C	70
Amine strength, %wt	20
Amine recirculation rate, GPM	357
Lean amine temperature, oC	32
Feed gas flowrate, MMSCFD	15
Feed gas CO_2 concentration, mol%	0.0124
Feed gas H_2S concentration, ppm	1045

Regarding the current case, the rich amine loading and strength are 0.35 and 20% respectively. The recommended range for amine loading and strength of MEA is up to 0.4, and up to 20% respectively which indicates that there is no risk of excessive corrosion of the rich solution of MEA [9]. From an economic point of view, the average price of MEA is about 7 $/gallon, and the estimated total power needed for the considered sweetening process is about 54000 KW.

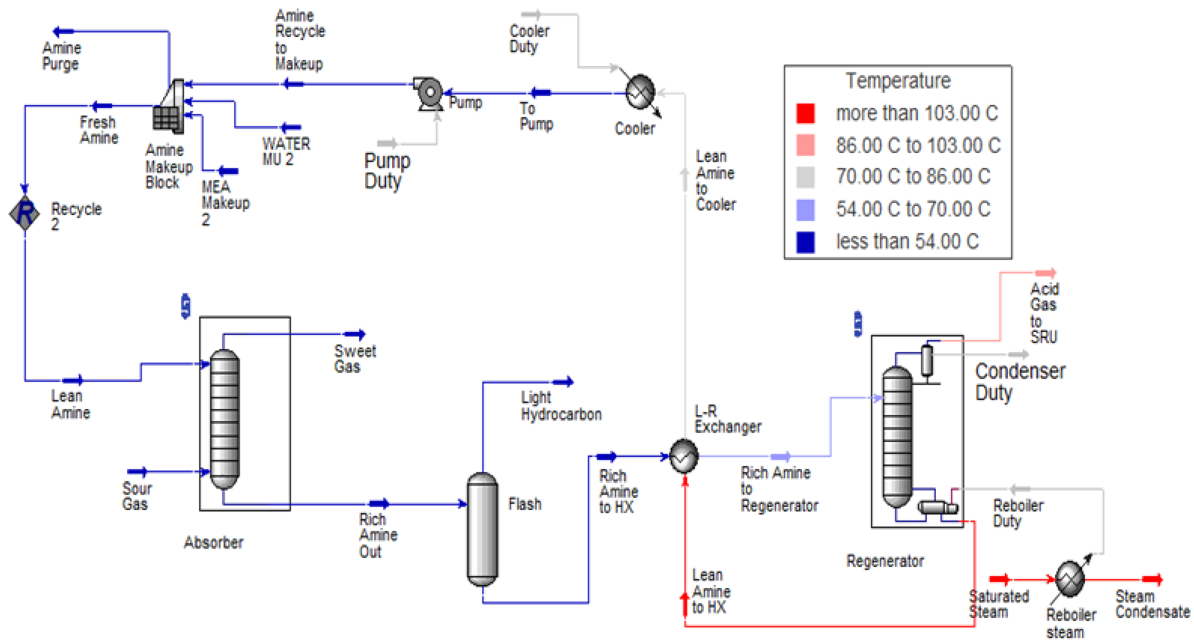

Figure 3. Simulation of the sweetening process using MEA as a solvent.

4.2. Sweetening process using DEA as a solvent

The simulation of the sweetening unit applying DEA solvent also depends on the feed gas composition tabulated in Table 2 and the operating conditions mentioned earlier. Figure 4 shows the simulation of the considered sweetening process with DEA. According to the simulation results, when applying 250 GPM of DEA, a sweet gas with a flow rate of 12.94 MMSCFD and of H_2S concentration of 0.702 ppm is produced as listed in Table 5 which shows the main data and operating conditions of the considered sweetening unit.

Table 5. The data and main operational conditions of the sweetening process with DEA cycle.

CO_2 concentration in sweet gas, mol%	5.019e-005
H_2S concentration in sweet gas, ppm	0.702
Rich amine loading	0.6115
Regenerator feed temperature, oC	93.33
Amine strength, %wt percent	26.00
Amine recirculation rate, GPM	250
Lean amine temperature, oC	33
Feed gas flowrate, MMSCFD	15
Feed gas CO_2 concentration, mol%	0.124
Feed gas H_2S concentration, ppm	1045

The second parameter to be considered is the corrosion influence of DEA. The rich amine loading for this process is 0.61, with an amine strength of 26%. The recommended ranges for amine loading and strength of DEA are up to 0.7 and up to 30% respectively. This consequently indicates that there are no harmful effects regarding corrosion of the DEA-rich amine solution [15]. The calculated total power needed for the investigated sweetening process with the DEA cycle is 9750 KW and the average price of DEA is about 9 $/gallon.

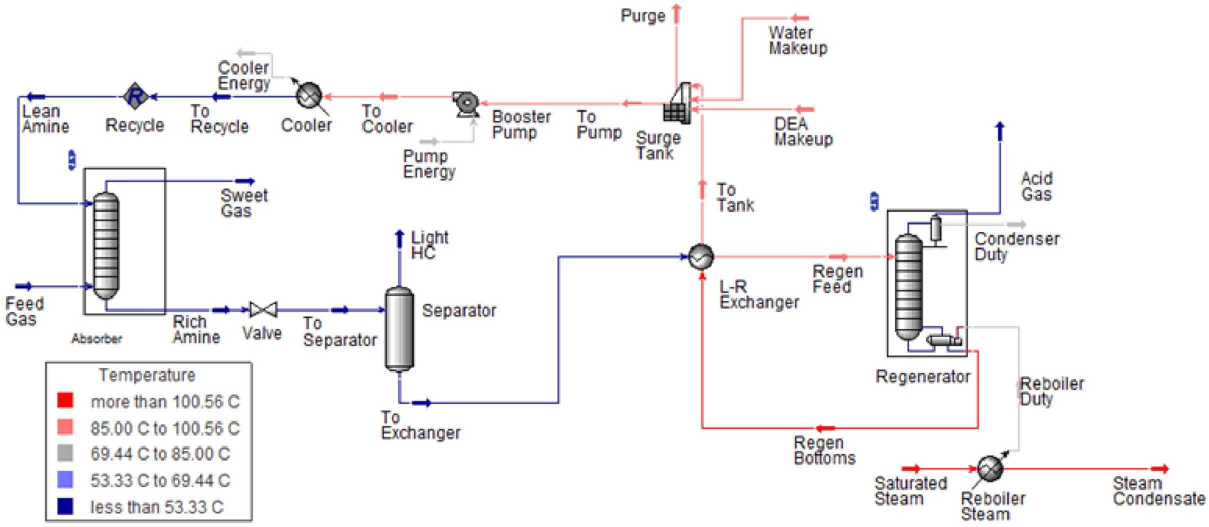

Figure 4. Simulation of the sweetening process using DEA cycle.

4.3. Sweetening process using MDEA as a solvent

The feed gas composition for the introduced sweetening unit using MDEA as a solvent is presented in Table 2. The simulated sweetening process with MDEA is shown in Figure 5. The simulation results show that 12.64 MMSCFD of sweet gas with 2.5 ppm of H_2S can be produced at a flow rate of 180 GPM of MDEA solution.

The rich amine loading and strength in the case of MDEA are 0.40, and 60% respectively. The optimum ranges for amine (MDEA) loading and strength are up to 0.4 and up to 60% respectively [14]. This in turn indicates no corrosion risk of the rich solution of MDEA. Table 6 lists the main data and operational conditions for the sweetening process with the MDEA cycle.

It should be noted that the average price of MDEA is about 10,25 $/gallon, and the calculated total amount of power required for the MDEA sweetening process is 8940 KW. This power requirement is the lowest power compared to 9750 KW in the case of the investigated DEA sweetening unit and to 54000 KW in the case of the considered MEA sweetening unit. This power reduction leads to a major reduction in the overall operating cost.

Table 6. The main data and operational conditions of the sweetening process with MDEA cycle.

CO_2 concentration in sweet gas, mol%	4.64e-002
H_2S concentration in sweet gas, ppm	2.49
Rich amine loading	0.4051
Regenerator feed temperature, oC	93
Amine strength, %wt percent	60
Amine recirculation rate, GPM	180
Lean amine temperature, oC	33
Feed gas flowrate, MMSCFD	15
Feed gas CO_2 concentration, mol%	0.0124
Feed gas H_2S concentration, ppm	1045

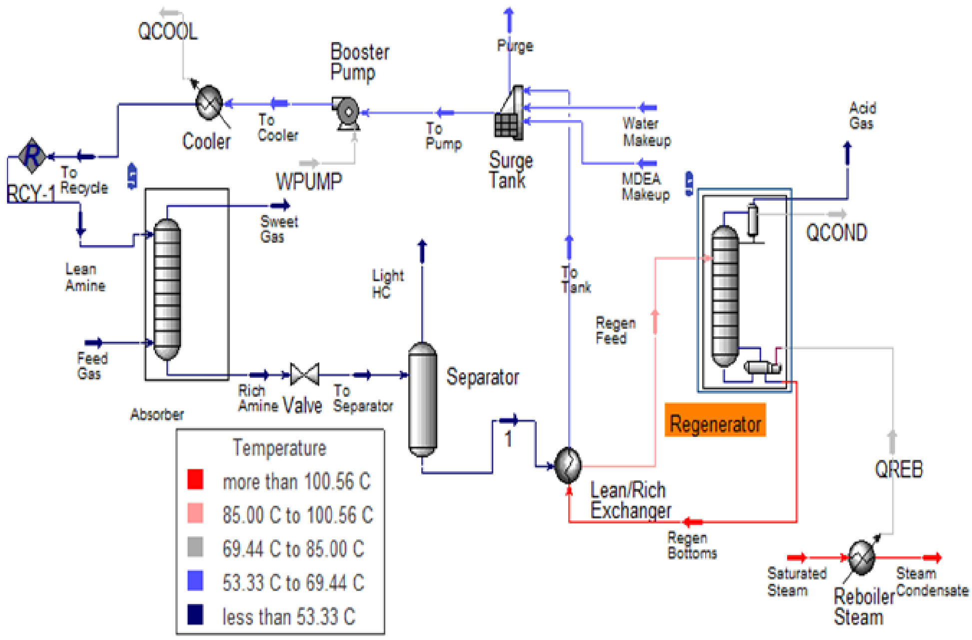

Figure 5. Simulation of the sweetening process using MDEA cycle.

4.4. Selection of the economic sweetening process

Regarding the previous simulation results, it is obvious that the three investigated types of amines can reach an acceptable limit of H_2S in the sales gas. That means all of the three amines can be used as a solvent for the introduced sweetening process. Thus, the selection of the best process will be based on the economic study of the previous alternatives.

Table 7 summarizes the operating cost of the sweetening process when applying the considered amines based on the average cost of power in Egypt. According to the results of Table 7, it is clear that MDEA is deemed to be the most cost-effective option because it can meet the sales gas specifications of acid gas content with the least amount of energy and circulation rate.

Table 7. The operating cost for different amines.

Item	MEA, 20 wt%	DEA, 26 wt%	MDEA, 60 wt%
Circulation rate, GPM	357	250	180
Amine cost, USD/gallon	7	9	10.25
Cost flow, USD/Min	500	585	1,107
Power, kW	54000	9750	8940
Power cost, USD/year	49,275,000	8,896,875	8,157,750

4.5. Main parameters affecting the sweetening process efficiency

After selecting the MDEA sweetening process as the optimum process. The present work study also the main operational parameters of the investigated sweetening process applying MDEA such as the contactor temperature and the flow rate of the used amine. In the following subsection, the effect of contactor temperature and the flow rate of amine on the sweetening process efficiency will be discussed.

4.5.1. Effect of the contactor temperature

The temperature of the contactor is very vital in the sweetening process. The quantity of acid gas that the amine solution will pick up depends on the temperature of the contactor. It is desirable to hold the lowest temperature in the contactor to remove the maximum amount of acid gases. Therefore, the inlet temperature of sour gas should be cooled as much as possible if applicable [24-25]. Figure 6 shows the effect of the temperature of the inlet lean amine (MDEA) on the acid gas content of the outlet gas stream.

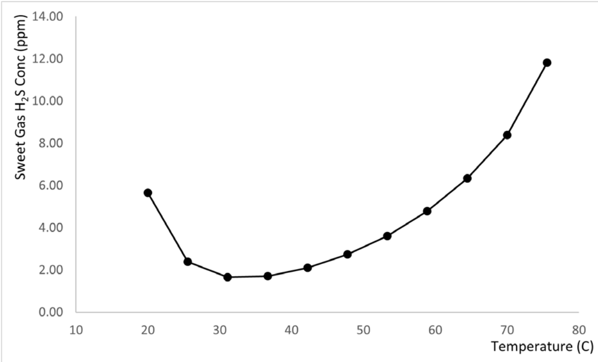

Figure 6. Effect of contactor temperature on the acid gas content of the sweet gas.

From Figure 6, it appears that cooling the lean amine entering the contactor as much as possible would be desirable to reduce the temperature in the contactor and absorb more acid gas. As a sensitivity analysis for the introduced unit, when the absorption process occurred at a temperature of 60ºC, an unacceptable sweet gas of 6 ppm H_2S is produced, while decreasing the contactor temperature to 40ºC at the same circulation rate will decrease the H_2S content of the sales gas to 2 ppm.

However, if the temperature of amine entering the contactor is less than the temperature of the feed sour gas, the gas will cool down, and some heavy hydrocarbon will condense out of the gas resulting in major losses of amine and an increase in the H_2S content in the outlet stream. Consequently, the lean amine entering the contactor should be 6-9 °C higher than the inlet sour gas. In the proposed cycle, the temperature of the acid gas entering the contactor is 25°C while the temperature of the MDEA amine is optimized to be 33°C.

4.5.2. Effect of the amine circulation rate

The quantity of acid gas removed from the sour gas depends mainly on the amine solution circulation rate. When the solution flow rate increases, more acid gases will be removed from the sour gas as presented in Figure 7. However, another important parameter that must be taken into consideration is rich amine acid gas loading.

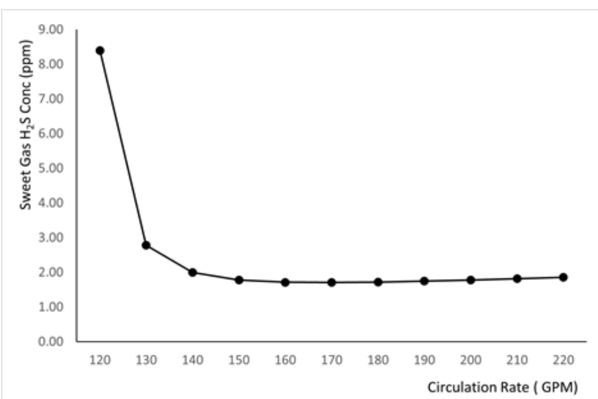

Figure 7. Effect of circulation rate of MDEA on the acid gas content.

If the amine loading increases above the recommended range, the rich solution will be very corrosive to the equipment. The maximum recommended ranges of acid loading of the rich solution for MEA, DEA, and MDEA are 0.4, 0.7, and 0.4 respectively [9,26].

To validate the previous concept, a case study will be conducted through the HYSYS simulation software for different circulation rates. For simplicity, the case study will focus mainly on the amine circulation rate, and the corresponding results for the acid gas content of the sweet gas, and the rich amine acid gas loading.

Table 8 shows amine loading at different circulation rates (130, 150,180,200, and 220 GPM) of the MDEA solution. It is noticed that the same acid content can be obtained at amine loading higher than 150 GPM. For amine concentrations from 130 to 220 GPM, the acid gas content of the sweet gas is within the acceptable range, but the rich amine solution will be very corrosive to the equipment.

The corrosiveness of the rich solution is lowered by decreasing the rate of amine pick-up; this is done by increasing the circulation rate. In the current proposal, The flow rate is optimized for each type of amine to not exceed the recommended rich amine acid gas loading.

Table 8. Rich amine acid gas content for different circulation rates of MDEA.

Case	Circulation rate, GPM	Sweet gas H_2S, ppm	Rich amine acid gas loading
Case 1	130	2.79	0.49
Case 2	150	1.78	0.43
Case 3	180	1.72	0.36
Case 4	200	1.78	0.32
Case 5	220	1.86	0.30

It also noticed from the previous table, that the acid gas content of the sweet gas is slightly increased when the amine circulation rate increased above 180 GPM due to the observed flooding in the absorber which decreases the efficiency of the natural gas sweetening process.

4.5.3. Effect of piperazine

Over the past few decades, numerous formulations and combinations of amines have been developed to enhance the effectiveness and efficiency of the sweetening process using a catalyst or an activator. Piperazine (PZ) is one of the most commonly utilized catalysts where it absorbs CO_2 and transfers the absorbed CO_2 gases to the MDEA [27-28].

The effect of piperazine's concentration on H_2S content is studied within fixed MDEA concentration, as well as the effect of piperazine's concentration on the reboiler duty. The results showed that for a PZ concentration of 3 wt%, the acid gas content of the sales gas decreased by 28%, and this percentage will be a 42% reduction in the acid gas content of the sales gas when the PZ concentration reaches 5 wt%.

As expected, the reboiler duty increased with the increasing PZ concentrations. The reason is that MDEA as a pure solvent requires a low heat of regeneration. When PZ is added, the heat of regeneration for the mixed solvent increases significantly because the CO_2 recovery is nearly 100%. For the PZ concentration of 3 wt%, the cycle heat duty increased by 4%, this percentage increased to 5% when the PZ concentration reached 5 wt%. The previous results showed that using piperazine as an activator is not economical for the low-scale sweetening unit where H_2S is the dominant acid gas not CO_2 as in the current research.

4.6. Economic study of the introduced proposal

The current direction is towards renting equipment instead of purchasing new equipment eliminating the Total Capital Investment (TCI). This can be attributed to several reasons like the uncertainty of reservoir life, short payback time, and reduction of investment hazards [29]. The Total Operating Cost (TOC) is broken down into unit rental cost, installation cost, and power cost [30]. Compared to similar and equivalent projects, the average annual rental cost of an amine sweetening unit is about 4,000,000 USD.

The installation cost of the project, which will be roughly 1,600,000 USD, is another crucial factor that must be considered. On the other hand, gas prices have witnessed a significant increase, as the gas price in the last 3 months according to Henry Hub, is about 6 USD/MM Btu. As a result, the MDEA proposal is considered very profitable according to the current gas price and the total expected costs, as shown in Table 9.

Table 9. The economic study summary of the introduced sweetening plant applying MDEA.

Item	First Year	Later Years
Power cost	(8,157,750.00)	(8,157,750.00)
Raw MDEA	(50,800)	0
Losses of MDEA 15%	(7,620)	(7,620)
Rental unit cost	(4,000,000)	(4,000,000)
Unit installation cost	(1,600,000)	0
Sales gas price	37,676,760.00	37,676,760.00
Annual profit	23,860,590.00 USD	24,015,640 USD

5. Conclusions

The main objective of the current research work is to study the applicability of an amine sweetening unit to remove hydrogen sulfide to an acceptable limit from 15 MMSCFD of sour gases extracted from the Eastern Desert oil fields. Regarding the proposed sweetening process, different types of amines such as MEA, DEA, and MDEA were used at various circulation rates and at different concentrations to produce on-spec sweet gases. The sweetening process is optimized to achieve the lowest cost taking into consideration the corrosion limit and the total power consumption of each amine type.

The second part of the current work is directed to study the effect of some operational conditions on the efficiency of the introduced sweetening plant. The simulation results showed that as long the temperature of amine entering the contactor is higher than the temperature of the feed sour gas, the acid gas content of the produced gas is proportional to the contactor temperature.

The effect of the amine circulation rate is also studied, and it was found within the acceptable limits of rich amine acid gas loading, the acid gas content of the produced gas is inversely proportional to the amine circulation rate. On the other hand, Piperazine as a catalytic will enhance the capability of MDEA to absorb acid gases from natural gas, but the cycle power consumption will significantly increase.

Even though MDEA is more expensive than MEA and DEA, MDEA is the recommended amine type since it has the lowest circulation rate and requires the least amount of power. According to the current gas prices and the overall estimated costs, the MDEA proposal is judged to have an outstanding economic return with an expected outcome that reaches 22 million USD annually. Furthermore, by application of the introduced sweetening process, the environmental pollution of the flared gas will be positively reduced as the flared gas quantities are reduced by 85%. The present study highly recommends utilizing the flared sour gases of the Eastern Desert oil fields through the installation of an amine sweetening unit. Future research work is also recommended to focus on studying the feasibility of producing elemental sulfur from the obtained acid gases since the resulting acid gas from the sweetening process is rich in H_2S which promotes utilizing the Sulfur Recovery Unit as an economical option to extract sulfur from the acid gas.

List of abbreviations

MEA	*Monoethanolamine*	*CS_2*	*Carbon disulfide*
DEA	*Diethanolamine*	*PSIA*	*Pound per square inch absolute*
MDEA	*Methyl diethanolamine*	*PPM*	*Part per million*
MMSCFD	*Million standard cubic feet per day*	*kW*	*Kilowatt*
MMBTU	*Million British Thermal Unit*	*CO_2*	*Carbon dioxide*
GPM	*Gallon per minute*	*NH_3*	*Ammonia*
H_2S	*Hydrogen sulfide*	*PZ*	*Piperazine*
COS	*Carbonyl sulfide*		

Declarations

Availability of data and materials: *The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.*

Competing interests: *The authors declare that they have no competing interests.*

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Authors' contributions

Ahmed Medhat Awad participated in conceptualization, methodology, software, validation, and writing-original draft. Dr Walaa M. Shehata, and Prof. Fatma k. Gad participated in supervision, conceptualization, methodology, data curation, resources, and writing-review and editing. Prof. Ahmed A. Bhran participated in formal analysis, investigation, visualization, data curation, and writing-review and editing of the current research paper. All authors have read and agreed to the published version of the manuscript.

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