Research Article

Modelling of CO₂ Removal and Capturing Process Using Different Solvents for Al-Halfaya Oil Field to Reduce the Total Emissions

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Abstract

Since there currently are no financially feasible sources of renewable electricity and since they are readily available and inexpensive, such as coal, fossil fuels; that will remain the primary energy source for decades. Consequently, it is imperative to create technologies that allow for the continued use of fossil fuels whilst reducing the amount of CO_2 released into the environment. In order to lower atmospheric emissions, CO_2 should be captured from sources of emissions. Increased oil recovery, ocean or subsurface storage, or perhaps both, might be accomplished using the recovered CO_2. Extracting high-purity CO_2 from flue gas, which is present in low concentrations (about 15 percent), is the most difficult step in the CO_2 capture process. The process of a selected separation approach will then be thoroughly examined by modeling it utilizing the Aspen Plus program while employing three solvents, including MEA, DEA, and NH3. Additionally, based on the simulation results provided by Aspen Plus, the present research intends to assess the environmental and economic implications of every solvent in order to choose the solvent with the minimum environmental impact and the best economic performance. Also, look at how the final CO_2 removal efficacy is affected by the pressure and temperature of the chosen solvents and absorber. According to the findings, DEA solvent outperformed NH3 and MEA in terms of CO_2 extraction effectiveness. Additionally, employing NH3 as a chemical solvent does not affect temperature or pressure, but using MEA and DEA negatively influences CO_2 extraction efficiency when the temperature is raised. However, when utilizing DEA and MEA as chemical solvents, the pressure of the solvent enhances the rate of CO_2 collecting.

Keywords

Carbon Capture, Chemical Absorption, MEA, DEA, NH₃

1. Introduction

The amount of carbon dioxide in the atmosphere rose from approximately 280 ppm to slightly over 400 ppm during the previous 150 years due to the continued usage of fossil fuels [1]. The endeavour to create Negative Emissions Technolo- gies, which allow for the direct removal of CO_2 from the atmosphere, has increased since worries about the impact of the rise on the global climate [2-4]. Recent research suggests that widespread adoption of negative emission technology is

likely necessary to stop the rise in global temp to roughly 2 degrees centigrade over the pre-industrial period by the end of this century [5].

Natural gas, a readily accessible and environmentally friendly energy source, is crucial in supplying the rising worldwide demand for several industries, including transportation, industrial, and electricity [6]. International Energy Outlook 2019 predicts that between 2018 and 2050, the world's natural gas consumption will increase by 40 percent, achieving around 200 quadrillion British thermal units (Btu) [7]. According to Figure 1 [8], natural gas's share of all energy sources climbed to 24 percent in 2018, representing one of the highest growth rates since 1984 [8].
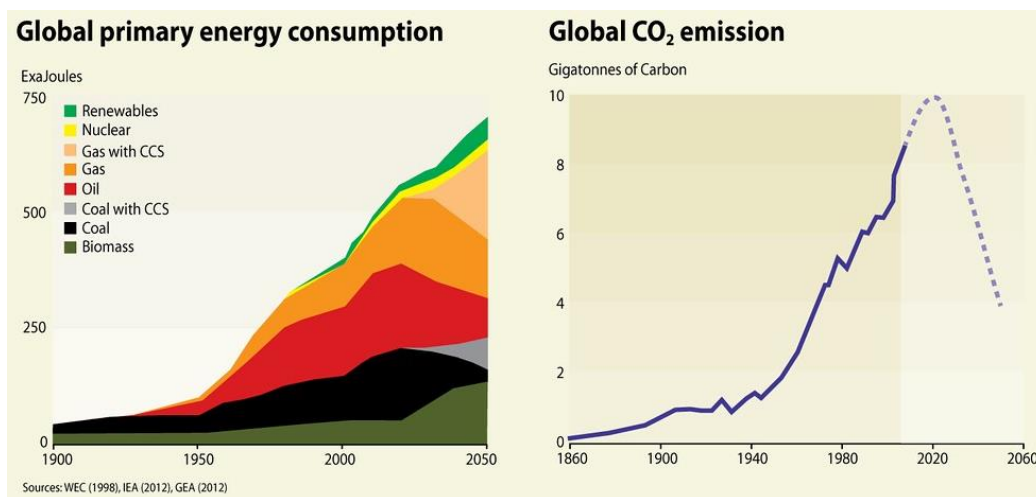

Figure 1. Shares of Global Primary Energy Consumption by Fuel.

USA, Iran, Iraq, and Russia were the four most wasteful countries in 2018, flaring almost 70000000000 m^3 of natural gas, depending on Offshore Energy [9, 10]. Iraq is ranked second amongst some of the top flaring nations. According to the Global Carbon Atlas, in 2018 Russia and Iraq each emitted 29000000 tons and 28000000 tons of carbon dioxide into the atmosphere, respectively [11]. Iraq's emissions of carbon dioxide from 2000 to 2018 are seen in Figure 2.
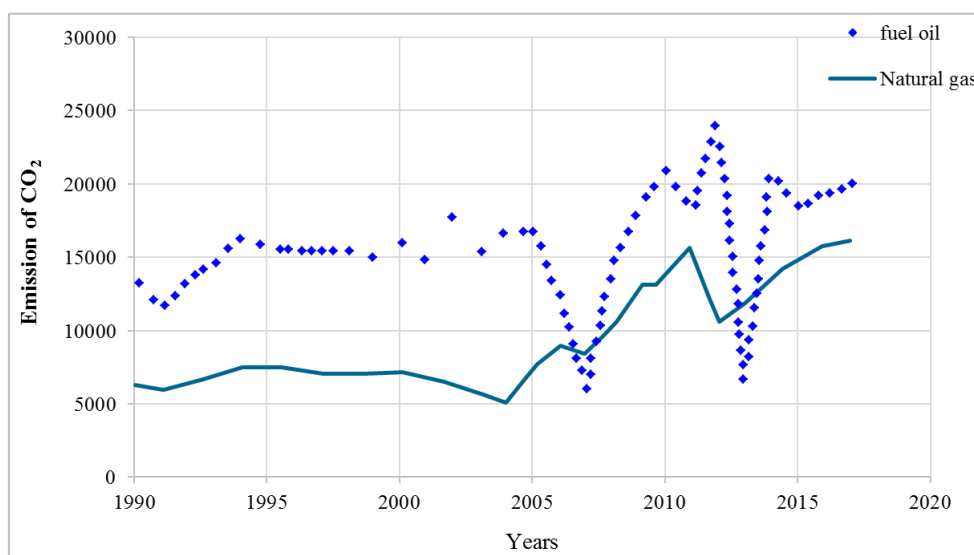

Figure 2. The Iraqi electrical sector's 1990–2017 CO_2 emissions through the use of crude oil, natural gas, and fuel oil [11].

In addition to the issues with global warming brought on by the excessive levels of carbon dioxide in the atmosphere, it influences individuals, and over time, various health issues start to appear. Chronic infections, bone atrophy, renal failure, loss of cognitive function, and a higher risk of cancer are a few of these [12].

The direct capture of CO_2 from the air (DAC) by chemical or physical processes has garnered significant interest among all suggested negative emissions technologies [3, 5] because of its benefits. For instance, DAC technology may be implemented on the rooftops of buildings in crowded places or isolated locations where the land is unsuitable and could be placed near storage/utilization sites. In comparison to other techniques for removing CO_2 from the atmosphere, it may also provide a higher removal capacity [13]. Furthermore, it was asserted that DAC could capture dispersed fugitive emissions, permanently lower atmospheric CO_2 concentrations (it can actually capture 100 percent of CO_2 emissions), and be used directly in a variety of industries, including those that produce beverages, greenhouses, and synthetic fuels [14, 15].

Numerous amine types, including piperazine (heterocyclic amine, PZ) [16], aminomethyl propanol (sterically hindered primary amine, AMP) [17], methyl diethanolamine (tertiary amine, MDEA) [18], diethanolamine (secondary amine, DEA), monoethanolamine (main amine, MEA), and others, were investigated in the CO_2 capture process. MEA is still recognized as the main solvent in aqueous alkanolamine-based capturing processes because of its minimal requirement for regeneration temperature, low cost of solvent, and high absorption rate [19]. Nevertheless, the high heat of interaction with CO_2 when employing MEA (about 85 kJ/mol CO_2) means that there is still a considerable energy demand for stripping. In low-pressure applications, DEA could be taken into consideration because of its lower reaction temp

with CO_2 (approximately 70 kJ/mol CO_2). Like DEA, secondary amines react with sulfur-containing compounds in much lower amounts, and the by-products are not very corrosive. All these reasons make DEA an attractive CO_2 collecting technique. Nevertheless, DEA's poor kinetics are a disadvantage [20-22].

By utilizing Aspen Plus software to conduct numerical simulations on the selected solvents, the present research may achieve the following goals: reducing CO_2 emissions caused by fossil fuel usage to improve oil recovery. In order to discover the most cost effective and environmentally friendly solvent, it is also important to optimize the operating factors for the process and then assess the results of the simulation model.

2. Study Area

East of Amarah, Iraq, there is an oil field called Halfaya Field. Halfaya is known to have a recoverable resource of 4.1 billion barrels (650,000,000 m^3) and can produce between 200,000 and 535,000 barrels/day (31,800 and 85,100 m^3/d). The consortium headed by the China National Petroleum Company completed the first phase in June 2012, 15 months ahead of plan, and raised output from three thousand barrels/day (480 m^3/d) to hundred-thousand barrels/day (16,000 m^3/d). The study area coordinates are southern-east 32°10'37.37", 47°26'11.77". The field is 332.43 km away southeast of Baghdad.

Figure 3. The location of the study area.

3. Methodology

A sample of feed gas was taken from the Al-Halfaya site in Maysan, Iraq, in May 2018. Tables 1 and 2 illustrate the outlet Figure 4 and the gas compositions from the power plant depict the power plant. To conform to the product standards and envi-

ronmental regulations, processing gas should meet market limits of 100 ppm CO_2 and 1 ppm Hydrogen Sulfide.

Table 1. The outcomes of gas compositions from the power plant.

Components	Mole percent	Site: Maysan- Al-Halfaya	
Methane (CH_3)	86.431	Testing date	2018
Ethane (C_2H_6)	4.675	Sample type	Natural gas
Propane (C_3H_8)	0.361	Operation situations	
i-Butane (C_4H_{10})	0.053		
n-Butane (C_4H_{10})	0.054	Temperature	35-degree centigrade
i-Pentane (C_5H_{12})	0.015	Pressure	60 bars
n-Pentane (C_5H_{12})	0.011	Flow	250 tons/hr
Hexane (C_6H_{14})	0.019	Gas Density [kg/m^3]	49.433
CO_2	4.332	Molar Flow [MMSCFD]	389
H_2S	3.851		
Nitrogen N_2	0.198		

Table 2. Gas feeding situations and compositions.

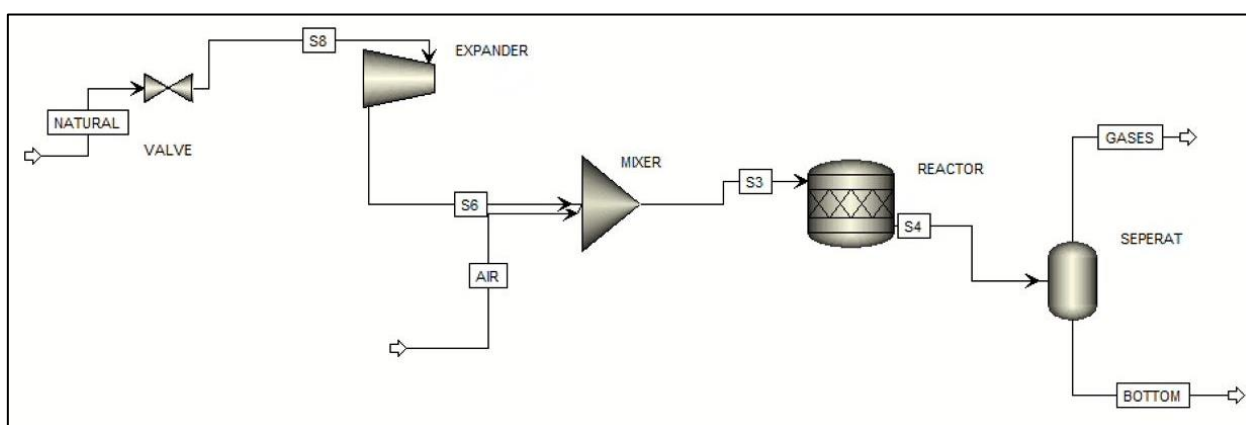| Components	Mole percentage
H_2O	71×10^{-3}
CO_2	85×10^{-3}
N_2	743×10^{-3}
O_2	101×10^{-3}

Figure 4. Power plant graphical plan.

3.1. Model Design Basis

The absorption of gases in liquids while being coupled with chemical processes appears to be one of the basic phases in numerous gas purification processes (commonly called reactive absorption). It combines interactions with mass transfer in two stages when interacting [23]. A loosely bound reaction

product is created when a liquid phase component and the absorbed gaseous constituents mix. Chemical operations may speed up the absorption rate, enhance the absorption capacity for solvents, and raise the selectivity only to dissolve certain chemicals. Carbon dioxide is absorbed into amine solutions by a process called reactive absorption.

The phrase "amine absorption techniques" refers to a method that uses an aqueous amine solution to eliminate CO_2 from gas compositions. It is a common process unit found in petrochemical plants, refineries, and other establishments that handle natural gas. Amines that have significant commercial significance for the gas purification process are monoethanolamine (MEA) and diethanolamine (DEA) [24]. The absorber, which operates at great pressure, and the stripper, which operates at great temp and low pressure, are the two essential parts of the amine absorption processes. A simplified process flow diagram for the amine absorption procedures is demonstrated in Figure 5.

As the flue gas moves counter-currently toward the absorber's bottom, the amine solution comes into contact with it, as depicted in Figures 5-8. CO_2 is taken up by the amine solutions, which then react with it to form a loosely connected molecule. Once the amine solution takes up carbon dioxide, a cleaner, treated gas rises to the top of the absorption tower. The stripper's bottom is where the warm lean amine solution enters the heat exchanger, and the absorber's bottom is the rich amine solution that is rich with CO_2 and leaves the absorber unit. After that, the solution will be moved to the top of the stripper, in which it would be heated with steam once again to start the desorption process, a type of opposite absorption process utilized to eliminate carbon dioxide from amine solutions. Lean amine solution was discharged back into the absorber, while CO_2 was expelled from the top of the stripper.
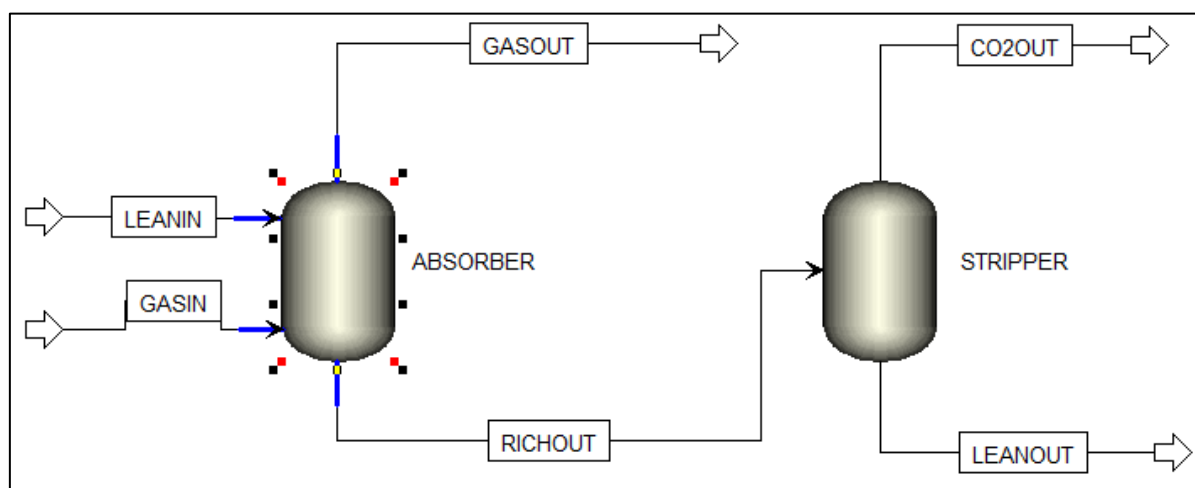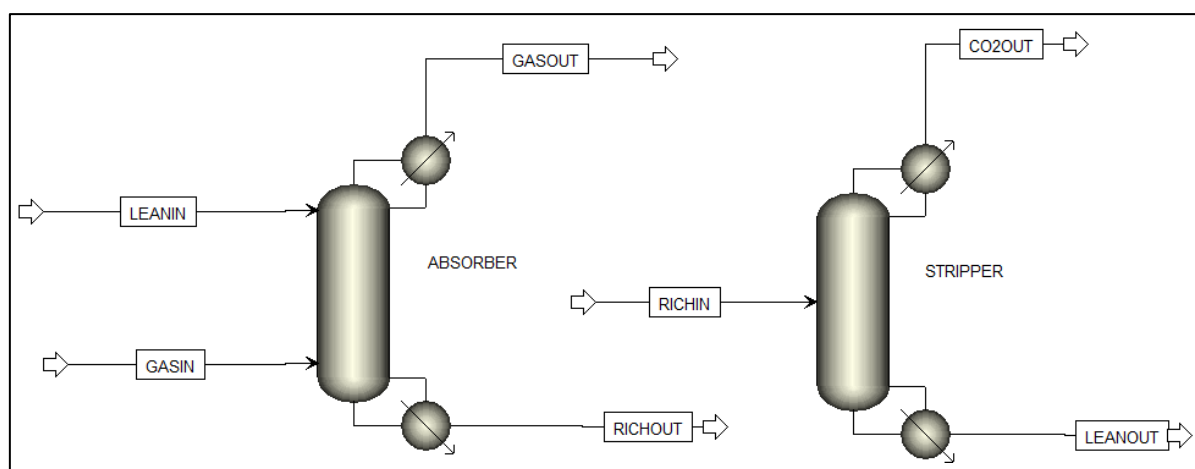

Figure 5. NH₃ process scheme.
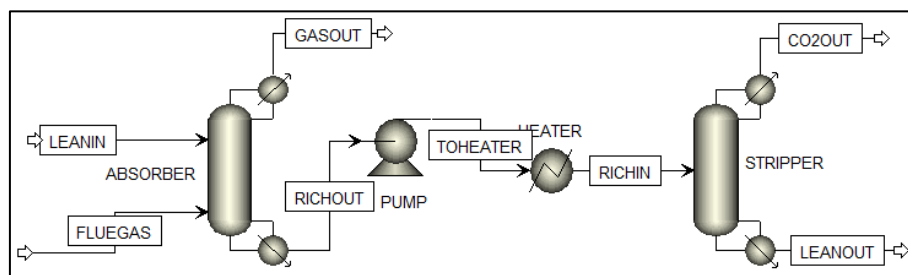

Figure 6. DEA process scheme.
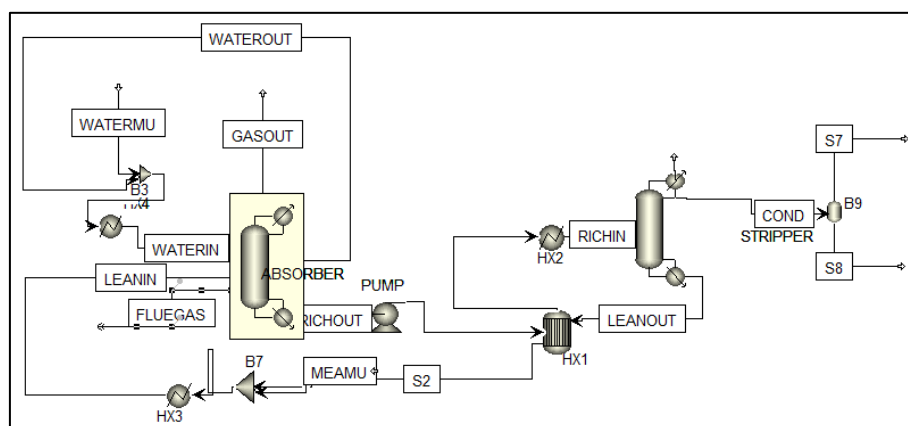
Figure 7. *MEA process scheme.*

Figure 8. *Flow sheet for MEA solvent.*

3.1.1. Amine Absorption Capacity

Once an organic radical replaces one or more atoms of hydrogen, the result is an amine, which includes derivatives of ammonia [24]. Monoethanolamine (MEA) and diethanolamine (DEA) are the two amines frequently used in cleaning applications. Amines' capacity to absorb CO_2 is quickly diminished in the existence of SO_2, NO_2, HCl, HF, or O_2 in the gas stream. These chemicals create irreversible by-products which complicate the solvent recovery process while also slowing the response rate during the absorption process. The removing or absorbing effectiveness (η, defined in equation (1), in which y_o and y_i were the pollutant quantity reported as a molar fraction at the outflow and intake, respectively) may be used to describe the scrubber performance. Some publications have wrongly referred to absorption efficacy as a solvent property even though it might vary across two scrubbers that employ identical solvents. [24].

$$\eta = \frac{y_i - y_o}{y_i} \qquad (1)$$

The solvent's absorption capacity is defined as the maximal molar amount of a contaminant, which could be absorbed/solvent mole. This feature is utilized to set the proper loading (pollutant/solvent molar proportion) in scrubber designs. Low loading creates columns with inefficient absorption rates, whereas high loading leads to increased solvent

demands and operational expenses. How successfully amines can absorb carbon dioxide depends on the quantity of the solvent, the gas stream's composition, and the operational temp [25]. Amines may chemically and physically absorb carbon dioxide. Physical absorptions are governed by Henry's hypothesis that explains how carbon dioxide molecules in the aqueous and gaseous phases are in thermodynamic equilibrium [26, 27]:

$$P_A = y_A P = H_A x_A \qquad (2)$$

Where, in the gas phase equilibrium of component A, P_A is a partial pressure, P is the total pressure, H_A is Henry's theory constant in the gas phase, y_A is the equilibrium concentration (stated as a fractional molar), and in the liquid phase of equilibrium of component A (also stated as a fractional molar).

3.1.2. NH₃ and DEA Flow Sheet Process

The solvent equipment was built under appropriate conditions after the substances utilized in the process were described, the estimation technique for the NH_3 process was established, and the chemical formula was set. The utilized equipment, in this case, was two flash tank separators, one of which served as an absorber and the other as a stripper.

In contrast to DEA, where each solvent's equipment has been built under suitable conditions after the material utilized in the process was described, the determination technique for the process has been established, and the chemical formula

was set, here the used equipment consisted of two separators, one of which served as an absorber (Rad-Frac), and the other as a stripper (Rad-Frac). Nevertheless, the DEA and NH₃ solvents have been tested using the current ENRTL-RK technique with the composites listed in Table 3.
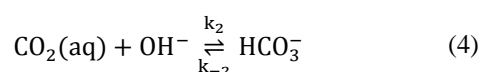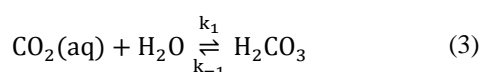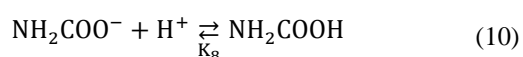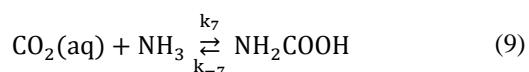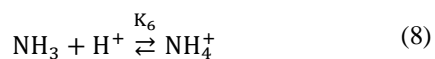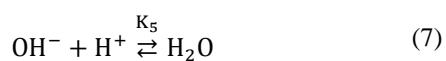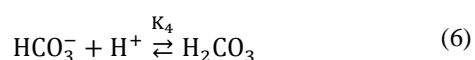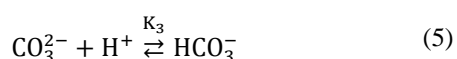
3.1.3. For MEA Process

The elements of typical MEA absorption operations, including absorbers, strippers, and a cross-heating exchanger, are shown in Figure 8. As shown in Figures 7-8, a storage (buffer) tank is a distinct operational element in the MEA absorption processes considered in this study. This component is placed in front of the absorber column. This storage tank with a large volume of liquid solvent was included in the pilot plant to minimize any disruption from the stripper column [28]. The storage tank permits any fluctuations in composition coming from the stripping column to be attenuated to maintain the optimal amount of lean loading into the absorber column. The absorber-packed column provides intimate contact between the amine solvent and flue gas to remove CO_2 molecules from the gas form to the solvents' liquid state. The stripper-packed column acts as a regenerator by removing carbon dioxide from the solvent so that it may be regenerated back into the absorbent. The solvent tools were built in the appropriate situations after the substances utilized in the process were described, the determination technique for the process was established, and the chemical formula was established. The tools utilized in this case were two separators, one of which served as an absorber (Rad-Frac) and a stripper (Rad-Frac). Nevertheless, the MEA solvent with the composites listed in Table 3 has been studied using the ELECNRTL technique.

Table 3. Components of NH₃, DEA, and MEA solvents.

ENRTL-RK Technique		ELECNRTL Technique
NH₃	DEA	MEA
WATER		
AMMONIA	DIETHANOLAMINE	MONOETHANOLAMINE
CARBON-DIOXIDE		
H_3O^+		
OH-		
NH_4^+	DEA^+	HCO_3^-
HCO_3^-	HCO_3^-	MEA^+
CO_3^-		
	HS^-	$MEACOO-$
NITROGEN	S^-	NITROGEN
AMMONIUM-HYDROGEN-CARBONATE	HYDROGEN-SULFIDE	HYDROGEN-SULFIDE
OXYGEN		
CARBON-MONOXIDE		
HYDROGEN		
CARBAMATE	PROPANE	HS^-
-	NITROGEN	S^-
-	DEACOO-	
-	METHANE	
-	ETHANE	

$$CO_2(aq) + H_2O \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} H_2CO_3 \qquad (3)$$

$$CO_2(aq) + OH^- \underset{k_{-2}}{\overset{k_2}{\rightleftharpoons}} HCO_3^- \qquad (4)$$

$$CO_3^{2-} + H^+ \overset{K_3}{\rightleftharpoons} HCO_3^- \qquad (5)$$

$$HCO_3^- + H^+ \overset{K_4}{\rightleftharpoons} H_2CO_3 \qquad (6)$$

$$OH^- + H^+ \overset{K_5}{\rightleftharpoons} H_2O \qquad (7)$$

$$NH_3 + H^+ \overset{K_6}{\rightleftharpoons} NH_4^+ \qquad (8)$$

$$CO_2(aq) + NH_3 \underset{k_{-7}}{\overset{k_7}{\rightleftharpoons}} NH_2COOH \qquad (9)$$

$$NH_2COO^- + H^+ \underset{K_8}{\rightleftharpoons} NH_2COOH \qquad (10)$$

The DEA chemical reactions formulas

$$DEAH^+ + H_2O \rightleftharpoons DEA + H_3O^+ \qquad (11)$$

$$DEACOO^- + H_2O \rightleftharpoons DEA + HCO_3^- \qquad (12)$$

$$2\ H_2O \rightleftharpoons H_3O^+ + OH^- \qquad (13)$$

$$CO_2 + 2\ H_2O \rightleftharpoons HCO_3^- + H_3O^+ \qquad (14)$$

$$HCO_3^- + H_2O \rightleftharpoons CO_3^{-2} + H_3O^+ \qquad (15)$$

$$H_2S + H_2O \rightleftharpoons HS^- + H_3O^+ \qquad (16)$$

$$HS^- + H_2O \rightleftharpoons S^{-2} + H_3O^+ \qquad (17)$$

The MEA chemical reactions formulas

$$2.0\ H_2O \rightleftharpoons H_3O^+ + OH^- \qquad (18)$$

$$CO_2 + 2.0\ H_2O \rightleftharpoons HCO_3^- + H_3O^+ \qquad (19)$$

$$HCO_3^- + H_2O \rightleftharpoons CO_3^{-2} + H_3O^+ \qquad (20)$$

$$MEAH^+ + H_2O \rightleftharpoons MEA + H_3O^+ \qquad (21)$$

$$MEACOO^- + H_2O \rightleftharpoons MEA + HCO_3^- \qquad (22)$$

$$H_2S + H_2O \rightleftharpoons HS^- + H_3O^+ \qquad (23)$$

$$HS^- + H_2O \rightleftharpoons S^{-2} + H_3O^+ \qquad (24)$$
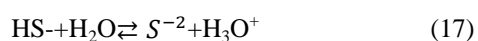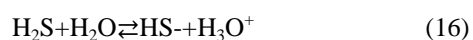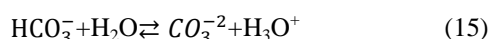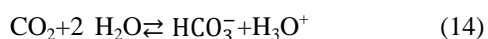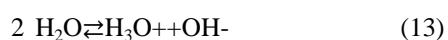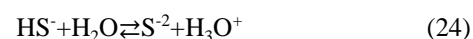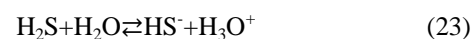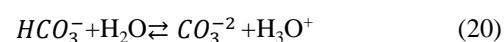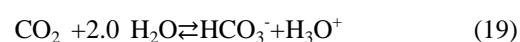
3.2. CO$_2$ Capturing Cost—Standard Design

The Aspen Capital Cost Estimation and standard chemical engineering design criteria were used to calculate the CO$_2$ capturing cost for air capture, which came to \$1,691/tonne of CO$_2$. It is important to note that this computation depends on a particular capture amount of 0.291 tCO$_2$.h^{-1}. Greater economies of scale [29] would result in lower costs per ton of CO$_2$ collected for larger-scale systems. Table 4 displays the costs of significant equipment, overall investment costs, operating costs, and a breakdown of CO$_2$-capturing costs. A illustrates the distribution of capture costs across capital, operational, and energy costs. Heating consumption accounts for the least amount of the cost of CO$_2$ capture at 7%, followed by O&M at 23% and electricity at 9%. The capital component makes up 61% of the cost of CO$_2$ capture. The percentage of heating and electricity to total cost may be significantly reduced when more accessible, and reasonably priced heating and energy sources are available. The sensitivity analysis of numerous economic factors, such as the price of energy and heating, is included in the following section.

Table 4. The estimated cost of air capture.

Main apparatus	Cost, Million $	Operation expenses	Cost, Million $
Washing column	4.38	Annual O&M cost	0.757
Absorbers	4.22	Annual heat cost	0.213
Desorbers	0.13	Annual electrical cost	0.286
Fans and Blowers	1.66	Capture cost	$/ton CO$_2$
Heating-exchanger	0.39	Capital	1.033
Pump	0.3	O&M	396
Tank	0.4	Heat	111
Other apparatus	0.22	Electricity	150
Total direct cost	11.7	Total	1691
Total indirect cost	2.27		

This research compares the effectiveness and costs of post-combustion CO_2 collecting with amine and ammonia approaches. It does this by using the station derating of a CO_2 capturing on the power plant and the Levelized revenue required as two essential parameters. The "energy penalty," also known as the plants' derating for CO_2 collecting, is shown as a declining percentage in the net station output for given energy input.

$$\text{Station Derating } (\%) = \frac{\text{Plant Efficacy without Capturing} - \text{Plant Efficacy with Capturing}}{\text{Plant Efficacy without Capturing}} \tag{25}$$

$$\text{Revenue Required } (\$/MWh) = \frac{\text{Total Plant Costs} \times \text{Fixed Charge Factor} + \text{O\&M Costs}}{8760 * \text{Capacity Factor x MWh Produced}} \tag{26}$$

4. Results and Discussion

4.1. Feeding Flow Influence

Comparing (MEA, DME, and NH_3) solvents by determining the $CO_2\%$ capturing rate for each solvent:

$0.085 * 72 = 6.12$ kg.h^{-1} CO_2 feed

CO_2 amount released from MEA absorber=1.67474 (kg.h^{-1})

$$CO2\% = \frac{6.12 - 1.67474}{6.12} \times 100\% = 72.6 \, w/wt\%$$

CO_2 amount released from DEA absorber=0.0056 (kg.h^{-1})

$$CO2\% = 99.9 \, w/wt\%$$

CO_2 amount released from NH_3 absorber=2.28082 (kg/h)

$$CO2\% = 62.7 \, w/wt\%$$

DEA solvent showed the greatest Carbon dioxide capturing rate with 99.9% for the majority of the randomly chosen feeding flow, according to the feeding flow for the solvents that utilized MEA, DEA, and NH_3 that are identified in Figure 9, in which the rate of capture for the solvents increased with enhancing the feeding flow from 30-80 kg/hr. The large quantity of CO_2 released from the absorber once employed by NH_3 and MEA also causes an increase in feeding flow when the CO_2 removal rate for NH_3 and MEA is improved. The measured absorption rate rises when the gas-liquid amount, temp, solvent amount, and flow rate of the gas all go up. MEA has a higher capacity for absorption than NH_3 and DEA, however MEA has a lower absorption efficiency. The best capacity for absorption belongs to NH_3. In the presence of carbon dioxide [30].
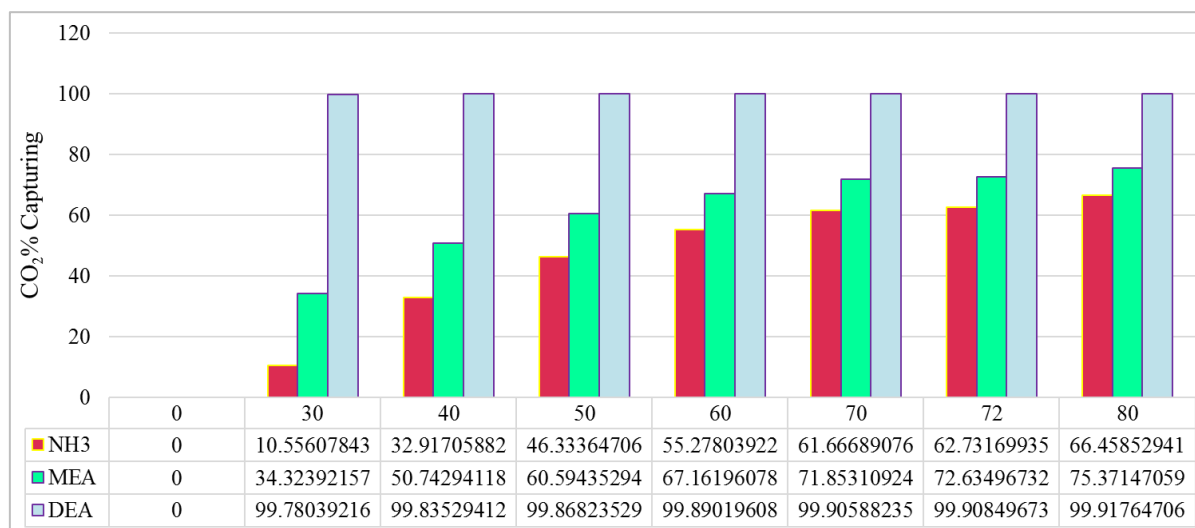

	0	30	40	50	60	70	72	80
NH3	0	10.55607843	32.91705882	46.33364706	55.27803922	61.66689076	62.73169935	66.45852941
MEA	0	34.32392157	50.74294118	60.59435294	67.16196078	71.85310924	72.63496732	75.37147059
DEA	0	99.78039216	99.83529412	99.86823529	99.89019608	99.90588235	99.90849673	99.91764706

Figure 9. The association between CO_2 Capturing rate and feeding flow.

4.2. Effect of Temperature

To clear up the uncertainty around the phase Vapour Liquid Equilibrium (VLE) data, constants of Henry's laws for the binaries DEA- CO_2, MEA- CO_2, NH_3- CO_2, and H_2O- CO_2 have been altered (often lowered or increased by 20 to 50%).

The whole pressure range and temp were then used to vary the variables. Additionally, the impact of altering the interfacial area on absorption efficiency was examined. Along with variable modification, a small assessment of the effect of discretization film on the simulation results was made. Since the performance of the absorption column frequently sets the

standards for the plant's rest, it was thought desirable to examine the absorber performance in this research. Figures 10, and 11 show the influence of temperature on the absorption capacity. Figures 10 and 11 demonstrate that as solvent temperatures rise, the effectiveness of CO_2 removal decreases. For example, Figure 10 shows that the DEA capturing rate decreased from 0.25 to 0.2 kg/hr as the temp rose to 44-degree centigrade, whereas Figure 11 shows that the MEA capturing rate decreased from 4 kg/hr to 3.2 kg/hr. Since the NH_3 reaction is carried out in the absence of temp, as illustrated in Figure 12, the solvent temperature does not affect the effectiveness of CO_2 removal when employing NH_3. Based on [31] rise the temperature for more than 20 degree centigrade cause a reduction in CO_2 capturing amount for all selected solvents.
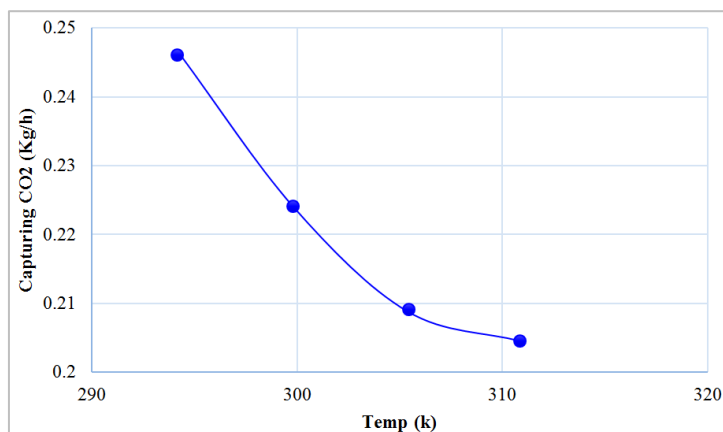

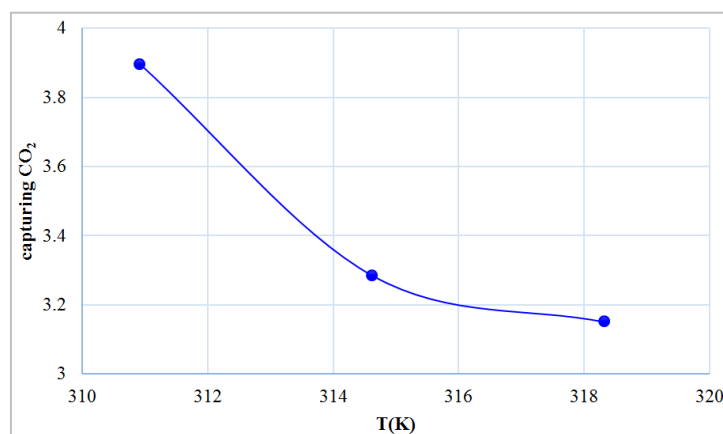*Figure 10. The temperature influence on removal efficiency of DEA.*

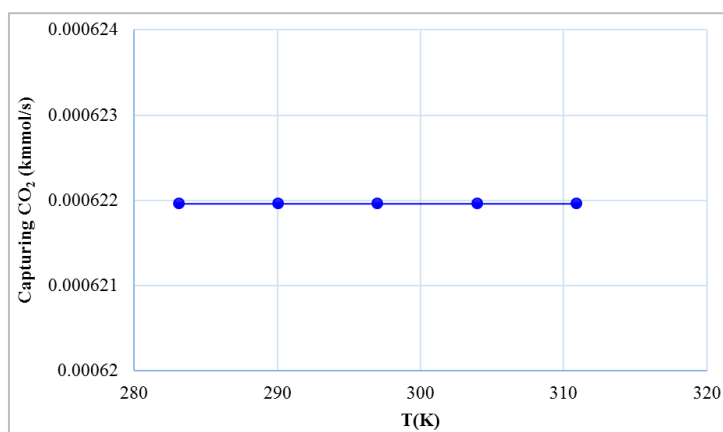*Figure 11. The temperature influence on removal efficiency of MEA.*

Figure 12. The temperature influence on removal efficiency of NH_3.

Figure 12 depicts the connection between temp (Kelvin) and the rate of CO_2 adsorption utilizing NH_3, showing that the natural interaction between CO_2 and NH_3 ensures that temp increases do not affect the effectiveness of CO_2 removal. The compounds of ammonium carbonate progressively break down in the presence of air at air temp to ammonia, whereas ammonium bicarbonate breaks down into carbon dioxide, water, and ammonia when heated over 60 degrees Celsius [32].
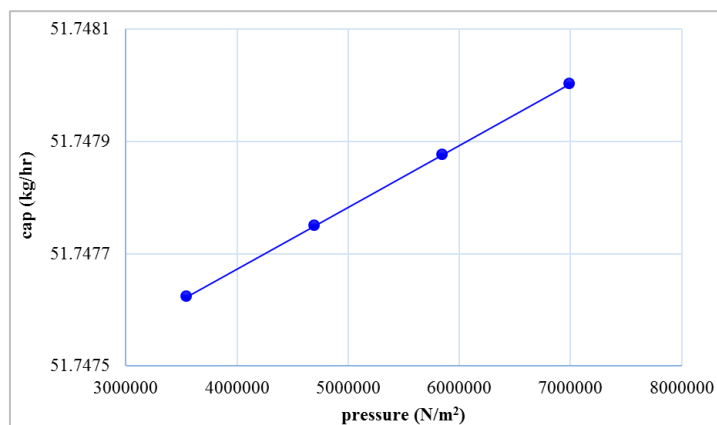
4.3. Pressure Influence

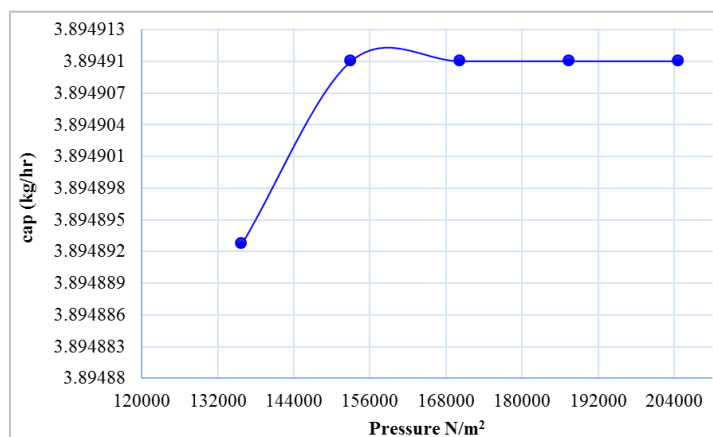*Figure 13. The Pressure influence on removal efficiency of the DEA.*

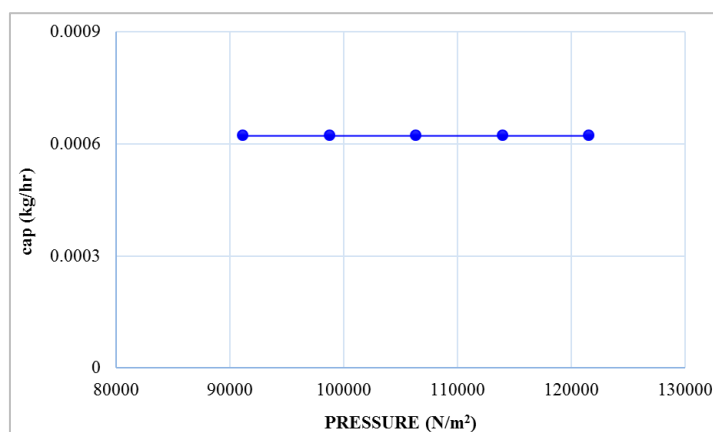*Figure 14. The Pressure influence on removal efficiency of MEA.*

Figure 15. The Pressure influence on removal efficiency of NH_3.

The pressure effect on CO_2 capture rate changes based on the solvents used. For example, when employing NH_3 as a solvent, a change in pressure does not affect CO_2 capture, as is seen in Figure 13. However, as seen in figures 14 and 15, higher pressure increases the capture rate for both MEA and DEA, although DEA operates more effectively under the greatest pressure. According to [33, 34] increasing the pressure lead to increasing the capturing efficiency and this results are compatible with the obtained results in the current study.

4.4. Energy Requirements

The power required for regeneration Once a natural gas sweetening plant is built, the processing is one of the most important factors. However, rising energy consumption will result in higher operating costs. The results show that increasing the AM solution volume increases the need for re-boiler energy to recover the lean AM. The size of the regeneration unit grows along with an increase in circulation rate, necessitating more re-boiler energy. Consequently, using the ideal operating conditions of 50-degree centigrade and 405000 Kg/hr from the study, a comparative analysis of the required energy was carried out. In conclusion, it was shown that increasing the AM quantity raises the energy needed because more heating is required to re-boil the AM solution.

Table 5. The required energy for CO_2 Capturing by NH_3, DEA, and MEA solvents.

Power plant's Duty	Magnitude [Watt]
Separator Heating-duty	6.3978773409E-07
Compressors Net-work necessary	-7806088.8
Determined heating duty reactor	-3420872054.0604
Duty of NH_3	
Absorber	-15027.4072 (absorbing heat)
Stripper	34314.9876
Duty of stripper re-boiler	
DEA	5502441.96
MEA	530040.925

DEA was rated as having the greatest prior energy use, but NH_3 had the lowest due to the boiler's absence. Nevertheless, in terms of energy needs, NH_3 is regarded as the best option since energy use results in the production of CO_2 and a return to the Carbone cycle.

4.5. Cost Evaluation

According to Table 6, labor costs for solvents, equipment costs, and operating costs, NH_3 may be provided at the lowest cost (1467 ($€/m^3$)) compared to other chosen solvents, whereas DEA seems to have the greatest supply cost (1720 ($€/m3$)). Consequently, NH_3 is regarded as the most suitable solvent based on the cost of the solvents, followed by DEA and MA as the last option. Based on increasing CO_2 amount lead to decrease investment costs [35, 36].

As is well knowledge, CO_2 capture by NH_3 does not need the use of a heat exchanger; as a result, the heating-exchanger cost as just a cost of apparatus is not included once estimating that the operation would be more cost-effective owing to reduced costs for electricity and heating. According to the anticipated cost value shown in Table 4, NH_3 has the lowest operating and apparatus cost, followed by DEA and MEA, which have the greatest costs. Consequently, NH_3 is regarded as the most suitable solvent, followed by MEA and DEA, based on the cost of operation and equipment [38].

Table 6. The chemical solvents costs [37].

Solvents	Cost ($€/m^3$)
NH_3	1467
DEA	1720
MEA	1650

5. Conclusion

A rate-base model in Aspen Plus assessed the technical and economic aspects of a traditional absorption process-based

MEA, DEA, and NH3 for collecting CO_2 straight from the air. Following its establishment, a benchmark situation was further examined, utilizing a sensitivity analysis considering several variables. The simulation model's output may be used to derive the following conclusions:

NH3 seems to have the lowest cost with the least expensive operating end equipment, despite DEA having the greatest energy needs, which results in DEA emitting CO_2 as a result of electricity production. As a result, it is regarded as the best option; however, when compared to MEA or DEA, its removal effectiveness for NH3 is the lowest.

DEA is the best option in two situations, with the lowest feeding ratio and a 99.9% elimination effectiveness. The capture method only needed a tiny quantity of DEA compared to MEA and NH3, which raised two issues: the first connected to removing effectiveness and the second to the expense of the solvent.

Abbreviations

MA	Ammonia
DEA	Diethanolamine
MEA	Monoethanolamine
CC	Carbon Capture

Author Contributions

Ali Alkhazrajie: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing

Ali Ibrahim Neamah: Funding acquisition, Investigation, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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