Energy Consumption in Amine Process For Carbon Dioxide Capture

by

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13488

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

May 2014

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CERTIFICATION OF APPROVAL

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(CHEMICAL ENGINEERING)

Approved by,

_____
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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2014

ABSTRACT

Carbon Dioxide capture technologies have recently attracted considerable attention because of the need to reduce CO_2 emission. A highly effective technology is chemical absorption using amine solvents. Two amine solvents were chosen for this project, which are Mono Ethanolamine (MEA), and di-ethanol amine (DEA). The aim of this project is to present a comprehensive analysis of the energy performance of the CO_2 capture process. The study is done by comparing the energy consumption of the process using MEA and DEA at different operational parameters. The comparison is made using HYSYS simulation models. Data from an actual natural gas sweetening process were used to validate the model, whose results were found to fit the data well. The results of the study show that the process using DEA has lower overall energy consumption. It also shows that the best trade-off between CO_2 capture capacity and energy consumption using DEA occurs at solvent concentration of 49.9% and solvent feed temperature of 55°C.

ACKNOWLEDGMENT

I'd like to express the deepest appreciation to my Final Year Project supervisor, Dr. Usama Mohamed Nour from the department of Chemical Engineering at Universiti Teknologi PETRONAS, who continually provided me with support and motivation. Without his guidance and persistent help this dissertation wouldn't have been possible. I would also like to give thanks to everyone in the Final Year project committee at Universiti Teknologi PETRONAS for their support on this project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 Process Description

The sour gas, containing H_2S or CO_2 enters the process through an inlet separator in order to remove any impurities. The gas then enters the bottom of the absorber flowing upwards in a counter-current interaction with the lean amine solution. This permits the amine to absorb the acid gas components from the gas stream. The treated gas then leaves the top of the column through an outlet separator. (Bullin, 2003)

In many units, the rich amine solution is sent from the absorber to a flash tank, to recover hydrocarbons that may have dissolved or condensed in the amine solution in the absorber. (Mokhatab, Poe, and Speight, 2006)

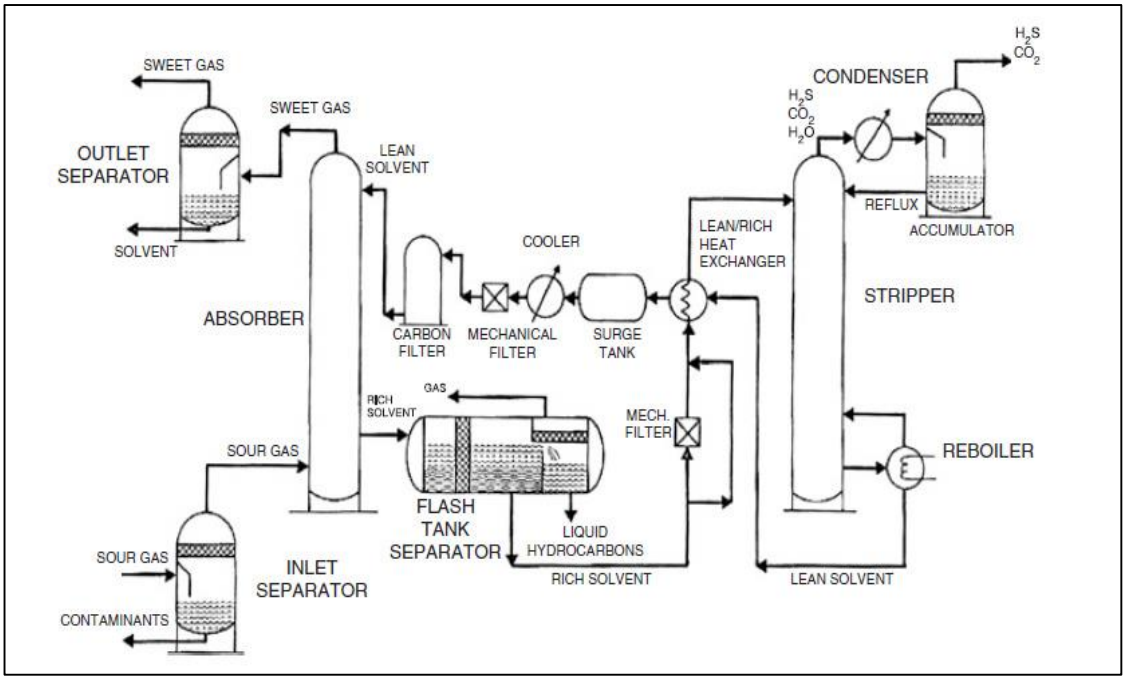


Figure 1: Schematic of amine gas-sweetening process flow diagram

1.1.2 Amine Selection

Selecting the proper type of amine solvent has a huge impact on the performance of absorption unit. Nevertheless, a number of factors should be taken into consideration when selecting an amine solvent for CO2 absorption. (Polasek and Bullin, 1994)

In this project, four factors are considered in the selection of the proper amine:

- Solvent kinetics
- Heat of absorption
- Cyclic capacity
- Degradation resistance

The kinetics between CO_2 and amine affects the height of the absorber column directly, and consequently the cost of the capture unit. The heat of absorption supplies the steam demand of the reboiler heat duty. Cyclic capacity is defined as the difference between rich solvent loadings and lean solvent loadings (in $mol_{CO2}\backslash mol_{amine}$); it determines the amount of amine solvent required to reach the desired capture capacity. The resistance to thermal and oxidative degradation characterizes the solvent loss that must be compensated by a solvent make-up. (Neveux, Moullec, Corriou, and Favre, 2013)

Table 1: Comparison of Amines

Solvent	**MEA**	**DEA**	**MDEA**
Concentration%	15	30	35-50
Capacity (Mol_{CO2} / Mol_{Amine})	0.50	0.32	0.12
Capacity Increase % (MEA BASE = 100)	100	118	175
Heat of reaction with CO_2 (BTU/POUND)	820	650	577
Selectivity *	0.89	2.27	3.85

*Selectivity is defined as ratio of (mole percent of H_2S removed to mole percent of H_2S in feed gas) to (mole percent of CO_2 removed to mole percent of CO_2 in feed gas)

According to Astarita. Et al. (1983) 50 to 70% of initial investment on amine sweetening is directly associated with the amount of solvent circulation rate, and around 10 to 20% is dependent on energy required for regeneration.

Table 2: Recommended ranges of Amines Concentration - Rich and Lean Amines Loading

Amines	Conc. Weight %	Rich Loading M/M	Lean Loading M / M
MDEA	35-55	0.45-0.55	0.004-0.01
DEA	25-30	0.35-0.40	0.05-0.07
MEA	15-20	0.30-0.35	0.10-0.15

Since selection of a proper amine can greatly reduce both regeneration energy requirement and circulation rate, choice of the amine best suited to the conditions can have a dramatic impact on the overall performance and energy consumption of the unit. (Polasek and Bulllin, 1994)

MEA is chosen as a reference solvent to compare energy performance. The advantages of MEA include, according to (Sheilan et al., 2009):

- Low Cost
- Good Thermal Stability
- Easily reclaimed to concentrate irreversible degradation products.

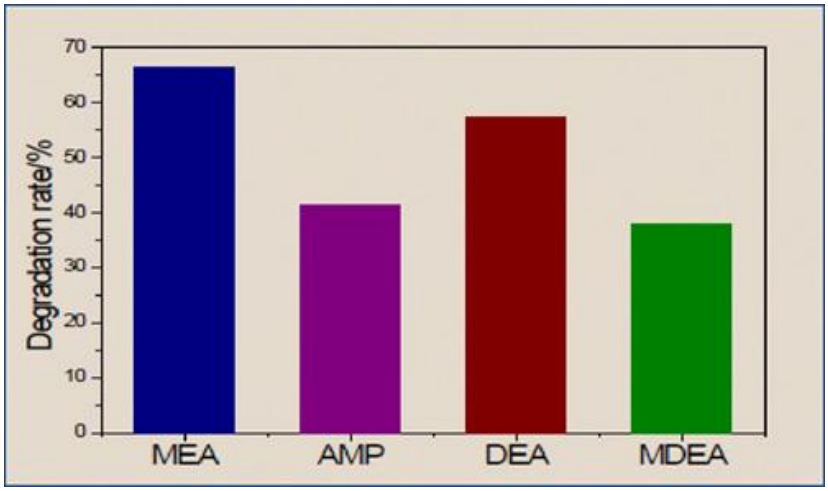


Figure 2: Degradation rate of different amines

Table 3: Corrosion of different amines

Solvent	Corrosion Rate MPY
30% Wt MEA	32
50% Wt DEA	25
15% Wt MEA	13
20% Wt DEA	8
50% Wt MDEA	3

According to Blanc et al. (1982), MDEA has several advantages compared to primary and secondary amines such as:

- Lower vapor pressure
- Lower heats of reaction (600 BTU/lb CO_2)
- Higher resistance to degradation
- Less corrosion problems.

1.2 PROBLEM STATEMENT

CO_2 capture process using amine has proven to be very effective; however, the energy consumed throughout this process is quite high. This project aims to tackle some matters regarding the CO_2 capturing process. Finding a simple, user-friendly and accurate tool to monitor the process performance, in order to detect any performance deviation, thus, preventing further errors from occurring. This project also studies the possibility of improving the capability of the amine solvent in order to optimize both capture capacity and energy consumption.

1.3 OBJECTIVES

1. To simulate and validate CO_2 capture process using two different amines; MEA and DEA.
2. To analyse and compare the energy performance of the CO_2 capture process using MEA and DEA.
3. To determine an approach for optimizing both energy consumption and capture capacity.

1.4 SCOPE OF STUDY

The scope of work for this project:

- Conducting an extensive study of CO_2 capture process using amine, with a main focus on energy optimization.
- Choosing the most optimum process design with maximum capture capacity.
- Simulating and validating the process using Aspen HYSYS and calculating the overall energy consumption of the process using MEA and DEA.
- Evaluating the overall energy consumption for the different amines
- Proposing methods for energy optimization.

CHAPTER 2

LITERATURE REVIEW

Studies focus either on the development of process flow scheme or selecting new solvents in order to reduce energy consumption. However, both aspects should be studied simultaneously since the energy efficiency of the modified process modifications also rely on the considered solvent.

The conventional process used for chemical absorption of CO_2 is a standard absorption/desorption loop operating with MEA, where the CO_2 is separated from the sour gas by chemical absorption in the solvent and the solvent is thermally regenerated in a stripper, sensible heat being exchanged between the hot lean solvent and the cold rich solvent. (Neveux et al., 2013)

The absorption of carbon dioxide by aqueous mono ethanolamine solutions involves a complex system of parallel and consecutive reactions in the liquid phase:
Kinetically controlled reversible reactions.

$$CO_2 + MEAH + H_2O \Leftrightarrow MEACOO^- + H_3O^+ \quad (R1)$$

$$CO_2 + OH^- \Leftrightarrow HCO^- \quad (R2)$$

Instantaneous reversible reactions

$$HCO_3^- + H_2O \Leftrightarrow CO_2^{3-} + H_3O^+ \quad (R3)$$

$$MEAH + H_3O^+ \Leftrightarrow MEAH_2^+ + H_2O \quad (R4)$$

$$MEAH + HCO_3^- \Leftrightarrow MEACOO^- + H_2O \quad (R5)$$

$$2H_2O \Leftrightarrow OH^- + H_3O^+ \quad (R6)$$

The rate of CO_2 absorption (Q_{CO_2}) at a given time is computed from:

$$Q_{CO_2}\left[\frac{mol\ CO2\ in\ solution}{s}\right] = (n_{CO2}^{in}\left[\frac{mol\ CO2}{s}\right] - \frac{x_{CO2}^{out}[mole\ fraction]n_{N2}\left[\frac{mol\ N2}{s}\right]}{(1-x_{CO2}^{out})[mole\ fraction]})$$

CO_2 absorbed is logged as a function of time and the data is integrated to obtain the accumulated amount of CO_2. Cyclic capacities (Q_{cyc}) and amount of CO_2 removed per cycle (ΔC_{CO_2}) (solvent carrying capacity) for each absorbent are determined through the concentration difference between loading after absorption (α_{abs}) and stripping (α_{strp}). (Ugochukwu E. Aronua, 2009)

The main energy consumers for the amine process are the steam furnaces, which supply steam to the reboiler and reclaimer. Other, much smaller, energy users are the pumps involved in the process, which are assumed to use an electromotor. This required electrical energy is transformed into corresponding gross heating value of natural gas. The energy cost distribution listed in Table 2 below. (Rijke, 2012)

Table 4: Energy Cost distribution for a 125 MMscf/day gas stream

Amine Energy Cost Distribution	**% of total Energy Cost**
Heating Rich Amine	37.49%
Heating Reflux drum water	17.60%
Breaking CO_2-amine bond	16.58%
Vaporizing water in reboiler	2.74%
Steam Piping Heat Loss	2.20%
Steam Furnace inefficiency	20.12%
Steam Production Total Heat Required	96.72%
Rich Amine Pump	Not Used
Lean Amine Pump	3.26%
Steam Condensate pumps	0.01%
Reflux Pump from condenser	0.001%
Reclaimer Feed Pump	0.004%
Electricity Consumption Total Heat Required	3.28%
Total Heat Required	100.00%

Cousins et al. (2010) have implemented a screening of several flow scheme improvements and Le Moullec and Kanniche (2010) have simulated single adjustments and combinations of them with MEA as solvent.

MEA is the most basic of the amines used in acid treating and thus the most reactive for acid gas removal. It has the advantage of a high solution capacity at moderate concentrations. (Arthur J. Kidnay, 2006)

The advantages of MEA include, according to (Sheilan et al., 2009):

- Low Cost.
- Good Thermal Stability.
- High reactivity due to its primary amine character.
- Easily reclaimed.

Some of the disadvantages of MEA are:

- High solvent vapour pressure, which results in higher solvent losses than the other alkanolamines
- Higher corrosion potential than other alkanolamines
- High energy requirements due to the high heat of reaction with H_2S and CO_2
- Nonselective removal in a mixed acid gas system

Both Monoethanolamine and Diethanolamine sweetening processes are similar in their flow schemes and operations. They are used as aqueous solvents to selectively absorb CO_2 from sour natural gas streams. Monoethanolamine is more reactive than Diethanolamine and similarly more corrosive. As a result, the concentration of MEA is restricted to 10 to 20 weight percent, while DEA strengths range from 20 to 30 weight percent.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

This project is carried out through computational simulations using Aspen HYSYS® where, the effect of the modifications proposed will be examined and a comparison between different processes will be made.

The First stage of the Project is to conduct an extensive study of all potential literature available related to CO_2 capture process using amine, with a main focus on the literature dedicated to energy optimization. The Literature Review examined is a head start to build a deep understanding for the problem.

The second stage of the project is to determine the ideal process design with maximum capture capacity through comparison of different process adjustments and their effect on the performance. Once a process modification is selected, energy performance of the process will be assessed for two different solvents, MEA and DEA. These assessments will be carried out using a simulation model for the examined unit and processes.

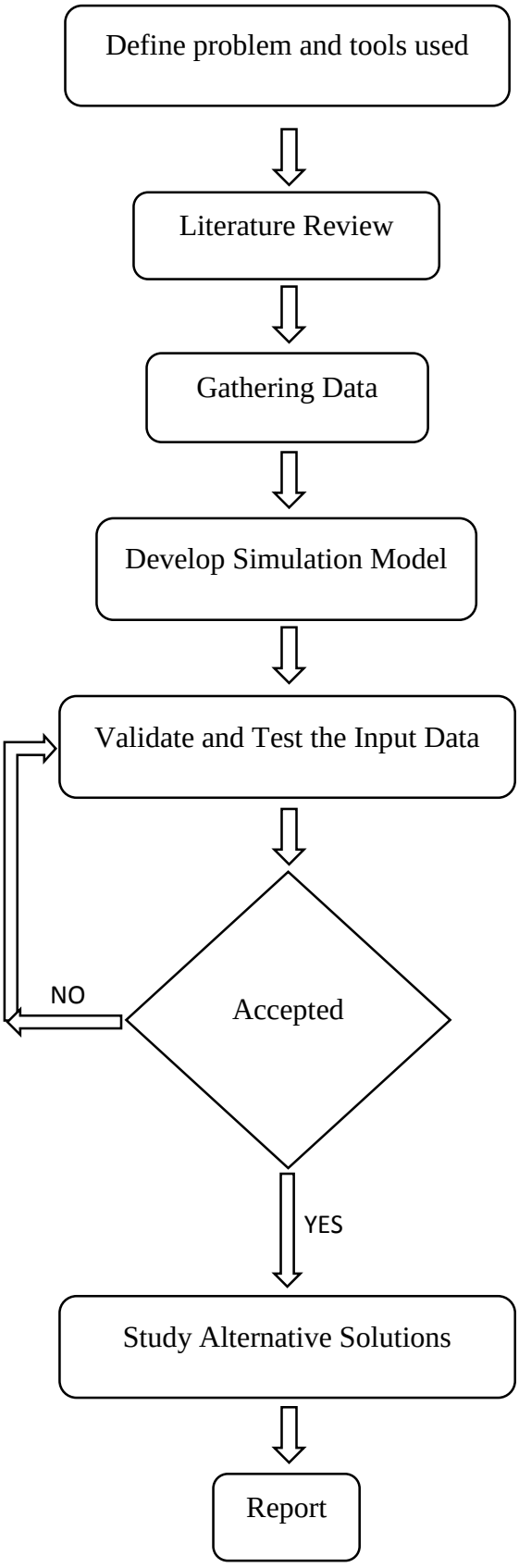
As energy consumption is either thermal (steam demand) or electrical (compressors, pumps etc.), the total equivalent work is used as objective function. This equivalent work, expressed in kWh/t_{CO2}, represents the overall energy penalty on the power plant production due to implementation of a CO_2 capture unit. Such a work is written as follows (Neveux et al., 2013) :

$$W_{eq,total}\ (kWh/t_{CO2}) = W_{parasitic} + W_{compression} + W_{auxilliary}$$

Where,

- $W_{parasitic}$ is the parasitic load, which represents the impact of the steam draw off to provide reboiler heat duty on the power plant electric production.
- $W_{compression}$ is the compression related work, including the CO_2 compression up to 110 bars for transportation and the work of cooling water pumps.
- $W_{auxilliary}$ is the auxiliary work of the capture unit, corresponding to solvent pumps, cooling water pumps, flue gas fan and additional compressors.

1.2 RESEARCH PROCESS:



1.3 GANTT CHART & KEY MILESTONES

Table 5: Gantt Chart of the project

	FYP 1															FYP 2													
Description	**W 1**	**W 2**	**W 3**	**W 3**	**W 4**	**W 5**	**W 6**	**W 7**	**W 8**	**W 9**	**W 10**	**W 11**	**W 12**	**W 13**	**W 14**	**W 1**	**W 2**	**W 3**	**W 4**	**W 5**	**W 6**	**W 7**	**W 8**	**W 9**	**W 10**	**W 11**	**W 12**	**W 13**	**W 14**
Problem understanding & sketching out objectives																													
Reviewing literatures related to the study																													
Gathering data																													
Submission of Extended Proposal																													
Proposal defence																													
Developing process flow diagram and simulation model																													
Submission of Interim Report																													
Simulation of Amine absorption process																													
Validating the process simulation model.																													
Submission of Progress Report																													
Energy analysis & process optimization																													
Pre EDX																													
Conclude the study and Finalize Project work																													
Submission of Dissertation																													
Submission of Technical paper																													
Oral presentation																													

1.4 PROJECT WORK

In this study, Amine absorption process is simulated for two solvents: MEA and DEA. The simulation model was developed using Aspen HYSYS V8.0. For the purpose of this simulation Amine fluid package and Kent-Eisenberg model were selected. The complete simulations of the processes are shown in the figures below.

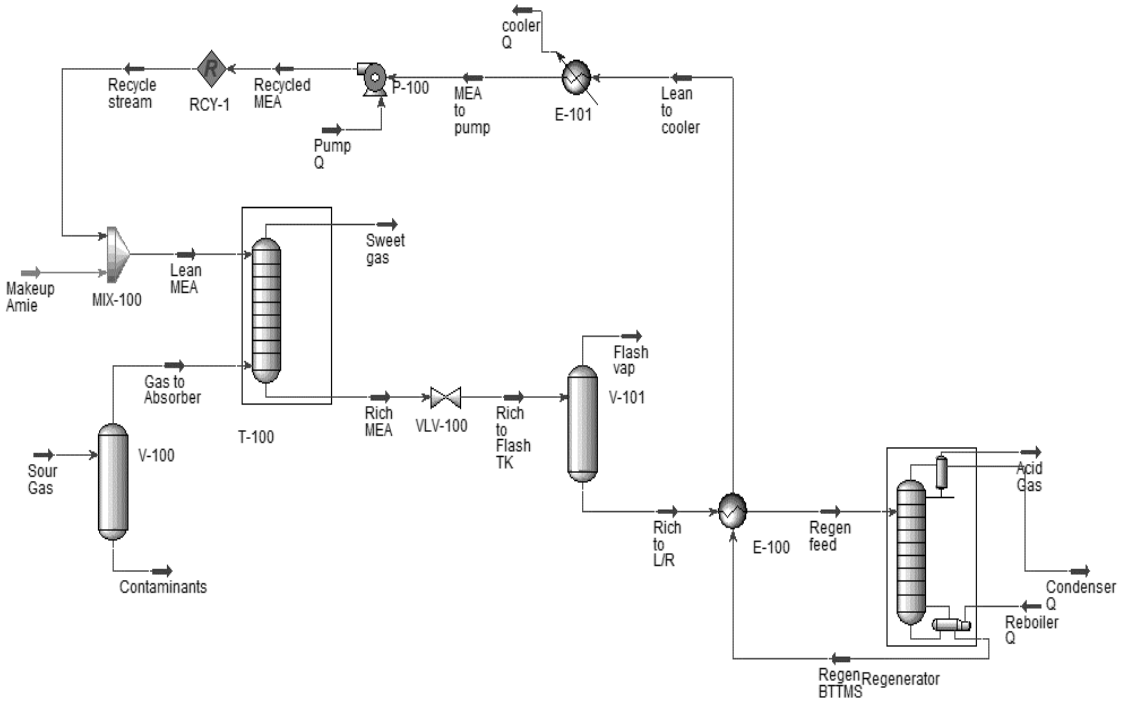


Figure 3: Simulation of Amine Absorption process using MEA

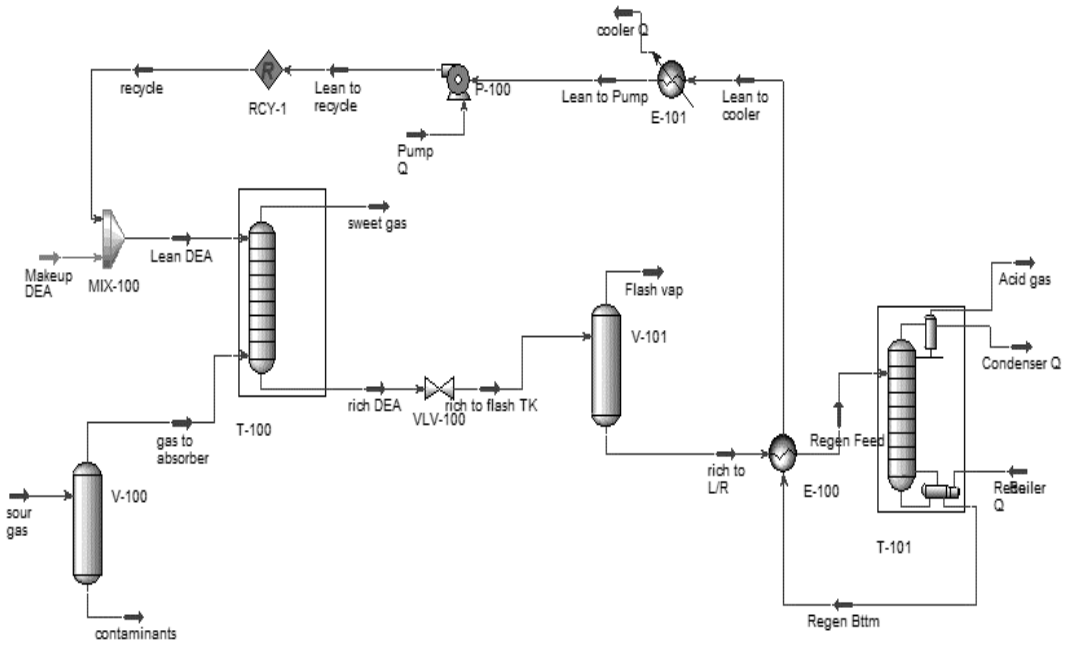


Figure 4: Simulation of Amine Absorption process using DEA

The simulation of the process begins with the simulation of the feed sour gas stream by specifying the gas compositions, temperature, pressure, and flow rate. Sour gas is fed to the process for Carbon dioxide gas removal which will occur inside the absorber column. The compositions of sour gas employed in both simulations are shown in the table below.

Table 6: Sour Gas Compositions

Inlet gas	
Flow rate (Kmol/h)	13,203
Composition (mol%)	
CO_2	19.31
N_2	1.33
Methane	76.58
Ethane	2.5
Propane	0.2
iso-Butane	0.03
n-Butane	0.03
iso-Pentane	0.01
n-Pentane	0.01
Temperature (°C)	30
Pressure (barg)	42.2

The sour gas together with Lean amine feed is sent to an absorber column. Then after the absorption of the CO_2 is done, a regenerator unit is introduced to remove the acidic gas component inside the solution and regenerate the lean amine, In order to reuse the Amine solvent.

The configurations for the absorber, regenerator as well as the lean solvent compositions used for simulation are illustrated in the tables below.

Table 7: Columns configurations

Absorber	
Number of stages	10
Top pressure (kPa)	4261
Bottom pressure (kPa)	4321
Regenerator	
Number of stages	20
Top pressure (kPa)	189.6
Bottom pressure (kPa)	217.2

Table 8: Lean Amine Specifications

MEA solvent	
Flow rate (Kmol/h)	47,000
Composition (wt%)	
MEA	29.9
H_2O	70.1
Temperature (°C)	52
Pressure (barg)	41.6
DEA Solvent	
flow rate (kmol/h)	37,000
Composition (wt%)	
DEA	49.99
H_2O	50.01
temperature (°C)	52
pressure (barg)	41.6

Monoethanolamine is more reactive than Diethanolamine and similarly more corrosive. As a result, the concentration of MEA is restricted to 10 to 20 weight percent, while DEA strengths range from 20 to 30 weight percent.
Rich solution loadings are normally limited to the range of 0.25 to 0.45 moles acid gas/mole MEA, while in DEA systems loadings may range from 0.5 to 0.6 moles acid gas/mole DEA. Aspen HYSYS limits the composition of MEA to 29.9 wt% while allowing a higher limit of 49.9 wt% for DEA. It should be noted that increasing the amine concentration generally reduces the required solution circulation rate and therefore the overall energy consumption.

Before the energy consumption throughout the process is analysed, the simulations of the process by MEA and DEA are validated by actual data and compared to the simulation from Mudhasakul et al.

Table 9: Simulation results using MEA vs. Actual data

Absorber				
Treated gas				
	Actual Data	Study using MEA	Difference	%Error
CO_2 (mol%)	0.10	0.08	0.02	20
Temperature (°C)	51.70	52.32	-0.62	-1.199
Flow rate (ton/h)	224.54	179.2	45.34	20.19
Rich MEA				
	Actual Data	Study using MEA	Difference	%Error
Temperature (°C)	84.30	91.97	-7.76	-9.09
Flow rate (ton/h)	1133.04	1193	-59.96	-5.29
Regenerator				
Acid gas				
	Actual Data	Study using MEA	Difference	%Error
CO_2 (mol%)	50.53	74.54	0.09	-47.52
Temperature (°C)	103.1	80.07	-0.3	22.34
Flow rate (ton/h)	95.94	102.2	45.34	-6.52
Regenerated Lean MEA				
	Actual Data	Study using MEA	Difference	%Error
Temperature (°C)	125.1	125.0	0.1	0.08
Flow rate (ton/h)	1016.03	1089	-72.97	-7.18

Table 10: Simulation results using DEA vs. Actual data

Absorber				
Treated gas				
	Actual Data	Study using DEA	Difference	%Error
CO_2 (mol%)	0.10	0.05	0.05	50
Temperature (°C)	51.70	52.08	-0.38	-0.735
Flow rate (ton/h)	224.54	179.5	45	20.04
Rich DEA				
	Actual Data	Study using DEA	Difference	%Error
Temperature (°C)	84.30	90.88	-6.58	-7.8
Flow rate (ton/h)	1133.04	1279	-145.96	-12.88
Regenerator				
Acid gas				
	Actual Data	Study using DEA	Difference	%Error
CO_2 (mol%)	50.53	74.63	-24.1	-47.69
Temperature (°C)	103.1	79.96	23.14	22.44
Flow rate (ton/h)	95.94	92.1	3.84	4.003
Regenerated Lean DEA				
	Actual Data	Study using DEA	Difference	%Error
Temperature (°C)	125.1	120	5.1	4.077
Flow rate (ton/h)	1016.03	1186	-169.97	-16.73

Tables 9 and 10 show a comparison between simulation results using MEA and DEA and actual plant design data. The simulation models give good predictions of the temperatures and flow rates for both processes. Although the CO2 composition of the treated gas stream has a relative error of 20% for MEA and 50% for DEA, the compared numbers of 0.1% from plant data and 0.08% for MEA and 0.05% for DEA, are very small. As a result, these small numbers render the comparison in terms of relative percentage rather meaningless. One should focus on the magnitude of these numbers which are within the target range of reducing CO2 concentration in the treated gas to 0.1%.

Below is a comparison between project simulation for MEA, DEA and the simulation results obtained from Mudhasakul et al. (2013).

Table 11: Project simulation vs. Mudhasakul Simulation

Absorber					
Treated gas					
	Simulation from Mudhasakul et al.	Project Simulation by MEA	Difference	Project Simulation by DEA	Difference
CO_2 (mol%)	0.09	0.08	0.01	0.05	0.04
Temperature (°C)	54.79	52.32	-0.62	-0.735	2.71
Flow rate (ton/h)	219.74	179.2	40.54	20.04	40.24
Rich Amine					
	Simulation from Mudhasakul et al.	Project Simulation by MEA	Difference	Project Simulation by DEA	Difference
Temperature (°C)	85.94	91.97	-6.03	90.88	-4.94
Flow rate (ton/h)	1137.81	1766	-628.19	1279	-141.19
Regenerator					
Acid gas					
	Simulation from Mudhasakul et al.	Project Simulation by MEA	Difference	Project Simulation by DEA	Difference
CO_2 (mol%)	49.03	74.54	-25.51	74.63	-25.6
Temperature (°C)	107.47	80.07	27.4	79.96	27.51
Flow rate (ton/h)	93.49	102.2	-8.71	92.1	1.39
Regenerated Lean Amine					
	Simulation from Mudhasakul et al.	Project Simulation by MEA	Difference	Project Simulation by DEA	Difference
Temperature (°C)	127.62	125.0	2.62	120	7.62
Flow rate (ton/h)	1015.32	1089	-73.68	1186	-170.68

CHAPTER 4

RESULTS AND DISCUSSION

4.1 PROCESS SIMULATION RESULTS:

4.1.1 Effect of different parameters on process behaviour:

a. Absorber height:

The figure below shows the effect of changing the number of stages of Absorber column on the CO_2 composition in the Treated gas stream, the plot below was developed based on the result obtained from the simulations done using MEA and DEA.

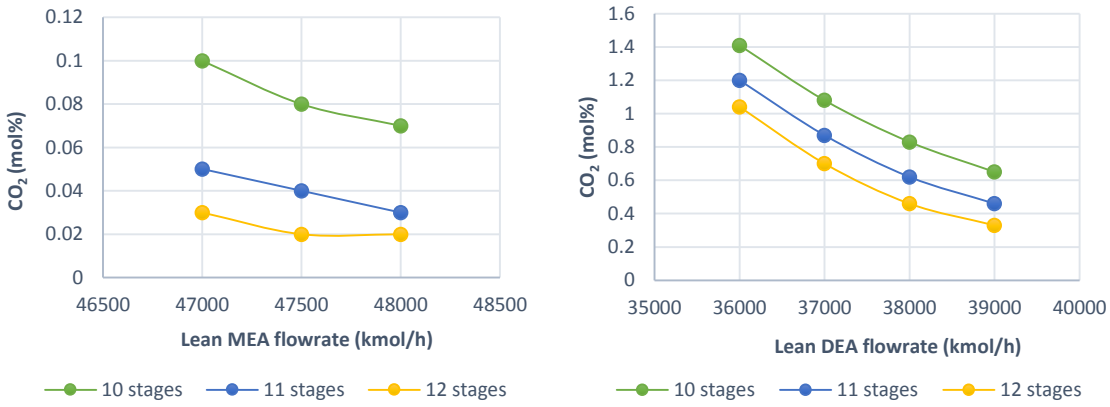


Figure 5: Effect of Absorber height on CO_2 content in treated gas for MEA and DEA respectively.

The height of the absorption column is varied by changing the number of stages. At a certain height, the amount of CO_2 captured from sour gas increases with increasing lean amine flow rate. The Capture capacity also increases with increasing the height of the absorber column as shown in the plot above.

b. Regenerator height:

The amine is stripped from CO_2 with heat added to the solution in the reboiler. The reboiler boils the solution, supplying heat to break the bond between amine and CO_2 and creating steam from the solution, which flows upward through the tower, in counter-current with the rich amine solution, heating the solution before it enters the reboiler.

The heated steam also lowers the partial pressure of CO_2 in the gas stream, enhancing the driving force of the acid gases from the amine solution. The effect of changing the height of the regenerator tower on the amount of CO_2 in the recycled amine stream is shown in the plot below.

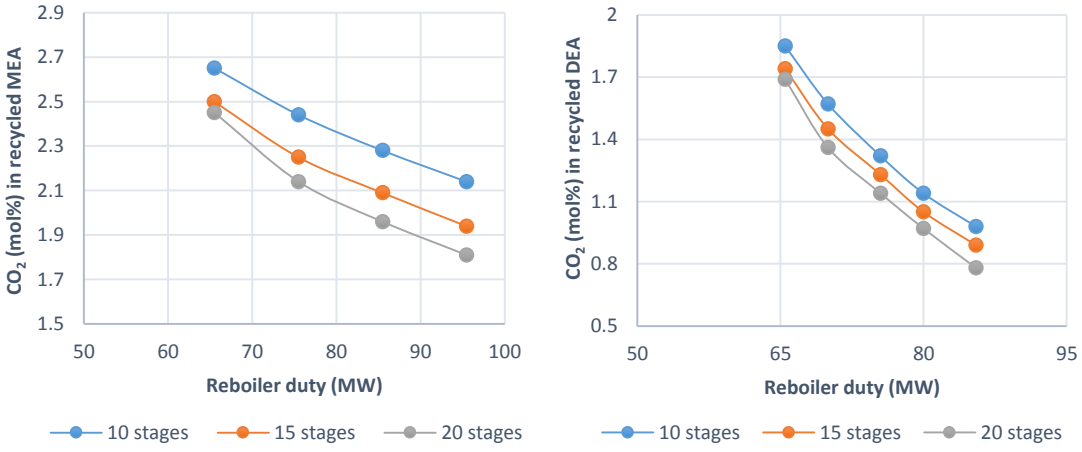


Figure 6: Effect of the Regenerator column height on CO_2 content in recycled Amine

When it comes to the amount of lean amine recycled by the regenerator tower, it is found that increasing the height of the tower, with increasing reboiler duty results in increasing the amount of regenerated Lean amine. This is shown in the figure below.

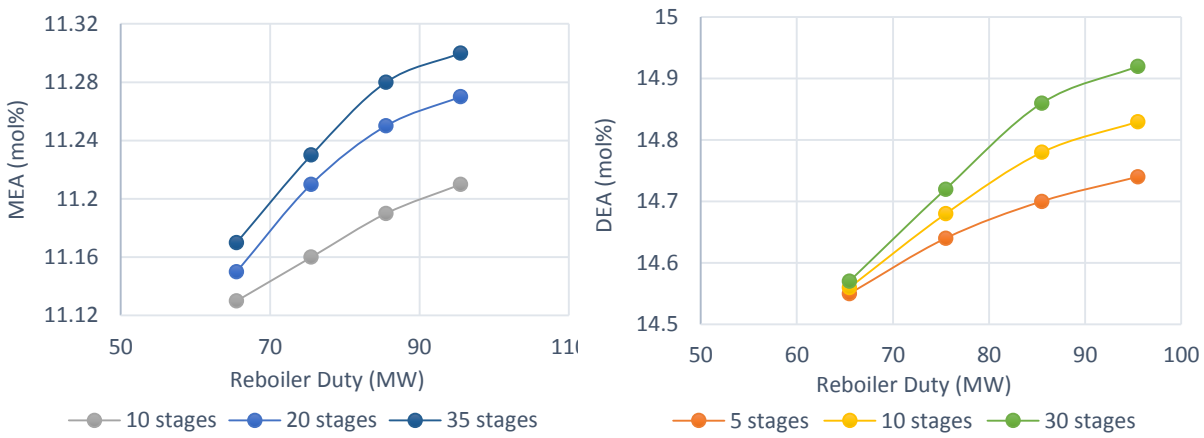


Figure 7: Effect of the Regenerator column height on recycled Lean amine

As observed in the plots above, at a certain height, as the reboiler duty increases, the amount of regenerated lean amine increases and the amount of CO_2 in regenerated amine decreases. Meaning that the regeneration capacity of the tower increases with increasing its height.

4.2 ENERGY ANALYSIS:

4.2.1 Overall energy consumption

By using Aspen HYSYS software, CO2 absorption process is simulated using MEA and DEA solvents. The overall energy consumption throughout each process is shown in the table below.

Table 12: Overall Energy Consumption

Absorption process using MEA	**Energy (MW)**
Regenerator pre-heater duty	17.294
Regenerator column reboiler duty	97.6
Regenerator column condenser duty	25.844
Lean amine cooler duty	72.34
Lean amine pump duty	1.649
Total energy consumed in the absorption unit	214.727
Absorption process using DEA	**Energy (MW)**
Regenerator pre-heater duty	18.26
Regenerator column reboiler duty	65.56
Regenerator column condenser duty	7.8276
Lean amine cooler duty	62.78
Lean amine pump duty	1.7193
Total energy consumed in the absorption unit	156.15

The energy consumption was investigated at a solvent feed temperature of 52 ˚C, pressure of 4261 kPa, reboiler temperature of 120 ˚C, and stripper operating pressure of 189.6 kPa. According to the results, the overall energy consumed throughout the process using DEA solvent is noticeably less than that consumed using MEA. This is due to the fact that at the set operating conditions, the process using MEA, using a less solvent concentration of 29.9 wt% requires a higher solvent flow rate of 47000 kmol/hr compared to DEA with a composition of 49.9 wt% and flow rate of 36000 kmol/hr, and consequently, a higher reboiler duty is required to heat the rich solvent feed to the stripper.

4.2.2 Effect of different parameters on energy performance

In this section, the performance for the absorption process using MEA and DEA is investigated in terms of energy consumption in regeneration unit. The regeneration energy is comprised of three energy contributors:

- Energy used for desorption of CO_2
- Energy used for generating stripping stream.
- Energy used for heating up the solvent.

In this part of the project, the effect of different parameters is shown on the energy consumption of the regeneration section for each solvent.

a. Effect of rich solvent loading

The effect of rich solvent was also investigated in this project, the results shown in the figures below.

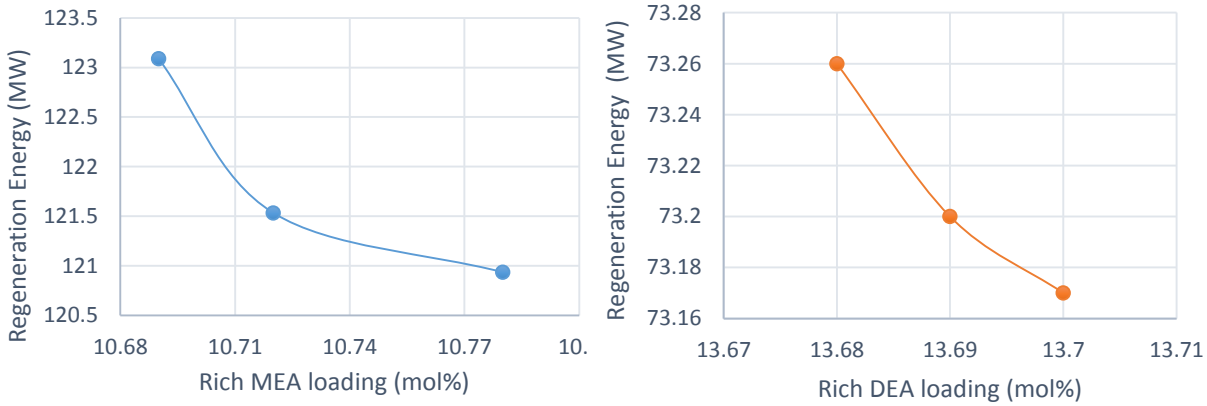


Figure 9: Effect of rich solvent loading on regeneration energy

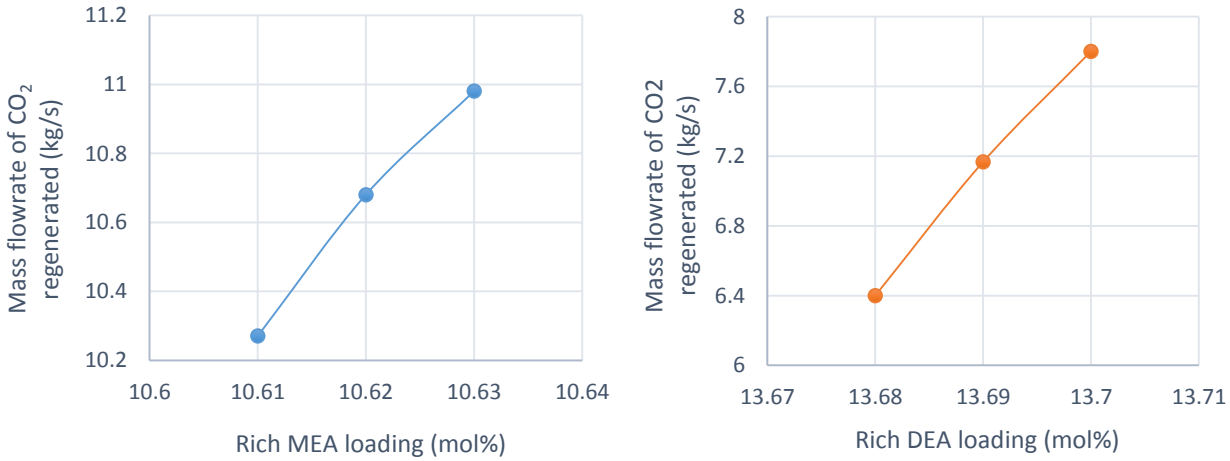


Figure 8: Effect of rich solvent loading on CO2 mass flow rate

When investigating the effect of the rich amine loading on both regeneration energy and regenerated CO_2 mass flow rate, the MEA concentration was 29.9 wt%, the feeding solvent temperature was 52 ˚C, the reboiler temperature was 125 ˚C and the stripper operating pressure was 189.6 kPa. As for DEA, the lean concentration was 49.9 %, the reboiler temperature was 119.8 ˚C, and the feeding solvent temperature and the stripper operating pressure remain the same as for MEA. As the figures above show, the regeneration energy decreases as the rich solvent loading increases.

It can also be observed that the mass flow rate of CO_2 increases significantly as the rich amine loading increases, so the sensible heat decreases accordingly. Meanwhile, the heat of water vaporization decreases as rich solvent loading increases. Which leads to decreasing the energy required for regeneration.

b. Effect of solvent feed temperature:

The effect of feeding solvent temperature was also investigated. At a constant MEA concentration of 29.9 wt% and mass flow rate of 13.06 kg/s , the reboiler temperature is fixed at 125 ˚C and the regenerator operating pressure is 189.6 kPa. For DEA, the solvent concentration is 49.9% and mass flow rate is 10 kg/s. The reboiler temperature is 121 ˚C and the regenerator also operate s at 189.6 kPa.

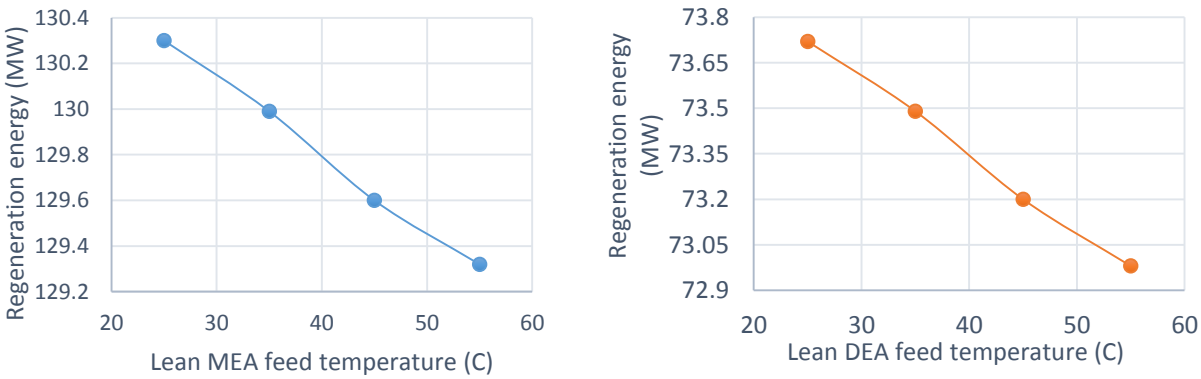


Figure 10: The effect of the solvent feed temperature on regeneration energy

As the previous figure shows, the regeneration energy decreases as the feeding solvent temperature increases. The results can be explained that the lower temperature difference between feeding solvent and reboiler leads to a lower sensible heat.

c. Effect of reboiler temperature:

Reboiler temperature is another important parameter that influences the regeneration energy. Figure 11 below illustrates the effect of reboiler temperature on regeneration energy.

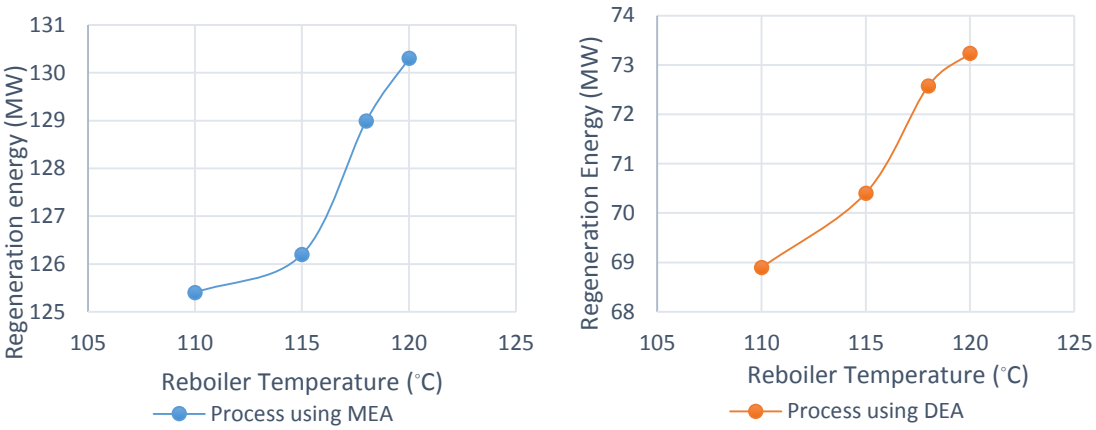


Figure 11: Effect of reboiler temperature on regeneration energy

According to the above plots, the regeneration energy increases as the reboiler temperature increases from 110 to 120 °C. The higher reboiler temperature leads to a higher load on the reboiler which increases the energy consumption, this is because the heat of water vaporization increases significantly as the reboiler temperature increases.

4.3 ENERGY OPTIMIZATION:

Based on the analysis done to investigate the effect of the different operating parameters on the energy performance of the unit, it was found that:

- The defining factor for amine systems is that the amount of circulated amine is directly proportional to the amount of moles of sour gas in the gas stream. Which directly affects energy consumption.
- The rich solvent loading is inversely proportional to the heat of water vaporization, therefore the regeneration energy consumption decreases.
- The absorber should be operated at high possible pressure and low temperature in order to enhance amine loading capacity
- The solvent feed temperature has a positive effect on energy optimization, sine a high solvent feed temperature means less reboiler duty required to heat the solvent, which means less energy consumption overall.
- The reboiler temperature has a negative effect on energy consumption. As reboiler temperature increases, the heat of water vaporization increases and so the regeneration energy required increases.

Optimization of the process was carried out by modification of some parameters in absorption process using DEA to meet the project objectives. The values for the modified parameters are shown in table of data below.

Table 13: Optimized parameters

Parameter	Optimized value
Number of stages in Absorber	18
DEA feed Temperature (°C)	55
DEA feed flow rate (kmol/h)	38000
Reboiler temperature (°C)	114
Number of stages in regenerator	20

After manipulating the parameters to achieve the best balance between capture capacity and minimising overall energy consumption. A comparison is done between the results before optimization and after. Table 14 below illustrates the results.

Table 14: Energy consumption comparison

Overall Energy consumption	
Before optimization	**Energy consumed (MW)**
Regenerator pre-heater duty	18.26
Regenerator column reboiler duty	65.56
Regenerator column condenser duty	7.8276
Lean amine cooler duty	62.78
Lean amine pump duty	1.7193
Total energy consumed in the absorption unit	**156.15**
After optimization	**Energy consumed (MW)**
Regenerator pre-heater duty	15.306
Regenerator column reboiler duty	47.77
Regenerator column condenser duty	6.404
Lean amine cooler duty	60
Lean amine pump duty	1.735
Total energy consumed in the absorption unit	**131.215**

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

In conclusion, it can be said that the objectives of this study has been achieved.

1. A model has been developed to optimize the operating conditions for the absorption process using two different solvents MEA, and DEA.
2. Overall energy evaluation was carried out.
3. Energy optimization study has been carried out.

According to the energy analysis carried out in this project it was found that increasing the rich loading and feeding temperature of the solvent has a positive effect on optimizing regeneration energy consumption, while increasing the reboiler temperature has a negative effect. Manipulating these parameters was the chosen method for energy optimization. Minimizing the overall energy consumption as well as attaining a CO_2 absorption capacity within the desired range are the main objectives of this project and they were successively achieved.

Changing the DEA solvent temperature from 52 to 55 ˚C, and reboiler temperature from 120 ˚C to 114 ˚C had the largest effect on minimizing the reboiler duty and therefore the energy required for solvent regeneration.
There is a lot of room for improvement, in optimization of the process scheme and especially in characterization of new promising solvents in order to reduce energy consumption.

CHAPTER 5

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