

SIMULATION OF CO₂ CAPTURE PROCESS USING DIFFERENT TYPE OF SOLVENTS

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Abstract - High amount of carbon dioxide is not suitable for the Earth as it can cause various environmental problems such as greenhouse gas effect as well as rise of Earth temperature. This phenomena can cause the elevation of sea water level due to melt of iceberg in North Pole and South Pole. However, the amount of carbon dioxide gas can be reduced by capturing the gas by using absorption process. This research project used Aspen HYSYS V8.8 in order to simulate the absorption process that consist absorber tower, distillation column, heat exchanger and pump. The feed of flue gas come from coal power plant which is about 5.35 % of carbon dioxide. Blending of piperazine (PZ) and monodiethanolamine (MDEA) was used in this study as the solvent in capturing carbon dioxide. The solvent can be regenerated by using stripper column that generate heat from the boiler thus strip the carbon dioxide from solvent. From this simulation, 0.1 MDEA and 0.1 PZ with 0.8 of water composition was chose as the best solvent which can fully absorbed carbon dioxide present which was 7820.9508 kg/h. Later on, the absorber tower was tested with solvent temperature in range 40° C - 100° C. Increasing feed solvent temperature will reduce the CO₂ absorption capacity

Keywords – Carbon dioxide, Blending MDEA-PZ, HYSYS Simulation, Absorption

I. INTRODUCTION

Current CO₂ emission in the world is a serious problem. This emission came from natural sources and human sources. Natural sources are much bigger emission compared with human sources however human sources have disturbed the natural balance that exist thousand years ago due to human activities (Denman et.al, 2007). This problem can be solve by using carbon dioxide treatment. Various method can be used in other to remove the CO₂ such as cryogenic, scrubber, membrane separator and many more (Anand B. Rao et.al, 2002).

Current chemical absorption that widely used are by using monoethanolamine (MEA) and monodiethanolamine (MDEA) (Bouallou, C.; Kaniche, M., 2007) (Khalid Osman et.al, 2012). However, these solvents cause problem in terms of amount of capturing capacities, rate of absorption, energy requirements and corrosion (Ana B. Lopez et.al, 2015) (Abenzidagen et.al, 2008). Referring to Dashti, 2015, blend of solvents is suggested at different composition which can counter the problems mentioned.

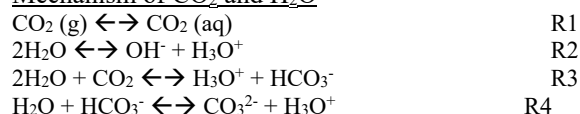
The objectives of this simulation are finding the best amine blending composition (MDEA+PZ) and effect of the temperature on the absorption capacity. This simulation will be using HYSYS V8.8 with Acid Gas Package as the fluid packages used.

II. METHODOLOGY

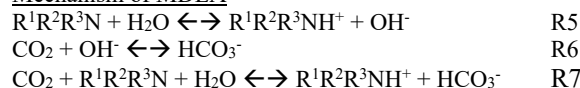
A. Process Description

Process flow diagram (PFD) that will be used as the base condition is shown in Figure 1. Flue gas from natural gas which contain 5.35% mol of CO₂ was fed at the bottom of absorber tower. At the same time, MDEA solvent was fed into the same tower. The reaction between the CO₂ and MDEA are as follows:

Mechanism of CO₂ and H₂O



Mechanism of MDEA



The CO₂ lean gas then enter the scrubber to recover the water and solvent and recycled back to prevent solvent loss (Mohammad R.M. Abu-Zahra et.al, 2007). The gas that have been treated is vented to the atmosphere. Rich amine CO₂ is pumped and heated before entering the stripper. The pressure and temperature of the stripper must be operated at suitable condition which is higher than absorber tower in order to regen the solvent. Condenser is used to recover the steam and fed back into the stripper. CO₂ that have been absorbed are also released at the top of the condenser. The lean solvent is pumped and cooled down before entering the absorber

B. Solvent Used

Amine type solvent used were commonly used for CO₂ absorption. Each solvent have their own pros and cons. This studied focus on blending of MDEA and PZ as it were rarely reported hence not thoroughly studied. Table 1 shows the advantages and disadvantages of the solvent PZ and MDEA.

Table 1. Advantages and Disadvantage of PZ and MDEA

	Advantage	Disadvantage	References
PZ	- Double the absorption rate - More stable at high temperature - Less prone to oxidation	- Limited solvent solubility - Problem when process upsets and temperature fluctuation - Demand advanced handling technique	(Le Lia et.al, 2013) (Anoar Ali Khana et.al, 2017)
MDEA	- Less energy consumption for regeneration - Less corrosive effect to the equipment - High capacity to capture carbon dioxide	Slower reaction rate with carbon dioxide	(Ana B. López et. al, July 2015) (Khalid Osman et. al, 18 April 2012) (Abenzidagen et.al, 2008)

C. Parameter on Absorber and Stripper

The main equipment which were absorber tower and stripper column was set according to (Majeed S. Jassim, 2016) condition as shown in Table 2. Absorption of CO₂ occur in absorber tower with the help of amine solvent meanwhile stripper was used to strip the CO₂ from the solvent by using heat.

Table 2. Condition of Absorber and Stripper

	Absorber	Stripper
Number of Trays	10	20
Inside diameter (m)	1.75	1.4
Tray Type	Valve	Valve
Tray Spacing (m)	0.50	0.55
Weir Height (mm)	57	77
Weir Length (m)	1.6	1.245
Solvent Feed	1	3
Location from Top, Tray		
Bottom Pressure (kPa)	4680	200
Pressure Drop, (kPa)	60	20

D. Flue Gas Composition

This flue gas come from natural gas processing.

Table 3. Feed Composition of Flue Gas

Composition	Wet Gas (vol %)
Methane	80.26
Ethane	1.63
Propane	0.35
Butane	0.18
Pentane	0.24
H ₂ S	0.05
N ₂	11.34
CO ₂	5.35

E. Simulation 1 and Simulation 2

Simulation 1 was used as the base case according to (Majeed S.Jassim, 2016) while Simulation 2 was used by modified the base case in order to achieve the first objective which is to study the performance of the solvents in capturing carbon dioxide gas which were (MDEA + PZ) while the second objective was to study the effect of absorber temperature on the CO₂ absorption capacity. Figure 3 and Figure 4 shows how simulation was done.

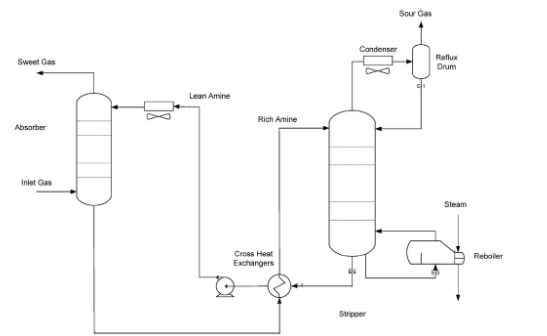


Figure 3. Base condition of Simulation 1

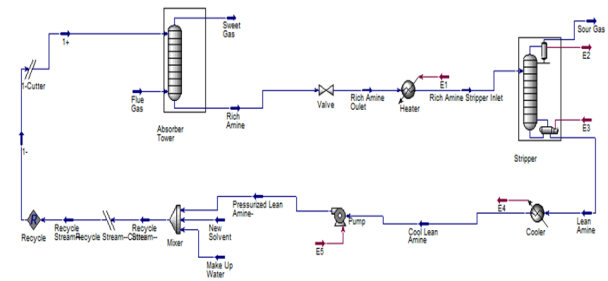


Figure 4. Modified Simulation

Data obtain from this simulation was recorded and tabulated in results and discussion part.

III. RESULTS AND DISCUSSION

A. Comparison data between Simulation 1(Majeed S. Jassim) and Simulation 2

Comparison error between Simulation 1 and Simulation 2 were calculated and shown in Table 4.

Table 4. Comparison data between Simulation 1 and Simulation 2

Process Variable	Simulation 1	Simulation 2	Percentage Error
Sweet gas flowrate (kg/h)	58 845	58 630	0.365%
H ₂ S in sweet gas (kg/h)	1.2	0	100%
CO ₂ in sweet gas (kg/h)	4024	4152.8826	-0.032%
Rich amine flowrate (kg/hr)	63 396	122 400	-93.07%
Rich CO ₂ loading (mol CO ₂ / mol MDEA)	0.6715	0.1146	82.93%
Rich H ₂ S loading (mol H ₂ S/mol MDEA)	0.0131	0.0002561	98.04%
Lean amine flowrate (kg/h)	60 108	102 300	-70.194
Lean CO ₂ loading (mol CO ₂ /mol MDEA)	0.0028	3.3369 x 10 ⁻⁵	0.99%
Lean H ₂ S loading (mol H ₂ S/mol MDEA)	0	9.8460 x 10 ⁻⁶	0 %
Tail gas flowrate (kg/h)	3686.6	20 170	-447.12%
CO ₂ in tail gas (kg/h)	44.1	3 369	-7539.46%
H ₂ S in tail gas	3501	53.6781	98.47%

Based on Table 4.1, there were uncertainty of the data as the error was too high. A big different data value between the two simulation. This is mainly due to the fact that the HYSYS version used was different. Besides, the fluid package used could also contributed to the high percentage error. In this simulation, Acid Gas Package was used as the fluid package as carbon dioxide absorption and removal was suitable for it.

B. Effect of solvent composition

Various composition of amine solvent (MDEA+PZ) were tested in this simulation. Composition that were tested were 0.7 water (H₂O), 0.8 H₂O and 0.9 H₂O. According to the Figure 3.1, it was shown that at the blending composition at 0.7 H₂O and 0.8 H₂O, CO₂ present can fully absorbed by the absorbed meanwhile when only single MDEA was used, it cannot fully absorbed. At 0.9 H₂O composition with 0.03 MDEA + 0.07 PZ, about 96% CO₂ absorption was achieved.

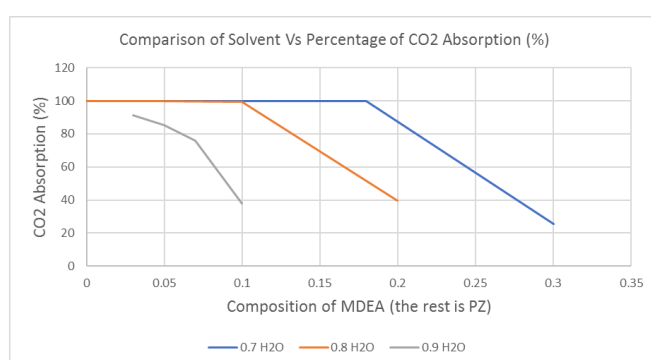


Figure 5. Comparison between various composition of water of MDEA + PZ blending

Referring to the Figure 4.4, the data shows that when only MDEA was used to capture CO₂ in the simulation, it failed to achieve 100% of absorption. On the other hand, blending of at least 0.1 mol % of PZ amine resulted in better absorption of CO₂. It was determined that 0.8 of H₂O, 0.1 of PZ and 0.1 of MDEA was chose as the best solvent as it can achieved the best absorption which was 7820.9508 kg/h in Figure 4.5. Sajjad Sharif Dashti, 2015, said that when 5% and above of PZ was used CO₂ captured increase significantly. The lesser the amount of solvent used is more recommended as it can save on cost (Dashti, 1 June 2015). Moreover, PZ solvent is more expensive compare to MDEA solvent. 100% of CO₂ absorption with lesser PZ solvent is preferable. PZ can capture twice amount of CO₂ compare to other amine as it have cyclic molecular structure (Le Lia et.al, 2013). As a result, blending of 0.1 MDEA + 0.1 PZ with 0.8 H₂O was chose as the best blending amine compared with other blending composition.

C. Effect of Temperature on Absorption Capacity

From the Figure 5, the best composition amine blending was 0.1 MDEA + 0.1 PZ with 0.8 of water composition. At that composition, all CO₂ present was fully absorb. Although there were some other composition that can achieve 100% CO₂ absorption, this composition blending was chosen because the greater the amount of amine used, the more expensive the solvent (Dashti, 1 June 2015).

From this best composition of MDEA + PZ, temperature of absorber tower was set from 40°C -100 °C to achieve the second objective. Various temperature of solvent was tested in this simulation at the absorber tower. The aim of this objective is to

study the effect of temperature on the absorber which can affect the amount of CO₂ absorbed by the amine. The result can be shown in Figure 6 below.

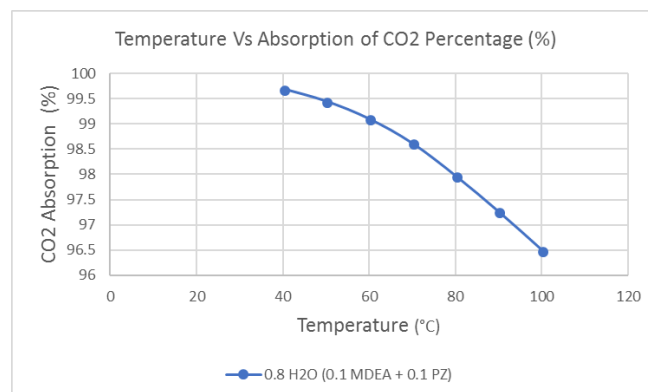


Figure 6. Effect of Temperature on Absorber Tower

According to Figure 4.6, it is shown that when operating temperature of the absorber increases, the absorption capacity decreases. This happened because as temperature increases, the solvent intend to undergoes degradation process which affect the absorption capacity. These problem can be solved by operating the absorber tower at suitable temperature or adding another equipment which can support the solvent which is known as make-up water.

IV. CONCLUSION

This simulation had proved that blending amines had better absorption capacity compared with single amines used (Dashti, 1 June 2015). It also counteract each other disadvantages with their own advantages as mentioned in Chapter 2. The first objective which was to study the performance of blended amine which was monoethanolamine (MDEA) and piperazine (PZ). The best composition was when by using 0.1 MDEA + 0.1 PZ with 0.8 of water composition. It was simulated that at this composition, all carbon dioxide present at the flue gas was fully absorbed which was about 7778.2589 kg/h. From this composition, various operating absorber temperature were tested in other to achieve the second objective. It was believed that as temperature of the absorber is higher, the absorption carbon dioxide capacity decreases. This happened due to the solvent tend to degrade and vaporize elevated temperature.

ACKNOWLEDGMENT

Thank you to my supervisor, Dr Ruzitah Salleh and Sir Meor Muhammad Hafiz Shah Buddin for all your knowledge sharing and supervise my research project since 2017.

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