Simulation to Improve CO_2 Capture using Vapor Recompression Combined with Split Stream Process

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***Abstract*— In this era of globalization, carbon dioxide (CO_2) has become one of the main component of greenhouse gases emitted into the atmosphere. Due to this problem, CO_2 capture technologies have been developed which it is one of the techniques that could be used to reduce CO_2 emissions from human activities. The most well-known technology for post combustion CO_2 capture from exhaust gas is absorption in amine-based solvent followed by desorption. The solvent used in this absorption process is monoethanolamine (MEA). The objective of this study is to improve CO_2 capture using vapor recompression combined with split-stream process and study the parameters that affect CO_2 capture. Simulation using Aspen HYSYS version 8.8 was used in this study. The fluid package used is Amine Property Package with Kent-Eisenberg model. The inlet pressure, inlet temperature and MEA composition are varied to investigate the effect on CO_2 capture. The result shows that the CO_2 removal efficiency increase as the inlet temperature and concentration of MEA increase. However, the increment is too small which can be concluded as these parameters just give small impact on percentage of CO_2 removal. In contrast with inlet pressure, CO_2 removal efficiency is highly dependent on the inlet pressure of the natural gas. The best operating condition obtained from this study is at 80 °C, 400 kpa and 0.14 wt% MEA concentration.**

***Keywords*— carbon dioxide (CO_2), post-combustion, split stream, monoethanolamine (MEA), Aspen HYSYS.**

I. Introduction

CO_2 also is the major contributor to the global warming phenomena due to its abundance comparing to other greenhouse gases. As the results, it is considered to be a primary target for reduction. The emission of carbon dioxide is mostly come from burning of fossil fuels, vehicles, process industries and others (Eggleton & Eggleton, 2013) Due to this problem, for the better environment and ecosystem, most of the people have started to create a CO_2 capture technologies and several of these technologies have been proposed.

There a several strategies that being considered in order to reduce the CO_2 emissions such as post-combustion capture, pre-combustion capture, oxyfuel combustion and also electrochemical separation (Aaron & Tsouris, 2005). One of the methods that are well-known for post-combustion CO_2 capture from exhaust gas is chemical absorption of CO_2 in an amine-based solvent which is monoethanolamine (MEA). It is the most standard technology for large scale post combustion CO_2 capture from exhaust gas.

Basically, there are two types of CO_2 capture for post-combustion by absorption which are physical absorption and also chemical absorption. For post combustion CO_2 capture, absorption of CO_2 in amine based solvent has been used widely in the industry. However, the drawback of this method can be seen from a few aspects. One of the problems with this method is large heat consumption needed for absorption in this process (Yu et al., 2012). The higher consumption of heat at the absorber may damage the equipment in the process. In order to reduce the high energy consumption at the absorber, several alternative configurations have been proposed such as split-stream process, vapour recompression and vapour recompression combine with split-stream process (Rochelle, 2003). In this study, we are focusing on the vapour recompression process combined with split-stream process.

The problem faced in this study is in terms of lower performance of CO_2 efficiency where by the CO_2 captured in the rich mea from the absorber was low. The target of the CO_2 captured in the rich mea is 85% from inlet feed. In order to improve and get a higher CO_2 for the process, a few parameters have been varied in this study. Basically, the inlet temperature of the natural gas, the inlet pressure of the natural gas and the concentration of MEA were varied to find the best condition for the process for given specification.

II. Methodology

A. Process Specification

In this study, Aspen HYSYS version 8.8 is used in the simulation process. The fluid package used for this process is Amine Property Package and it is described by the use of this package. The typical solvent used for this process is amine based solution which is monoethanolamine (MEA). For this configuration of vapor recompression process combined with split-stream process, it has been compared with the standard process (base study). The standard specification data is shown in table 1.

Table 1: Vapor recompression process combined with split-stream process input specifications for 85% CO_2 removal

Parameter	Value
Composition	MEA: 27,0 weight%
	CO_2:4,4 weight%
	H_2O: 68,6 weight%
Lean amine loading	
Temperature	40 °C
Pressure	101 kPa
Flow rate	4,55 *10^4 kgmole/h

For the specification of vapor recompression combined with split-stream process, the regenerated amine stream is split into two at a ratio of 1.0 and 0.9 for the semi-lean and the lean amine streams respectively. The semi lean was sent to stage 8 of the absorber. The absorber liquid feeds are 45500 kgmol/h of amine and sour gas feed are 109141 kgmol/h. In this study, the standard operating data for monoethanolamine (MEA) used was 15 wt% in concentration. Table 2 shows the feed gas composition, table 3 shows the absorber configuration and configuration of regenerator.

Table 2: Feed Gas Composition (Union Gas)

Components	**Mol (%)**
CO_2	0.7
N_2	1.0
methane	94.9
Propane	0.2
i-butane	0.03
n-butane	0.03
i-pentane	0.01
n-pentane	0.01
ethane	3.2
oxygen	0.02

Table 3: Configuration of the absorber and regeneration

Absorber		
	Column Diameter (mm)	3900
	Packing Height (mm)	29450
	Material	CS / SS
Top Section	Bed 1 Packing Type	2.5'' S.S Pall Rings
Bottom Section	Bed 2 Packing Type	3.0'' S.S Pall Rings

Regenerator		
	Column Diameter (mm)	4400
	Packing Height (mm)	39420
	Material	Top: 304 SS Bottom: CS
Top Section	Bed 1 Packing Type	2.5'' S.S Pall Rings
Intermediate Section	Bed 2 Packing Type	3.0'' S.S Pall Rings
Bottom Section	Bed 3 Packing Type	3.5'' S.S Pall Rings

B. HYSYS Simulation Procedure

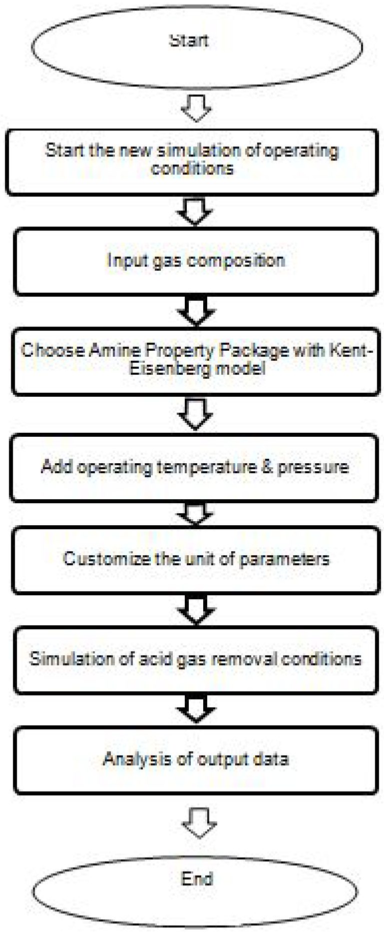

Figure 1 shows the flow of HYSYS procedure where firstly the software of Aspen HYSYS 8.8 was opened and the new case was chosen. Then, the component list was chosen at the properties and after that fluid amine property package of acid gas was chosen for this study. Start the simulation process as shown in the figure 2 below. Lastly, analyze the output data based on the simulation that have been run for the process.

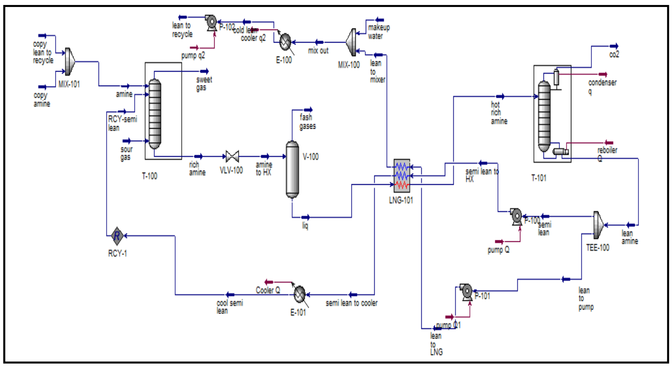

Fig. 2: The process flow diagram for CO_2 removal simulation using Aspen HYSYS

III. RESULTS AND DISCUSSION

A. Simulation result

Figure 7 shows the overall process flow for CO_2 removal unit by using vapor recompression combine with split stream process.

There are various simulation tools that can be used. However, this study is focusing on one simulation tools at the time and Aspen HYSYS 8.8 has been the preferred tool. All the data that has been used in this study was based on standard base case. In this process, the absorber and regenerator units are the main part of CO_2 removal process. For the simulation, acid gas fluid package was used in this process and this study will be focusing on the absorber unit.

Based on the simulation result, there are small deviations in values occurs compared to the base case results that shows 85% of CO_2 removal was achieved. However, the result from this study was slightly above 85% of CO_2 removal. This is due to the starting values in the model and the accepted sensitivity deviations in the software function. As the sensitivities are reduced, this deviations may be reduced. For example tighter convergence limits.

Besides that, the deviation is also due to simplified model. The process flow for this study is more simplified compared to the real process flow. A real process flow consists of more auxiliary equipment and components. These equipment will generate higher pressure drop and more heat loss. However, heat loss from the equipment and the pressure drop throughout the process were neglected in this study. In addition, adiabatic efficiencies might also be one of the reason. The value for adiabatic efficiency in the pump may not be accurate enough for a detailed pump power study. The value was set at 75% which is the default value in Aspen HYSYS.

B. *Effect of inlet temperature on CO_2 removal efficiency*

Figure 3 shows the effect of inlet temperature of the natural gas on the CO_2 removal efficiency for inlet gas pressure of 400 kpa, 300 kpa, 200 kpa and 100 kpa. It can be concluded that the CO_2 removal efficiency increases as the inlet temperature increases. However, there is only slight increment in CO_2 removal efficiency. For example at 400 kpa, when increasing the inlet temperature from 40 °C to 50 °C, the percentage of CO_2 removal efficiency is 95.7% and 96.1% respectively. The difference between these two temperatures is only 0.4%. At pressure 200 kpa and 100 kpa, the trend shows that the CO_2 removal efficiency increase more gradually compared to 300 kpa and 400 kpa. This can be seen from the slope of the line. CO_2 removal efficiency is higher at pressure 300 kpa and 400 kpa which is above 90% The result also shows, at inlet pressure of 100 kpa with inlet temperature of 40 °C has the lowest CO_2 removal efficiency with only 52.3% CO_2 being removed from the natural gas. While inlet pressure of 400 kpa at temperature of 80 °C has the highest CO_2 removal efficiency which is 97% CO_2 being removed.

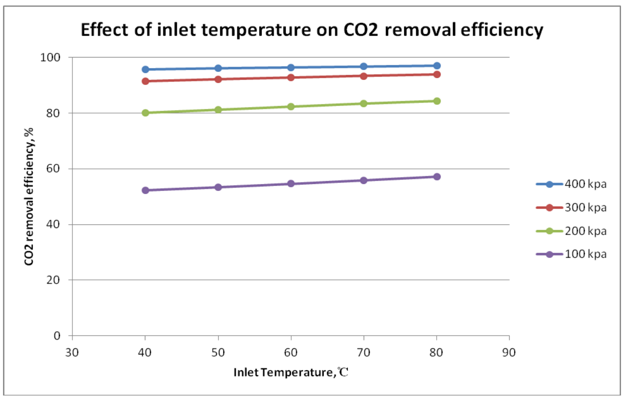

Figure 3: CO_2 removal efficiency for inlet pressure of 400 kpa, 300 kpa, 200 kpa and 100 kpa at different inlet sour gas temperature

C. *Effect of inlet pressure on CO_2 removal efficiency*

Figure 4 shows the effect of inlet pressure line on CO_2 removal efficiency for inlet temperature of 100 °C, 85 °C, 70 °C and 55 °C. Overall result shows that the percentage of CO_2 removal increase as the pressure increase. From the slope of the trend, it can be seen that the CO_2 removal efficiency increase drastically which shows that inlet pressure line gives big impact on the CO_2 removal efficiency. The trend also shows that the CO_2 removal efficiency increase drastically at low inlet pressure line and became more gradually as the inlet pressure line increase. Figure 4.2 above also shows that the value of CO_2 removal efficiency is almost the same at same inlet pressure even though the inlet temperature is different. This proves that the CO_2 removal efficiency is highly dependent on the inlet pressure line of the process. The lowest CO_2 removal efficiency is at inlet pressure of 100 kpa for inlet temperature line of 55 °C which is 54.1% which 30.9% lower than the requirement 85%. The highest percentage of CO_2 removal is at inlet pressure of 450 kpa for inlet temperature line of 85 °C which is 98%. This value is higher 13% than the requirement.

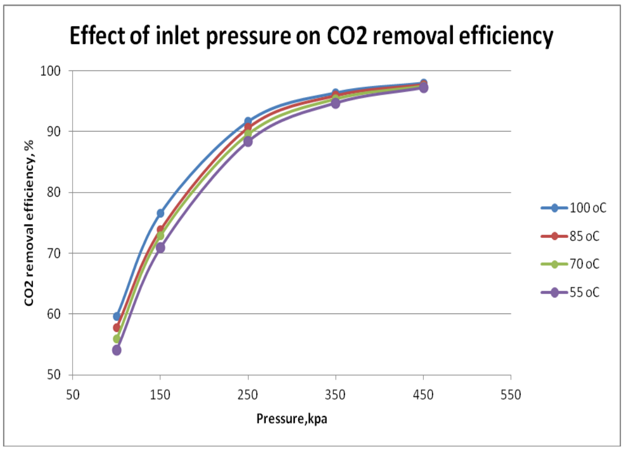

Fig. 4: CO_2 removal efficiency for temperature of 100 °C, 85 °C, 70 °C and 55 °C at various inlet sour gas pressure

D. *Effect of aqueous MEA concentration on CO_2 rmoval efficiency*

Figure 5 shows the effect of aqueous MEA concentration on CO_2 removal efficiency. The result obtained shows that the CO_2 removal efficiency increases as the concentration of MEA increases. The trend also shows that the efficiency increase more gradually at low inlet temperature which is at 200 kpa and 300 kpa. However, the percentage of CO_2 removal efficiency for inlet gas pressure of 200 kpa is below 85% which is the base target that need to be achieved. At 300 kpa, 400 kpa and 500 kpa, all values of CO_2 removal efficiency is above 85% which fulfilled the requirements. The trend of increasing CO_2 removal efficiency for inlet pressure 500 kpa and 400 kpa is almost the same from 0.12 wt% MEA concentration to 0.2 wt%.

Overall result shows that the aqueous MEA concentration have moderate impact on CO_2 removal efficiency compared to inlet temperature of natural gas. The lowest CO_2 removal efficiency is at the inlet pressure line of 200 kpa with the concentration of MEA is 0.12 wt% which is 73.2%. For the best CO_2 removal efficiency is 97.7% which is at the inlet gas pressue line of 500 kpa and concentration of MEA is 0.2 wt%.

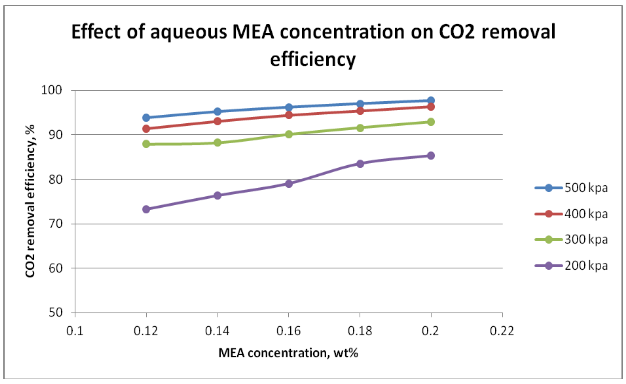

Figure 5: CO_2 removal efficiency for inlet pressure of 500 kpa, 400 kpa, 300 kpa and 200 kpa at different concentration of MEA.

E. The best operating condition obtained from this study

From this study, table 4 shows the best operating condition of the system obtained based on the parameters studied which is for inlet temperature line, inlet pressure line and concentration of MEA.

Table 4: Best operating condition obtained

Parameter	**Value**
Inlet temperature	80 ºC
Inlet pressure	400 kps
Concentration of MEA	0.14 wt%

The selection of the best operating condition is not focusing only on the CO_2 removal efficiency, but also taking economical criteria and applicability in industry as consideration. At 80 ºC and 400 kpa, CO_2 removal efficiency is 97% which can be considered as the best result even though the highest percentage obtained for CO_2 removal is at 100 ºC and 450 kpa. The efficiency of CO_2 removal is higher at high concentration of MEA. However, the effect of the concentration on the percentage of CO_2 removal is small when compared between 0.2 wt% concentration and 0.12 wt%. Therefore, 0.14 wt% is taken as the best concentration for aqueous MEA.

IV. CONCLUSION

From this study, it shows that by varying those three parameters will gives a significant impact on the performance of CO_2 removal efficiency. Throughout this study, it can be observed that, by increasing the inlet temperature at the absorber, it will increase the performance of CO_2 removal efficiency but it only gives a slightly impact on it compared to pressure and concentration as the parameter to be varied. Besides that, by varying the inlet pressure at the absorber as the parameter also gives significant impact to the performance of CO_2 removal efficiency. As the pressure increases, the CO_2 removal efficiency also increases. It can be seen that the CO_2 removal efficiency increase drastically which shows that inlet pressure line gives big impact on the CO_2 removal efficiency. Lastly, the concentration of MEA also gives significant impact to the performance of CO_2 removal efficiency. Increasing the concentration of the monoethanolamine (MEA) will increase the CO_2 removal efficiency. This is due to MEA which has the ability to enhance CO_2 absorption when contacting with CO_2 as the solvent which means that more CO_2 can be absorbed by increasing the concentration of aqueous MEA

Hence, it can be concluded that, among those three parameter that have been varied, inlet pressure at the absorber gives the highest impact on the performance of CO_2 removal efficiency compared to temperature and also concentration of monoethanolamine (MEA).

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