

Evaluation and Comparison of Carbon Dioxide Capture Using MEA and DEA

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Abstract—Global warming, a phenomenon that is indicated by increasing of earth's surface temperature, is being discussed recently. Increasing greenhouse gasses concentration in the atmosphere is suspected as a cause of global warming. Several solutions have been proposed, with post-combustion technology using absorption method becomes the most common and used technology. This research aims to evaluate the effect of changing the number of tray in stripper column in carbon dioxide absorption process using MEA solvent and compared with DEA solvent as an alternative solvent. From the research, it is shown that number of tray in stripper column has an effect to energy requirement for reboiler, recovery of carbon dioxide, and amount of fresh solvent needed. The greater number of tray in stripper column gives a smaller amount of utility required in reboiler and make-up solvent needed, although carbon dioxide recovery is decreasing. Changing solvent from MEA to DEA gives a better result in terms of utility required for reboiler and make-up solvent needed, carbon dioxide recovery for DEA solvent gives a slightly worse result than MEA solvent.

Keywords—absorption, diethanolamine, carbon capture, monoethanolamine

I. INTRODUCTION

Global warming is a phenomenon that is being discussed by international community recently. It is indicated by the increasing of earth's surface temperature by $0.74 \pm 0.18^\circ\text{C}$ over the last hundred years [1]. Global warming mainly caused by high level of greenhouse gases in the atmosphere.

Increasing concentration of greenhouse gases in the atmosphere is caused by increasing requirement of energy. Energy that is supplied using fossil fuel, such as natural gas or coal, will produce gaseous emission and mostly contains of carbon dioxide. This gas, alongside with the other gases, will form greenhouse gases that leads to global warming.

Some solutions have been proposed to reduce the amount of carbon dioxide in the atmosphere. Several solutions focus on substituting fossil fuel with renewable energy, while the others focus on improving the existing technologies. One of the proved solution is carbon dioxide capture technology. This technology consists of three main technologies, which are [2]:

- Pre-combustion carbon capture

- Post-combustion carbon capture
- Oxy-fuel combustion carbon capture

From those three technologies, post-combustion carbon capture using absorption method is the most common and most used technology [3]. Its ability to absorb carbon dioxide is the reason why this technology is widely used. Another reason is its simple application to existing process. This technology only needs a little change to existing process, since it is an end of pipe technology.

This research aims to evaluate the performance of carbon dioxide capture process using MEA solvent by changing the number of tray in stripper column. Performance criteria that will be compared are energy requirement for reboiler, recovery of carbon dioxide and amount of fresh solvent needed. Solvent for absorption process is then changed to DEA as an alternative solvent and compared with MEA.

II. PROCESS DESCRIPTION

Absorption of carbon dioxide mainly consists of two steps, those are absorption and desorption of carbon dioxide. Flue gas from sources, such as stacks of power plant, enters absorber from bottom of the column. Solvent enters absorber from top of the column and contacts with flue gas in the column. Exhaust gas, which is clean from carbon dioxide, will leave absorber from top of the column, while rich solvent, which contains carbon dioxide, exits absorber from bottom of the column for regeneration process. Rich solvent is then pumped to stripper column for regeneration process. Purified carbon dioxide leaves stripper from top of the column, while regenerated solvent leaves from bottom of the column and pumped back to absorption column. Sketch of typical carbon dioxide capture process is shown in Fig. 1. [4]

Monoethanolamine, usually called as MEA, is a primary amine with chemical formula $\text{C}_2\text{H}_7\text{NO}$. MEA has already been proven and well-documented worldwide. It is a common used solvent for capturing carbon dioxide, not only from natural gas, but also from coal fueled power plants. Reaction between MEA and carbon dioxide are according following reactions [5]:

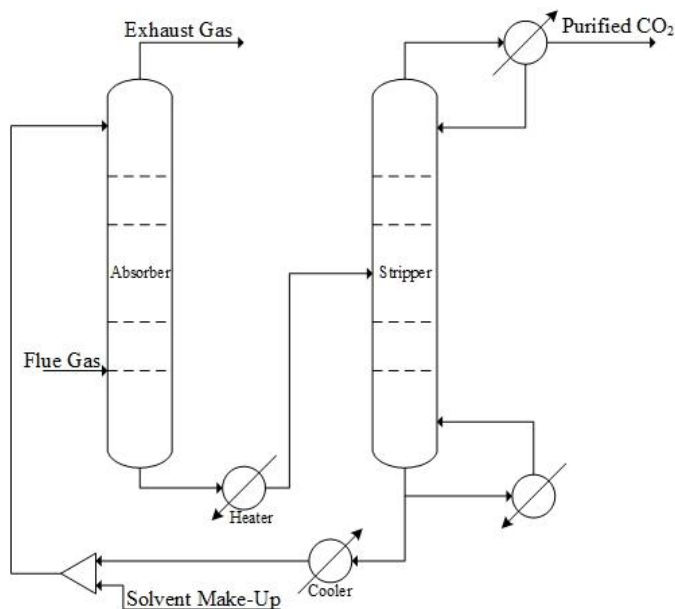
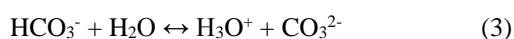
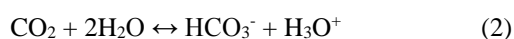
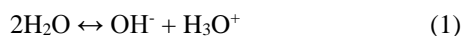


Fig. 1. Sketch of carbon dioxide absorption process



Main problem of MEA usage is its corrosion rate to the equipment used. Therefore, MEA concentration needs to be limited or an inhibitor must be used.

Diethanolamine, usually called as DEA, is a secondary amine with chemical formula $\text{C}_4\text{H}_{11}\text{NO}_2$. Compared with MEA, DEA has an advantage that a higher concentration may be used for the same corrosion potential. Its advantage allows DEA to absorb carbon dioxide at a lower circulating amine rates with less overall energy usage. Typical operating conditions of both MEA and DEA are shown in Table I [6].

III. BASE CASE DEVELOPMENT

Base case of absorption process is developed for capturing carbon dioxide using MEA solvent. Specification of flue gas and solvent are shown in Table II.

As described before, flue gas enters from bottom of absorber while MEA solvent enters from top of absorber. Rich solvent is then heated to 384.15 K before entering stripper column. Regenerated solvent is cooled to 319.15 K and added with fresh solvent to compensate solvent loss in absorber and stripper column. Solvent is then pumped back to absorber column. Specification of absorber and stripper column is shown in Table III [7].

TABLE I. TYPICAL OPERATING CONDITION OF SOLVENTS

Component	Typical Operating Conditions			
	Solution concentration (wt%)	Maximum concentration (wt%)	Temperature (K)	Acid gas loading (mol/mol)
MEA	15-30	30	298.15-403.15	0.3-0.35
DEA	25-35	50	298.15-403.15	0.3-0.35

TABLE II. SPECIFICATION OF FLUE GAS AND SOLVENT

Specification	Flue gas	Solvent
Pressure (kPa)	157	101
Temperature (K)	320.49	319.15
Mass flow (kg/s)	156.04	672.22
Mass fraction		
CO ₂	0.2316	0.0344
N ₂	0.7267	0
H ₂ O	0.0417	0.6755
MEA	0	0.2901

TABLE III. SPECIFICATION OF ABSORBER AND STRIPPER

Specification	Absorber	Stripper
Number of tray	3	12
Tray type	Valve tray	Valve tray
Column top pressure	101 kPa	121 kPa
Column pressure drop	57 kPa	56.8 kPa
Reboiler	No	Kettle reboiler
Condenser	No	Partial condenser
Feed inlet stage	Solvent at 1 st stage Flue gas at 3 rd stage	3 rd stage

IV. RESULT AND DISCUSSION

From base case, results of carbon dioxide absorption process are obtained. Some results that are taken from base case are shown in Table IV, Table V, and Table VI.

TABLE IV. CONDITION OF EXHAUST GAS AND PURIFIED CO₂

Specification	Exhaust gas	Purified CO ₂
Pressure (kPa)	101	121
Temperature (K)	329.91	290.15
Mass flow (kg/s)	127.24	36.1
Mass fraction		
CO ₂	1.9780E-03	0.9928
N ₂	0.8911	5.5801E-04
H ₂ O	0.1066	6.6152E-03
MEA	3.8374E-04	trace

TABLE V. BASE CASE SIMULATION RESULTS

Specification	Result
% recovery of carbon dioxide	85.37%
Amount of fresh solvent make-up	0.05004 kg/s

TABLE VI. UTILITY REQUIRED FOR THE PROCESS

Equipment	Media	Duty (kJ/s)
Heater	LP steam	242453.2
Cooler	Cooling water	168576.16
Reboiler	LP steam	442254.76
Condenser	Cooling water	496017.81

From Table IV, it can be seen that exhaust gas and purified carbon dioxide exit from both absorber and stripper are satisfying. Exhaust gas exits from top of absorber column contains 0.001978 of carbon dioxide with 0.25 kg/s of carbon dioxide mass flow. With that amount, it means that up to 99% of carbon dioxide enters absorber can be absorbed by MEA solvent. Purified carbon dioxide that exits from top of stripper column contains 0.9928 of carbon dioxide with 35.89 kg/s of carbon dioxide mass flow. The stream contains almost pure carbon dioxide, which is suitable for next process, whether carbon dioxide will be stored underground or used as reactant for other chemical products.

Table V shows amount of recovered carbon dioxide from the process and amount of make-up solvent needed. 85.37% of carbon dioxide is recovered from the process. Recovery of carbon dioxide is the amount of purified carbon dioxide produced from overall carbon dioxide that enters to the process. The process needs 0.05004 kg/s of fresh MEA solvent make-up. Solvent loss occurs in both absorption and regeneration process, where some amount of solvent is entrained in exhaust gas and purified carbon dioxide stream.

Amount of utility required for each heat exchanger is shown in Table VI. From the table, it is shown that reboiler of stripper column needs a big amount of utility. It needs 442254.76 kJ/s of low pressure steam. From the amount of utility required, condenser of stripper column actually needs bigger utility than stripper's reboiler with 496017.81 kJ/s of cooling water, but since price of low pressure steam is much more expensive than cooling water, utility required for stripper's reboiler is the most expensive one, and therefore the biggest one.

Number of tray in stripper column is then changed. Number of tray is varied from 6-16 trays. Changing the number of tray aims to evaluate the effect of tray number in the regeneration process. Regeneration process is the most important step in carbon dioxide capture process. Regeneration process is responsible for separating carbon dioxide from solvent. Performance of regeneration process will affect flow and purity of carbon dioxide in the top stream. Amount of carbon dioxide flow in the top stream of stripper is presented by percent recovery of carbon dioxide.

Regeneration process is also responsible for the biggest utility requirement of the whole process. By finding the effect of number of tray in stripper to reboiler duty, an optimization can be made to make a whole process more sustainable and energy efficient. Solvent loss also occurs in regeneration process, although the amount of solvent entrained in purified carbon dioxide stream is small. Effect of number of tray in stripper is shown in Fig. 2, Fig. 3, and Fig. 4.

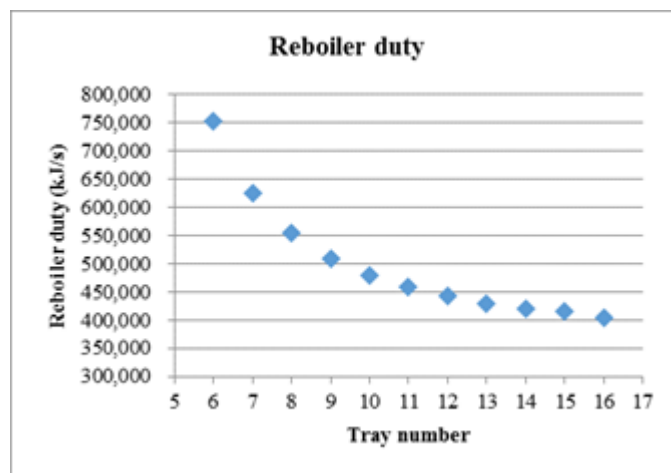


Fig. 2. Effect of tray number in reboiler duty

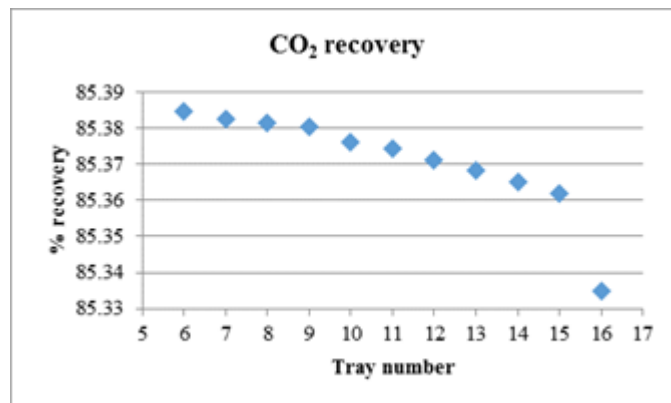


Fig. 3. Effect of tray number in carbon dioxide recovery

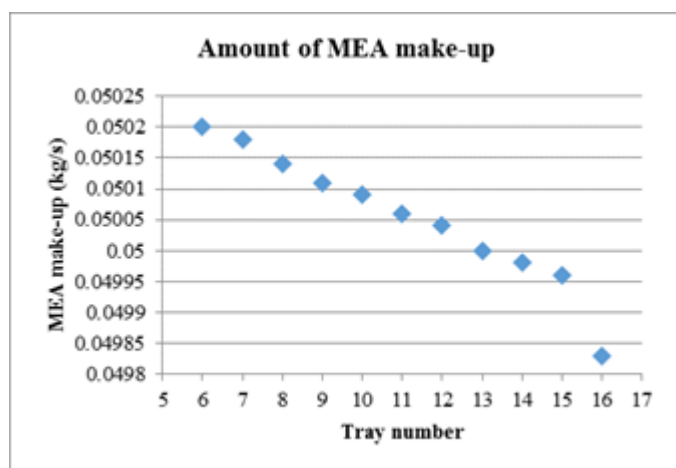


Fig. 4. Effect of tray number in amount of MEA make-up

From Fig. 2 above, it is shown the effect of tray number in stripper column in reboiler duty. Greater number of tray in stripper column gives smaller amount of utility required in reboiler. Changing tray number from 6 trays to 7 trays gives the biggest difference in required utility, which is 127824.17 kJ/s. Required utility difference from 15 trays to 16 trays only gives 10191.53 kJ/s difference. It means that greater number of tray in stripper column decreases required utility difference. Although required utility decreases by increasing number of tray, capital cost needed for purchasing stripper column increases as tray number increase. Therefore, it needs to be found the optimal number of tray in stripper column, which gives a minimal total annual cost.

From Fig. 3, the effect of tray number in stripper column in carbon dioxide recovery is shown. Contrary to required reboiler utility, carbon dioxide recovery gives a worse result with increasing of tray number in stripper column. Carbon dioxide flow produced from the process decreases as tray number in stripper column increases. Although carbon dioxide flow decreases, the purity of carbon dioxide is kept as base case, thus the quality of carbon dioxide produces is not reduced. Purity of carbon dioxide is an important parameter if carbon dioxide is converted into the other chemical products.

Fig. 4 shows the effect of tray number in stripper column in amount of MEA solvent make-up needed. Increasing number of tray in stripper column gives smaller amount of MEA solvent make-up needed. The difference between solvent make-up needed for each tray number might be just a little, except from 15 to 16 trays. Amount of solvent entrained in purified carbon dioxide stream is small, and therefore the effect of tray number in solvent make-up needed is not too much. However, solvent loss from the process needs to be concerned. Losses of the solvent means that the process will become more expensive, since price of the solvent is quite high.

MEA solvent is then changed to DEA solvent. Changing of the solvent aims to compare the performance of regeneration process, and evaluate whether solvent changing to DEA is feasible or not for the process overall. DEA solvent

is chosen because it has similar typical operating condition with MEA. With those similar operating condition, the process does not need any modification. Results of changing solvent to the process are shown in Table VII, Table VIII, and Table IX.

TABLE VII. CONDITION OF EXHAUST GAS AND PURIFIED CO₂

Specification	Exhaust gas	Purified CO ₂
Pressure (kPa)	101	121
Temperature (K)	318.77	293.93
Mass flow (kg/s)	120.02	33.96
Mass fraction		
CO ₂	4.9380E-04	0.9890
N ₂	0.9438	2.6390E-03
H ₂ O	0.0557	8.4088E-03
DEA	trace	trace

TABLE VIII. SIMULATION RESULTS

Specification	Result
% recovery of carbon dioxide	79.99%
Amount of fresh solvent make-up	0.0006131 kg/s

TABLE IX. UTILITY REQUIRED FOR THE PROCESS

Equipment	Media	Duty (kJ/s)
Heater	LP steam	214374.45
Cooler	Cooling water	125736.15
Reboiler	LP steam	431590.84
Condenser	Cooling water	346453.16

Table VII shows the condition of exhaust gas stream exits from top of absorber and purified carbon dioxide stream exits from top of stripper column. Compared with the same streams that use MEA as a solvent before, exhaust gas stream gives a better result. Exhaust gas stream contains more nitrogen, and less impurities, which is better than MEA solvent used before. For purified carbon dioxide stream, the result is slightly worse than MEA solvent. Flow of purified carbon dioxide stream, which is 33.96 kg/s, is smaller than MEA solvent. Purity of carbon dioxide produced also decreases. By using DEA solvent, purity of carbon dioxide is obtained at 0.989, compared to 0.9928 while using MEA solvent. Decreasing of carbon dioxide purity might not be a problem if carbon dioxide is addressed to be stored underground, but it could be a problem if carbon dioxide is used as a reactant for the other chemical products, since most of reactant needs pure carbon dioxide.

Table VIII shows results for recovered carbon dioxide and amount of DEA solvent make-up needed. Recovered carbon dioxide drops from 85.37% using MEA solvent to 79.99% using DEA solvent. Solvent make-up needed for the process gives a better result. Using MEA as a solvent, it needs 0.05004

kg/s of solvent for make-up, while using DEA as a solvent, it only needs 0.0006131 kg/s of solvent for make-up. Its small amount of make-up is due to there is almost no solvent loss in the process. With small amount of make-up, cost needed to buy fresh solvent can be minimized or even eliminated, which can lead to more economic process.

Table IX shows amount of utility required for the process. Utility required for each heat exchanger gives a better result than before. Utility required differences for each heat exchanger varies from 10000 kJ/s to 40000 kJ/s. Biggest differences is utility required for condenser reboiler, which is 496017.81 kJ/s of cooling water decreases to 346453.16 kJ/s of cooling water using DEA solvent. Reboiler condenser, which is responsible for the biggest utility required, also decreases by using DEA solvent. Utility required for reboiler stripper drops from 442254.76 kJ/s of low pressure steam using MEA solvent to 431590.84 kJ/s of low pressure steam using DEA solvent. Its decreasing of required utility can lead to more sustainable and optimized process.

V. CONCLUSION

From the research that has been done before, some conclusions can be taken. Greater tray number in stripper column gives a better result for required utility in reboiler stripper and amount of MEA solvent make-up needed. In contrary of that, carbon dioxide recovery decreases as tray number increases. Changing solvent from MEA to DEA gives an overall better result, except for carbon dioxide recovery, as the amount of carbon dioxide produced decreases with the

changing of solvent. Therefore, DEA can be considered as a solvent replacement for MEA.

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