Effect of Promoter Concentration on CO₂ Separation Using K₂CO₃ With Reactive Absorption Method in Reactor Packed Column

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Abstract. The presence of carbon dioxide (CO₂) in the gas is not expected because CO₂ can reduce heating value and CO₂ is the major emission contributor into the atmosphere. Various separation technologies can be used to reduce CO₂ content and improve quality of gas. Chemical or reactive absorption is most widely used because it provides higher removal rate. This paper will study the effect of the addition di ethanolamine (DEA) concentration into aqueous 30wt.% potassium carbonate(K₂CO₃) with reactive absorption method in a reactor packed column at temperature from 40°C to 80°C, DEA concentration range of (1% - 3%) and absorbent flow rate (0.5, 0.75 and 1) L. min⁻¹. Contacting the gas and absorbent are countercurrent flow in packed column with 1.5 m high and 50 mm in diameter. The absorption column was randomly packed with a packing material raschig rings 5 mm in diameter. The CO₂ loading in the liquid samples was determined by titration. It is found that the best result of CO₂ loading is 0.065594 mole/mole K₂CO₃ and CO₂ removal 28%. The result show that the loading capacity (mole CO₂/mole K₂CO₃) and CO₂ removal increased with the increase of DEA concentration. **Keyword:** potassium carbonate, promoted and packed column and reactive absorption

1. Introduction

Energy is an important part of human life, because most of human activity need energy. Indonesia is one of the countries that include in category of countries with the largest natural gas reserves in the world. Indonesia also known as a country that produce large natural resource that can be used as raw material to produce biogas. It means that gas is potential to be developed for use as an energy alternative in Indonesia. As an alternative energy, gas quality needs to be improved by reducing the CO₂ component so that methane content increases and the economic value of the gas can increase as well.

The presence of CO₂ in the gas is not expected because CO₂ can reduce heating value and CO₂ is the major contributor emission to the atmosphere. Various separation technologies can be used to reduce CO₂ content and improve quality of gas. Five methods that can be used are adsorption, cryogenic distillation, membrane separation, absorption both physically, and chemically. Since the chemical reaction in the solution affects the liquid phase absorption coefficient as compared with the physical absorption. Potassium carbonate is a solvent commonly used in chemical

absorption. The main advantage of potassium carbonate is high solubility of CO₂ in the carbonate or bicarbonate system, ease of regeneration, low solvent cost, low toxicity, and low degradation [1], but potassium carbonate has disadvantages that is low absorption rate. Various technologies can be used to improve the absorption rate of potassium carbonate by adding a number of promoters (activators) or by increasing mass transfer efficiency with equipment such as packing [2]. This study will be focused on adding promoter to potassium carbonate. The reaction of potassium carbonate with CO₂ in general can be written:

Amines have been widely used as promoters in CO₂ absorption. Every alkali amine has at least one hydroxyl group and one amine group. The group of hydroxyl used to reduce the vapor pressure and increase the solubility in water while the group of amine supply the necessary alkalinity in the solution to react with the acid gas [3]. One of the amine compound which can be used as a promoter in CO₂ uptake is a secondary amine DEA (di-ethanolamine) with acid gas loading rate of about 0.30-0.35 mole acid gas / mole acid amine [3] and has a

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corrosion-resistant advantage over MEA, high reactivity and fast absorption rate.

In the mechanism, the promoter is called homogeneous catalysis that is the promoter first forms intermediates with CO_2 and intermediates then hydrolyzed to produce the final product, bicarbonate.

In another mechanism, the so-called shuttle mechanism proposed by Danckwerts [4] states that the promoter acts as a carrier to provide additional lines for transporting CO_2 from the liquid gas to the bulk liquid, the carbonate ions then diffuse into the liquid and will react with the OH ion to produce Amine free of CO_2 so that amines can again diffuse into the interface to react with CO_2 . DEA reaction with carbon dioxide in general can be written:

Both these mechanisms can be summarized that the shuttle mechanism can describe the behavior of promoter at ambient temperature and at higher temperature the system is better represented by homogeneous catalysis mechanism [5].

This paper will study the effect of the addition diethanolamine concentration into aqueous 30wt.% potassium carbonate using chemical absorption method. The gas and absorbent were contacted with countercurrent flow in column with packing that serves to provide for long time contacted so that enhance CO_2 absorption. The absorption capacity performance of CO_2 into aqueous 30wt.% potassium carbonate solute is expressed as CO_2 loading and CO_2 removal.

2. Material and Methods

9. Absorbent Tank	1. Gas flowmeter
10. Valve on absorbent inlet to column	2. Absorbent tank outlet column
11. Absorbent flowmeter	3. Overflow tank
12. Valve on gas outlet column	4. Absorbent pump
13. Valve on discharge of absorbent pump	5. Valve on gas inlet to column
14. Valve on discharge by-pass of absorbent pump	6. Manometer on gas inlet to column
	7. Gas tank

Fig.1. The experimental apparatus

The experimental apparatus is shown in Fig. 1, the process is simple, the feed gas with the composition of 40% CO_2 and 60% N_2 is flowed with a fixed flow rate at 40 L.min^{-1} from the bottom of the column and absorbent with the DEA composition, aqueous solution of K_2CO_3 and water are flowed from the top of the column with a flow rate of variables of 0.5; 0.75; 1 L.min^{-1} flows through which contains packing that serves to provide for long time contacted so that enhance CO_2 absorption. The principle of absorption is the different solubility of the gas so that only CO_2 gas will be absorbed. The CO_2 content in the liquid samples was determined by acid-base titration using phenolphthalein. The apparatus with column of pyrex glass cylinder of 1.5 m high and 50 mm in diameter. The absorption column was randomly packed with a packing material of raschig rings 5 mm in diameter. The material used is potassium carbonate with purity > 99%, synthetic gas with CO_2 : 40% and N_2 : 60% composition, in ethanolamine with purity 98% and water. This research will use aqueous 30wt.% Potassium carbonate (K_2CO_3) and DEA Concentration range of (1% - 3%) with operating conditions temperature from 40°C to 80°C , absorbent flow rate (0.5, 0.75 and 1) L.min^{-1} , gas flow rate 40 L.min^{-1} and pressure 1 atm.

3. Results and discussion

The amount of absorbed CO_2 can be expressed in % CO_2 removal and CO_2 loading. Some factors that affect the % CO_2 removal and CO_2 loading are temperature, promoter concentration, absorbent flow rate

Fig.2. Effect of DEA concentration and Temperature on CO_2 Loading at Flow Rate 0.5 LPM

Fig.3. Effect of DEA concentration and Temperature on % Removal CO₂ at Flow Rate 0.5 LPM

Fig.4. Effect of DEA concentration and Temperature on CO₂ Loading at Flow Rate 0.75 LPM

Fig.5. Effect of DEA concentration and Temperature on % Removal CO₂ at Flow Rate 0.75 LPM.

Fig.6. Effect of DEA concentration and Temperature on CO₂ Loading at Flow Rate 1 LPM.

Fig.7. Effect of DEA concentration and Temperature on % Removal CO₂ at Flow Rate 1 LPM.

Table.1. Effect of Concentration, Flow Rate and Temperature on % CO₂ Removal.

T (C)	DEA (WT%)	CO ₂ REMOVAL (%)		
		0.5 LPM	0.75 LPM	1 LPM
40	1	6.218	6.991	9.322
50		7.773	11.652	12.429
60		6.995	13.983	13.983
70		6.218	9.322	9.322
80		6.218	8.156	9.322
40	2	7.768	9.321	9.322
50		9.322	11.652	12.429
60		11.652	13.983	15.536
70		12.429	18.644	21.751
80		9.322	13.983	15.536
40	3	7.768	9.322	13.983
50		9.322	13.983	17.09
60		13.983	23.304	27.965
70		15.536	23.304	27.965
80		13.983	17.478	18.644

Table.2. Effect of Concentration, Flow Rate and Temperature on % CO₂ Loading

T (C)	DEA (WT%)	CO ₂ LOADING (L.min ⁻¹)		
		0.5 LPM	0.75 LPM	1 LPM
40	1	0.026236	0.019703	0.019678
50		0.032795	0.032839	0.026237
60		0.039406	0.039406	0.029517
70		0.026236	0.026271	0.019678
80		0.026236	0.026271	0.019678
40	2	0.032817	0.026254	0.01969
50		0.03938	0.032817	0.026254
60		0.049226	0.03938	0.032817
70		0.052507	0.052507	0.045944
80		0.03938	0.03938	0.032817
40	3	0.032798	0.026238	0.029517
50		0.039357	0.039356	0.036076
60		0.065595	0.0590357	0.059034
70		0.065595	0.065594	0.059034
80		0.059036	0.049195	0.039356

3.1 Effect of Promoter Concentration

The concentration of DEA in K₂CO₃ gives a very important influence in the absorption of CO₂. In Fig.7 to Fig.4, Table.1 and Table 2 it can be seen that when the DEA concentration increases in potassium carbonate, CO₂ Loading and % CO₂ Removal will increase to 0.065594 mole/mole K₂CO₃ and 28% this is because DEA concentration contributes to increased diffusivity and higher mass transfer because the number of DEA molecules is greater in potassium carbonate, this results in more CO₂ absorption and increases CO₂ for contact and reacts with absorbent. The concentration of DEA in a solution of Potassium carbonate (K₂CO₃) causes the larger CO₂ absorbed.

3.2 Effect of Absorbent Temperature

Temperature has a big role in increasing the diffusion and mass transfer so that with increasing temperature will increase CO₂ Loading and % CO₂ Removal as shown in Fig.2 to Fig.7, Table.1 and Table 2. first at temperature 40; 50; 60; 70°C CO₂ loading and % Removal CO₂ up increases to 0.065594 mole/mole K₂CO₃ and 28% at 1 L.min⁻¹ and CO₂ Loading moles of CO₂/mole absorbent. In a previous study stated that higher temperatures contribute to higher mass transfer efficiency which can lead to increased CO₂ uptake [6]. In addition to increasing the diffusion and mass transfer of temperature can negatively affect the high temperature of CO₂ solubility will decrease as at temperature of 80°C CO₂ Loading and % CO₂ Removal value decreases to 0.039356 moles of CO₂/mole K₂CO₃ and 15.53% in 1 L.min⁻¹. According to previous study by Aroonwilas et al

[7] when the temperature is too high can cause a decrease in the efficiency of mass transfer this is caused by the exothermic thermodynamic properties of the process.

3.3 Effect of Absorbent Flow Rate

The absorbent flow rate significantly affects CO₂ reduction in the gas. The relationship between the absorbent flow rate on % CO₂ Removal is shown in fig.9,11,13 and Table.1 when the absorbent flow rate increases % CO₂ Removal will increase to 28% at the flow rate of 1 L.min⁻¹. The absorbent flow rate influences the degree of alkalinity of the packing area so that the contact between the gas and the absorbent becomes large and increases the performance of CO₂ absorption. An increase in the flow rate of the solution allows potassium carbonate to absorb more absorbed moles of CO₂. According to Aroonwilas et al [8], increasing flow rate will increase mass transfer in the liquid-side and more absorbent molecules react with CO₂ per unit time. The relationship between the absorbent flow rate on CO₂ loading is shown in fig.8,10,12 and table 2. at flow rate 0.5 to 0.75 L.min⁻¹ causing absorption of CO₂ increase so that the CO₂ loading also increase. Increasing of flow rate from 0.75 to 1 L.min⁻¹ CO₂ absorbed is not increase significantly so the loading also decreases. The decreased of CO₂ loading indicates that there are free K₂CO₃ or excess K₂CO₃.

Fig.8. Effect of Flow Rate on CO₂ Loading at concentration 1 Wt% DEA.

Fig.9. Effect of Flow Rate on % Removal CO₂ at concentration 1 Wt% DEA.

Fig.10. Effect of Flow Rate and Temperature on CO₂ Loading at concentration 2 Wt% DEA

Fig.11. Effect of Flow Rate on % Removal CO₂ at concentration 2 Wt% DEA

Fig.12. Effect of flow Rate on CO₂ Loading at concentration 3 Wt% DEA.

Fig.13. Effect of flow Rate on % Removal CO₂ at concentration 3 Wt% DEA.

4. Conclusions

The absorption of CO₂ by using potassium carbonate with promoter DEA get best result at temperature 70°C with value of CO₂ Removal and CO₂ loading equal 0.065594 mole/mole K₂CO₃ and 28% at absorbent flow rate 1 L.min⁻¹, concentration of promoter 3%, pressure 1 atm, packed column with 1.5 m high and 50 mm in diameter.

5. References

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