Investigation on Solubility of Carbon Dioxide in the Mixed Aqueous Solution of MEA and 2-MAE

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Investigation on Solubility of Carbon Dioxide in the Mixed Aqueous Solution of MEA and 2-MAE

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Abstract. Absorption with amine solution is a method to reduce CO_2 causing climate change. The commercial amine solution is MEA. The disadvantage of MEA is low CO_2-loading capacity. Also, 2-(methylamino)-ethanol or 2-MAE is a new solvent developed to improve absorption performance. The aim of this work is to measure the CO_2 solubility in the mixture of MEA and 2-MAE at 15:15 %wt, from 30 °C to 80 °C and CO_2 partial pressures ranging from 5 to 100 kPa. From the results, at the same conditions, 30 %wt of MEA has higher absorption capacity than that of 15:15 %wt of MEA:2-MAE and 30 %wt of 2-MAE for 4.51 % and 7.04 %, respectively. For cyclic capacity, 15:15 %wt of MEA:2-MAE has capacity greater than 30 %wt of MEA for 34.10 % but lower than 30 %wt of 2-MAE for 22.78 %. A mixed-amine solution can be applied to reduce the disadvantage of MEA solution.

1. Introduction

CO_2 is one of the greenhouse gases (GHGs) that cause an increase in global warming [1]. CO_2 is one of the by-products of all combustion processes due to the consumption of fossil fuel energy and especially from the power plants [2]. There are many ways to capture the huge amount of CO_2 before releasing to the atmosphere such as chemical and physical adsorption, absorption, cryogenics separation and membrane separation [3]. Chemical absorption by using amine solution is an alternative method to reduce CO_2 for post-combustion process from power plants [4]. The most widely used amine solution is MEA because of the high efficiency of CO_2 absorption performance and fast absorption rate. However, the disadvantages of MEA are low CO_2 loading capacity, corrosion and high energy consumption for solvent regeneration [5]. Also, 2-MAE is a new solvent that has been developed and applied to improve CO_2 absorption performance. However, the disadvantage of 2-MAE is high cost and higher heat of regeneration than MEA [6]. Thus, these solvents are mixed together to achieve higher efficiency. Therefore, the aim of this work is to measure the solubility and investigate the effect of parameters on the solubility of CO_2 in the mixture of MEA and 2-MAE at concentration of formulated solution, the partial pressures of CO_2 in a range of 5 to 100 kPa and temperature in a range of 30 ° C to 80 ° C. The results are compared with these of MEA and 2-MAE solutions at the same conditions. The rate of CO_2 loading change with time of MEA, 2-MAE and mixed amine solution are also compared.

2. Materials and methods

2.1. Materials

An industrial-grade cylinder of CO_2 and Nitrogen (N_2) are supplied by Linde, Thailand Public Company Limited with the purities of 99.5 % and 99.5 %, respectively. MEA with a purity of > 99.0 % is purchased from Sadara Chemical Company. 2-MAE with a purity of ≥ 98.0 % is purchased from Merck. Hydrochloric acid (HCl) at 1.0 N is purchased from RCI Labscan Limited. All amine solutions are prepared to concentration with de-ionized water from PURELAB Classic DI.

2.2. Experimental procedures

In this study, MEA and 2-MAE are mixed at concentration 15:15 %wt with de-ionized water to prepare an amine solution and fed into a reactor which is placed into the temperature-controlled water bath to maintain condition in a range of 30 ° C to 80 ° C. CO_2 and N_2 are mixed together and controlled by mass flow meters until it reaches the desired partial pressure of CO_2 and N_2 in a range of 5 to 100 kPa. In the reactor, CO_2 is absorbed in the solution and sent to the condenser to recover the moisture in the gas stream. The operation is continued to the equilibrium condition taking approximately 12-20 hours. The samples are taken for 3 times to get the average CO_2 loading at equilibrium. The solubility of CO_2 data is obtained by titration using 1.0 N HCl with methyl orange as the indicator.

3. Results and discussion

3.1. Verification

To ensure the experimental results, the procedure and equipment have been verified by comparing with the results of Shen and Li [7], Jou et al. [5], Aronu et al. [8], Yamada et al. [9] and Luemunkong [10] before running the experiment of the solubility of CO_2. Testing conditions are at 5.0 M of MEA solution, the temperature of 40 ° C and pressures used in the verification are 5 to 100 kPa and it can be seen that the results get along well with the ones from the previous works. The results of the equipment verification are shown in Figure 1. The average absolute deviation (%AAD) [11] compared with literatures [10] and [7] are 1.05 % and 1.06 %, respectively. Consequently, it can be concluded that the procedure and equipment are valid in order to perform a further study of this work.

3.2. Effect of type of solvents

Figure 2 shows the solubility of CO_2 in 30 %wt of 2-MAE, 15:15 %wt of MEA:2-MAE and 30 %wt of MEA at the temperature of 40 ° C and 80 ° C and partial pressure of CO_2 at 15 kPa. The results of CO_2 loading at 40 ° C shows that 30 %wt of MEA provides higher absorption capacity than that of 15:15 %wt of MEA:2-MAE and 30 %wt of 2-MAE for 4.51 % and 7.04 %, respectively. At 80 ° C, it shows that 30 %wt of MEA provides much higher absorption capacity than that of 15:15 %wt of MEA:2-MAE and 30 %wt of 2-MAE for 11.15 % and 19.38 %, respectively. This means that 30 %wt of 2-MAE can absorb less at regeneration condition. At partial pressure lower than 15 kPa, 30 %wt of 2-MAE provides less absorption capacity than the mixed amine solution and 30 %wt of MEA especially at the higher temperatures.

3.3. Effect of temperature and partial pressure

Figure 3 represents the solubility of CO_2 in each amine solution at the partial pressure of CO_2 from 5 to 100 kPa and temperature from 30 ° C to 80 ° C. The results can be observed that the solubility of CO_2 at higher temperatures have less capacity when compared with the solubility of CO_2 at lower temperatures. The absorption process is considered as absorption of CO_2 at low temperature when the temperature increases, it results in the lower CO_2 loading capacity. At high temperature, it is considered as a regeneration condition since the gas is removed from the solvent. In this study, the temperature at 40 ° C and 80 ° C are considered as the absorption and regeneration conditions,

respectively. Thus, it leads to an explanation of the cyclic capacity. In addition, the partial pressure of CO_2 increases from 5 to 100 kPa will become the mass driving force of CO_2 in the gas phase transfer to the liquid phase. Therefore, the higher of partial pressure of CO_2 can capture the higher amount of CO_2.

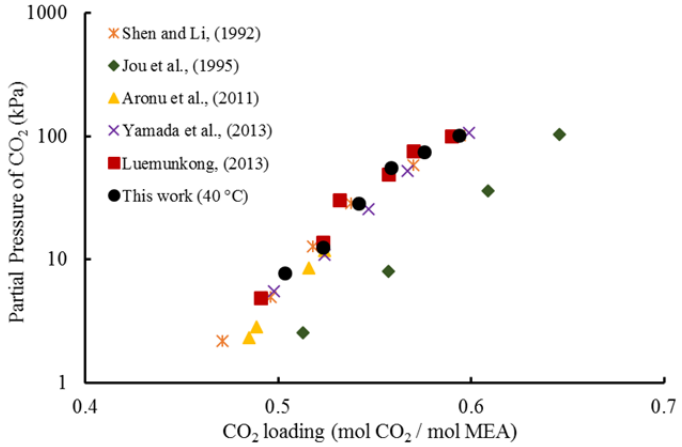

Figure 1. Comparison of the solubility of CO_2 in 5.0 M MEA solution at 40 ° C.

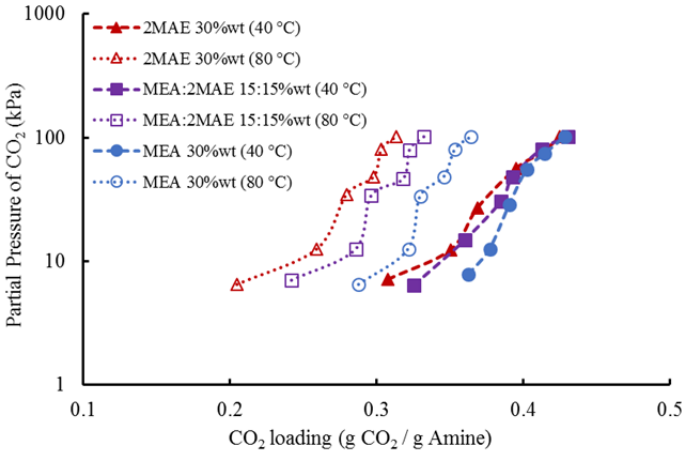

Figure 2. Comparison the solubility of CO_2 in three amine solutions at 40 ° C and 80 ° C.

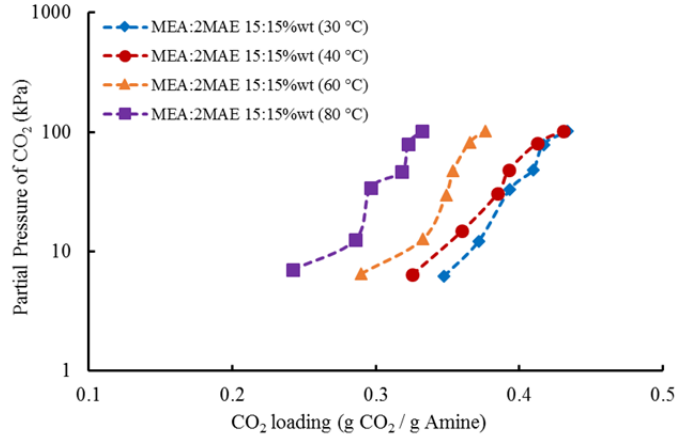

Figure 3. The solubility of CO_2, 15:15 %wt of MEA:2-MAE, from 30 ° C to 80 ° C and 5 to 100 kPa

3.4. Cyclic capacity of the solution

The cyclic capacity is clarified as the difference in CO_2 solubility at the absorption and regeneration conditions [9]. The CO_2 loading is derived from the mole and/or mass of absorbed CO_2 per mole and/or mass of amine. In this study, the temperature 40 ° C of absorption condition and 80 ° C of regeneration condition. Thus, the temperature is important that affects the CO_2 capture capacity of the solvent and the increasing cyclic capacity will reduce the operating cost and CO_2 capture cost [12]. Figure 4 shows the cyclic capacity of 30 %wt of 2-MAE, 15:15 %wt of MEA:2-MAE and 30 %wt of MEA at 15 kPa. The results show that 15:15 %wt of MEA:2-MAE has greater cyclic capacity than that of 30 %wt of MEA for 34.10 % but lower than that of 30 %wt of 2-MAE for 22.78 % at the same condition.

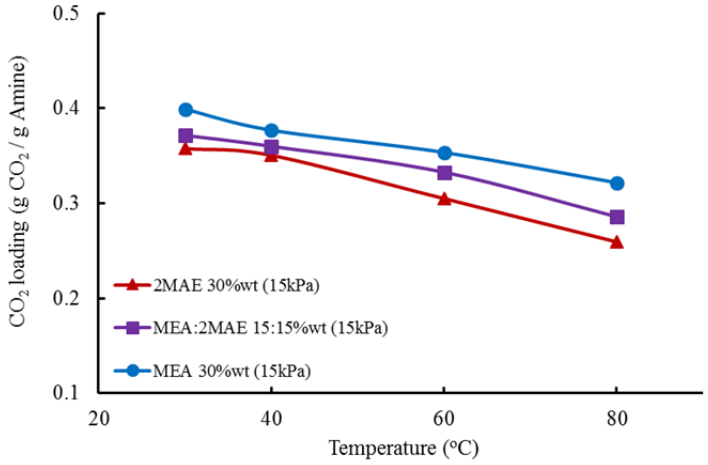

Figure 4. Cyclic capacity of three amine solutions at 15 kPa.

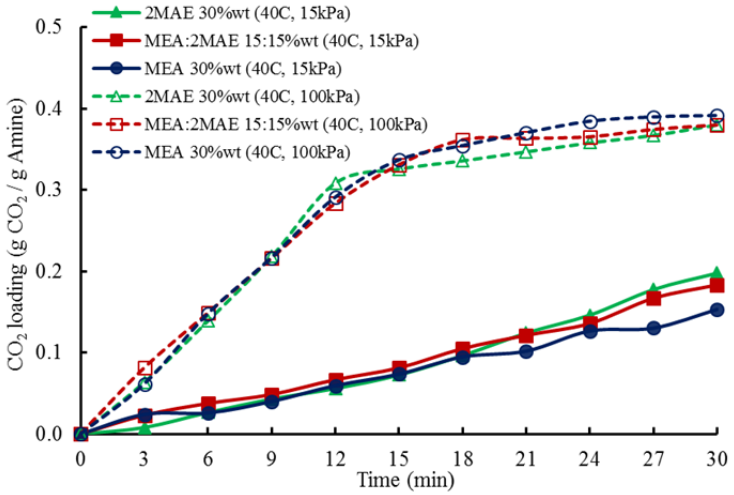

Figure 5. Rate of CO_2 loading change in three amine solutions at 40 °C

3.5. Rates of CO_2 loading change

Figure 5 represents the rate of CO_2 loading change in 30 %wt of 2-MAE, 15:15 %wt of MEA:2-MAE and 30 %wt of MEA at 40 ° C has been studied. In the first 30 minutes at 15 kPa, it can be seen that the rate of CO_2 loading of 30 %wt of 2-MAE can be reacted and higher absorption capacity than that 15:15 %wt of MEA:2-MAE and 30 %wt of MEA because 30 %wt of 2-MAE is required to form unstable carbamate when hydrolysis with water, it becomes the presence of more bicarbonate and less

carbamate because one free amine of 2-MAE solution. Therefore, more bicarbonate leads to higher CO_2 absorption capacity. And the rate of CO_2 loading change at 100 kPa, it presents slightly change absorption capacity of three amine solutions because of the partial pressure of CO_2 increases as the solubility of CO_2 increases due to the higher diving force leading to the rate of reaction.

4. Conclusions

The solubility of CO_2 is investigated in mixed amine solution at 15:15 %wt of MEA:2-MAE compared with 30 %wt of MAE and 30 %wt of 2-MAE in the same conditions at the partial pressure of CO_2 from 5 to 100 kPa and temperature ranging from 30 ° C to 80 ° C. The results represent that the solubility of CO_2 increases as the partial pressure of CO_2 increases whereas the CO_2 loading decreases as the temperature increases. The condition at 30 %wt of MEA is the highest CO_2 loading whereas at 30 %wt of 2-MAE is the lowest CO_2 loading on the mass bases. In the effect of temperature, it can be concluded that at 40 ° C is the optimum condition to absorb the CO_2 over a range of 0.360 grams of CO_2 per gram of amine. In term of cyclic capacity, 15:15 %wt of MEA:2-MAE has more cyclic capacity than 30 %wt of MEA for 34.10 % whereas lower than 30 %wt of 2-MAE for 22.78 %. Meanwhile, the rate of CO_2 loading change is becoming higher as the CO_2 partial pressure increases due to an increase in driving force in the liquid phase. Therefore, the CO_2 loading at 100 kPa is higher than CO_2 loading at 15 kPa.

Acknowledgments

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