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 CO₂ causing climate change. The commercial amine solution is MEA. The disadvantage of MEA is low CO₂-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 CO₂ solubility in the mixture of MEA and 2-MAE at 15:15 %wt, from 30 °C to 80 °C and CO₂ 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

CO₂ is one of the greenhouse gases (GHGs) that cause an increase in global warming [1]. CO₂ 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 CO₂ 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 CO₂ for post-combustion process from power plants [4]. The most widely used amine solution is MEA because of the high efficiency of CO₂ absorption performance and fast absorption rate. However, the disadvantages of MEA are low CO₂ 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 CO₂ 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 CO₂ in the mixture of MEA and 2-MAE at concentration of formulated solution, the partial pressures of CO₂ 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 CO₂ 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 CO₂ and Nitrogen (N₂) 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. CO₂ and N₂ are mixed together and controlled by mass flow meters until it reaches the desired partial pressure of CO₂ and N₂ in a range of 5 to 100 kPa. In the reactor, CO₂ 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 CO₂ loading at equilibrium. The solubility of CO₂ 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 CO₂. 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 CO₂ 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 CO₂ at 15 kPa. The results of CO₂ 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 CO₂ in each amine solution at the partial pressure of CO₂ from 5 to 100 kPa and temperature from 30 °C to 80 °C. The results can be observed that the solubility of CO₂ at higher temperatures have less capacity when compared with the solubility of CO₂ at lower temperatures. The absorption process is considered as absorption of CO₂ at low temperature when the temperature increases, it results in the lower CO₂ 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 CO₂ increases from 5 to 100 kPa will become the mass driving force of CO₂ in the gas phase transfer to the liquid phase. Therefore, the higher of partial pressure of CO₂ can capture the higher amount of CO₂.

**Figure 1.** Comparison of the solubility of CO₂ in 5.0 M MEA solution at 40 °C.

**Figure 2.** Comparison the solubility of CO₂ in three amine solutions at 40 °C and 80 °C.

**Figure 3.** The solubility of CO₂, 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 CO₂ solubility at the absorption and regeneration conditions [9]. The CO₂ loading is derived from the mole and/or mass of absorbed CO₂ 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 CO₂ capture capacity of the solvent and the increasing cyclic capacity will reduce the operating cost and CO₂ 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.](image)

Figure 5 represents the rate of CO₂ 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 CO₂ 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

![Figure 5. Rate of CO₂ loading change in three amine solutions at 40 °C](image)
carbamate because one free amine of 2-MAE solution. Therefore, more bicarbonate leads to higher CO₂ absorption capacity. And the rate of CO₂ loading change at 100 kPa, it presents slightly change absorption capacity of three amine solutions because of the partial pressure of CO₂ increases as the solubility of CO₂ increases due to the higher diving force leading to the rate of reaction.

4. Conclusions
The solubility of CO₂ 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 CO₂ from 5 to 100 kPa and temperature ranging from 30 °C to 80 °C. The results represent that the solubility of CO₂ increases as the partial pressure of CO₂ increases whereas the CO₂ loading decreases as the temperature increases. The condition at 30 %wt of MEA is the highest CO₂ loading whereas at 30 %wt of 2-MAE is the lowest CO₂ 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 CO₂ over a range of 0.360 grams of CO₂ 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 CO₂ loading change is becoming higher as the CO₂ partial pressure increases due to an increase in driving force in the liquid phase. Therefore, the CO₂ loading at 100 kPa is higher than CO₂ loading at 15 kPa.

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