Absorption process with aqueous solution of 2-(methylamino)ethanol for carbon dioxide removal from gas stream

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Abstract. In power generation and petroleum industries, carbon dioxide can cause operational problems such as corrosion, and heating-value reduction. However, it can be used in many industries like food industries and in petroleum to enhance the oil recovery for oil production. However, the amount of carbon dioxide or supply is not enough because the cost of carbon capture is high. The main sources of carbon dioxide come from power plants and natural gas processing. The technology is carbon capture and storage. Currently, the effective technology to remove carbon dioxide to the lower level is chemical absorption and chemicals used in this technology play an important role. Nowadays, the commercially used solvents are monoethanolamine. Nevertheless, it also has disadvantages such as low capacity, corrosion and high energy requirement for regeneration; thus, making this technology not economically viable. Therefore, many new solvents such as 2-(methylamino)ethanol have been developed to improve efficiency and to compensate the drawbacks of conventional solution for carbon dioxide capture. Consequently, the aim of this work is to measure the solubility data of carbon dioxide in a 5M aqueous solution of 2-(methylamino)ethanol as a solvent at the temperature from 30 °C to 80 °C and partial pressures ranging from 5 to 100 kPa. The solubility results of carbon dioxide in 2-(methylamino)ethanol solution are compared with that of the aqueous solution of monoethanolamine at the same conditions. In term of cyclic capacities, the results show that 2-(methylamino)ethanol provides higher performance which is up to 86.8% and 150.9% higher than that of monoethanolamine at 15 and 100 kPa, respectively. Furthermore, the results present that the loading can increase as partial pressure increases and decrease at higher temperature. This can result in the decrease in energy requirement for solution regeneration and liquid-circulation rate, leading to the reduction in the overall cost of carbon capture.

1. Introduction
In the power generation and petroleum business, carbon dioxide or CO2 can cause corrosion, pipeline plugging and heating-value reduction. However, CO2 can be used to enhance the oil recovery for oil production [1]. Nevertheless, the amount of CO2 supply is not enough because the cost of carbon capture is high [2]. The main sources of CO2 come from natural gas and LNG processing, power generation and other industries. At this moment, the technology to capture CO2 is carbon capture and storage or CCS [3]. Moreover, the effective method to remove CO2 from the natural gas processing and the power plants is chemical absorption and the chemicals used as the solvents in this technology play a key role [4].
Nowadays, the commercially used solvent for CO$_2$ capture is monoethanolamine (MEA). Nevertheless, it also has disadvantages such as low capacity and high energy requirement for regeneration; thus making CCS costly [5]. Many researchers have been working on the alternative solvents to increase the performance of CO$_2$ capture including the reduction in regeneration cost to make this technology viable [6-8]. Therefore, many new solvents have been developed to improve efficiency and to reduce the cost of CO$_2$ capture [9-10] and one of them is 2-(methylamino)ethanol or 2-MAE to compensate the drawback of a conventional solvent. Consequently, the objective of this work is to measure the solubility data of CO$_2$ in a 5M aqueous solution of 2-MAE as a promising solvent at the temperature from 30 °C to 80 °C and CO$_2$ partial pressures ranging from 5 kPa to 100 kPa and to compare the results with those of aqueous solution of MEA. However, the condition is limited to the low CO$_2$ partial pressure to fit for flue gas and liquefied natural gas (LNG) application.

2. Materials and methods

2.1 Materials
The feed gas is a mixture of 99.5% N$_2$ and 99.9% CO$_2$ purchased from Praxair at the desired fraction. The flow rate is controlled by using GFM17 flowmeters (Aalborg), calibrated weekly with ADM100 (Agilent Technology). This instrument has a range of use from 0.5 to 1,000 ml/min and accuracy of ±3% of reading. The temperature in Memmert water bath is controlled by Lauda water circulator.

For chemicals used in this work, MEA and 2-MAE are purchased from Sigma Aldrich with 99% and ≥ 98% purity, respectively. Aqueous solution is prepared by adding distilled water to the solvent. 5M concentration of solution is validated by titration with standard hydrochloric acid (HCl) purchased from Fisher Scientific with a purity of 99%.

2.2 Experimental procedures
The flow rates of N$_2$ and CO$_2$ are adjusted by flowmeters to reach the desired CO$_2$ partial pressure. The gas mixture is then fed to saturation cell and bubbled through the solution in the reactor until the reaction reaches the equilibrium. The outlet gas stream then flows through the condenser to recover the moisture in the gas stream before venting to the fume hood. To ensure that the reaction reaches the equilibrium, the experiment is conducted for 16 hours until it reaches the equilibrium. The CO$_2$ loading, presented in mole of CO$_2$ per mole of amine, is determined by titration of sample with 1.0 N HCl to calculate the solution concentration and amount of evolved CO$_2$ [11].

3. Results and discussion

3.1 Verification of the results
Figure 1 shows the solubility of CO$_2$ in 5M MEA solution at 40 °C in comparison with those from literature [9-10, 12-13].
The percent of average absolute deviation (%AAD) and maximum deviation compared with Shen and Li [12] are 2.67% and 11.05%, respectively. Thus, the data from this equipment and procedure are considered to be reliable enough for the next experiments.

3.2 Solubility results
The solubility results of CO\textsubscript{2} in 5M 2-MAE solution at designed conditions are presented in Figure 2-4. From Figure 2, it is illustrated that at higher CO\textsubscript{2} partial pressure, CO\textsubscript{2} can be absorbed more in 2-MAE solution. This is due to the vapor-liquid equilibrium (VLE) of CO\textsubscript{2} that shifts to the liquid phase when CO\textsubscript{2} partial pressure or concentration in feed stream increases. On the other hand, the result shows that at higher temperature, the solubility of CO\textsubscript{2} decreases because gas can dissolve less at higher temperature and VLE shifts to the gas phase.

Figure 1. Solubility of CO\textsubscript{2} in 5M MEA solution compared to literature results at 40 °C

Figure 2. Solubility of CO\textsubscript{2} in 5M 2-MAE solution from 30 to 80 °C
Figure 3. Comparison of solubility of CO₂ in 5M 2-MAE and MEA solutions at 40 °C and 80 °C

Figure 3 shows the solubility results of CO₂ in 5M 2-MAE solution and in MEA solution at 40 °C and 80 °C. It is obvious that at lower temperature, solubility of 2-MAE is higher than that of MEA up to 17.1%. On the contrary, at higher temperature, 2-MAE provides slightly lower solubility than MEA for 8.2%. This means that at higher temperature CO₂ can be absorbed less in 2-MAE and absorbed more at lower temperature.

Cyclic capacity for each absorbent is considered as the difference between CO₂ loading at absorption and regeneration conditions represented by the temperature of 40 °C and 80 °C, respectively [14]. Graphically, it can be explained as the gap between CO₂ loading at 40 °C and 80 °C as shown in Figure 4. It is clearly seen that aqueous 2-MAE solution has wider gap than that of MEA. Consequently, 2-MAE has a higher cyclic capacity than that of MEA at the same conditions. This indicates that 2-MAE solution requires less energy for solvent regeneration which is the one of the main costs for carbon capture and storage technology. Moreover, an increase in cyclic capacity can lead to the decrease in energy requirement for solution regeneration and liquid-circulation rate; thus leading to the reduction of the overall capital and operating costs and resulting in the decrease in carbon capture cost.

From Figure 4, the cyclic capacities of 2-MAE solution at 5M are 0.149 and 0.133 at 15 kPa and 100 kPa, respectively. 15 kPa is selected to present here because it represents the CO₂ concentration in the power plants especially from coal-fired power plants. Compared with MEA, they are higher than those of MEA for 86.8% and 150.9% at the same conditions.

In addition, for the use in the real application, only solubility study is not enough. The physical properties such as density and viscosity as well as the mass transfer study are required. Solvent stability and toxicity to environment are needed for further study.
Figure 4. Cyclic capacities of CO\textsubscript{2} in 5M 2-MAE and MEA at 15 kPa and 100 kPa CO\textsubscript{2}

4. Conclusions
In this study, the solubility of carbon dioxide in aqueous 5M 2-(methylamino)ethanol solution is investigated in term of carbon dioxide loading in comparison with 5M monoethanolamine solution. The conditions of this process are at temperatures ranging from 30 °C to 80 °C and partial pressure ranges from 5 kPa to 100 kPa. The results show that in term of cyclic capacities, 2-(methylamino)ethanol solution has a better capturing performance than that of monoethanolamine up to 151%. Furthermore, the results present that the loading can increase as partial pressure increases and decrease at higher temperature. This means that an increase in cyclic capacity can lead to the decrease in energy requirement for solution regeneration and liquid-circulation rate, leading to the reduction of the overall capital and operating costs and resulting in the decrease in cost of carbon capture.

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