Solubility, kinetics, absorption heat and mass transfer studies of CO\textsubscript{2} absorption into aqueous solution of 1-Dimethylamino-2-propanol

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Abstract

In this work, the performance of CO\textsubscript{2} absorption into aqueous 1-dimethylamino-2-propanol (1DMA2P) solution was investigated for possible CO\textsubscript{2} absorption application and compared with those of MEA and MDEA. The CO\textsubscript{2} absorption performance was presented in terms of equilibrium solubility, absorption rate, absorption heat, and overall mass transfer coefficient (K_{Gav}). The results show that 1DMA2P has a higher solubility and a lower absorption heat than those of MEA and MDEA, a faster absorption rate and a higher K_{Gav} than that of MDEA, but a lower K_{Gav} than that of MEA. Due to the high performance of the 1DMA2P, it can be considered to be a promising alternative solvent for CO\textsubscript{2} capture.

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1. Introduction

In recent years, considerable attention has been focused on worldwide global warming and climate change issues, resulting in extensive research being performed on carbon dioxide (CO\textsubscript{2}) capture. The absorption of CO\textsubscript{2} into aqueous amine solutions is regarded to be one of the most promising technologies for CO\textsubscript{2} capture due to its maturity, cost effectiveness, and capacity to handle large amounts of exhaust gas streams [1]. This technology relies

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greatly on the performances of solvents, which is dictated by its CO₂ loading capacity, reaction kinetics, energy for regeneration, and mass transfer characteristics. Recently, a new tertiary amine, 1-dimethylamino-2-propanol (1DMA2P), has drawn growing attention for its high kinetic performance for capturing of CO₂ [2]. However, it is well-known that the overall performances of any solvents are dependent not only on its kinetics, but also, on the absorption capacity, absorption heat, and mass transfer characteristics. Therefore, it is the objective of this study to comprehensively evaluate the performance of 1DMA2P and study these performance criteria parameters (CO₂ equilibrium solubility, CO₂ absorption heat, and mass transfer characteristics) compared with those of commercially available amines.

In this work, the CO₂ capture performances in aqueous solutions of 1DMA2P-CO₂-H₂O were investigated and compared with the conventional amines (e.g. MEA, MDEA) in the terms of CO₂ absorption capacity, absorption heat, absorption rate, and mass transfer.

2. Materials and Method

2.1. Materials

Reagent grade 1-dimethylamino-2-propanol (1DMA2P) with a purity of ≥ 97 wt% was obtained from TCI, Japan. MEA (with a purity of ≥ 98 wt%) and MDEA (with a purity of ≥ 99 wt%) were purchased from Tianjin Hengxing Chemical Preparation Co., Ltd, China. The solutions were prepared by mixing concentrated amines with deionized water to the desired concentrations. Commercial-grade CO₂ and N₂ (with a purity of ≥ 99%) were supplied by Changsha Jingxiang Gas Co., Ltd., China.

2.2. CO₂ Solubility

The apparatus used for the CO₂ solubility measurement in this work was similar to that used in the work of Tontiwachwuthikul et al. [3]. Initially, the amine solution at the desired temperature was fed into an absorption reactor which was immersed in a water bath with a temperature controller. After the solution in the reactor had reached the desired temperature, a mixture of N₂ and CO₂, which were individually controlled by separate mass flow meters and adjusted to the desired CO₂ concentration, was fed into the absorption reactor. The experiment was operated for at least 8 hours until equilibrium condition was obtained. Samples of CO₂-loaded solutions at equilibrium were taken for measurement of equilibrium solubility of CO₂ by titration using a known volume of 1.0 N HCl with methyl orange as the indicator.

2.3. Heat of CO₂ absorption in aqueous 1DMA2P solution.

The heat of absorption of CO₂-1DEA2P was estimated by applying the Gibbs-Helmholtz equation[4], as shown in Eq (1):

\[
\frac{d \left( \ln P_{CO_2} \right)}{dT} = \frac{\Delta H_a}{R} (1)
\]

where \( P_{CO_2} \) is the CO₂ partial pressure, \( T \) represents the temperature, \( \Delta H_a \) represents the heat of CO₂ absorption (J/mol), and \( R \) is the universal gas constant (J/mol K).

2.4. Mass transfer

The mass transfer performances in terms of the overall mass transfer coefficient (\( K_{oT} \)) were experimentally observed and compared using a laboratory-sized column, which was made of acrylic plastic with measurements of 28.0 mm internal diameter and 1.70 m total height. The packing height of the column was 1.20 m. Sulzer DX-type packing (made of 316L stainless steel and with 900 m²/m³ surface area per volume of elements). The schematic
diagram of the experimental setup is shown in Figure 1. The overall mass transfer coefficient \( K_G a_v \) of the \( \text{CO}_2 \) absorption in the packed column can be defined as shown in Eq. (2). Details on the determination of \( K_G a_v \) can be found in our previous work [5].

\[
K_G a_v = \frac{G}{P(y_{A,G} - y_{A}^*)} \frac{dY_A}{dz} \tag{2}
\]

where \( G \) and \( Y_A \) are the molar flow rate of inert gas and the mole ratio of \( \text{CO}_2 \), respectively. \( P \) represents the total pressure (kPa) of the packed column. \( y_{A,G} \) is the mol fraction of \( \text{CO}_2 \) in the gas phase and \( y_{A}^* \) is the mol fraction of \( \text{CO}_2 \) at interface in equilibrium with the bulk concentration.

![Schematic diagram of the absorption process.](image)

3. Results and discussion

3.1. \( \text{CO}_2 \) absorption capacity of aqueous 1DMA2P solution.

In this work, the equilibrium solubility of \( \text{CO}_2 \) in 2 M 1DMA2P solutions was measured at 313 K and over a \( \text{CO}_2 \) partial pressure range of 8-101 kPa. It can be found from Figure 2 that the equilibrium solubility of \( \text{CO}_2 \) in 1DMA2P solutions increased as the \( \text{CO}_2 \) partial pressure increased. In addition, it can be easily found that the equilibrium solubility of \( \text{CO}_2 \) in 2M 1DMA2P was higher than those of MEA and MDEA [6,7].
3.2. Heat of CO₂ absorption in aqueous 1DMA2P solution

In this work, the heat of CO₂ absorption into 1DMA2P was estimated based on the Gibbs-Helmholtz equation (Eq. (1)). The calculation results presented in Table 1 show that the heat of CO₂ absorption in aqueous 1DMA2P solution ($\Delta H_a$) was -28.3 kJ/mol, which was much lower than those in MEA and MDEA.

<table>
<thead>
<tr>
<th>Amine</th>
<th>Estimated $\Delta H_a$ (kJ/mol)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA</td>
<td>-84.3</td>
<td>[7]</td>
</tr>
<tr>
<td>MDEA</td>
<td>-54.6</td>
<td>[8]</td>
</tr>
<tr>
<td>1DMA2P</td>
<td>-28.3</td>
<td>This work</td>
</tr>
</tbody>
</table>

3.3. CO₂ absorption rates

In this study, the CO₂ absorption rate of 1DMA2P was obtained by plotting the CO₂ amount in liquid phase as a function of time. The absorption rates for CO₂ into 1DMA2P and MDEA at 298K are shown in Figure 3. It can be seen that 1DMA2P had a higher CO₂ absorption rate than that of MDEA. This is due to the higher reactivity of 1DMA2P toward CO₂, which has been demonstrated by Kadiwala et al. [2] who studied the CO₂ absorption kinetics into aqueous 1DMA2P solution using a stopped-flow technology. They found that the second order rate constant ($k_2$) of 1DMA2P was higher than that of MDEA.

3.4. Mass transfer.

The mass transfer performances of CO₂ absorption into MEA, MDEA, and 1DEMA2P were conducted at amine concentration of 2M, inlet temperature of 313K and atmospheric pressure. All the experimental results are shown in Figure 4. It can be seen clearly that $K_{cad}$ of 1DMA2P was higher than that of MDEA, but lower than that of MEA. This is because the reaction kinetics of CO₂ absorption into the three amines can be ranked as MEA>1DMA2P>MDEA. Although the mass transfer performance of 1DMA2P was lower than that of MEA, the
higher CO₂ capacity and reactivity compared with that of MDEA as shown in the previous sections make 1DMA2P more attractive to be used in the CO₂ capture, especially for the process with high volume of CO₂.

4. Conclusion

The performance of CO₂ absorption into aqueous 1-dimethylamino-2-propanol (1DMA2P) solution was investigated for possible CO₂ absorption application. It was observed that 1DMA2P can be considered to be a promising solvent for CO₂ capture due to its good performance on the CO₂ absorption capacity, CO₂ absorption heat, CO₂ absorption rate, reaction kinetics and mass transfer.

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