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CO2 capture using absorbents of mixed ionic and amine solutions

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Abstract

Studies have been conducted to find new absorbents for post-combustion CO2 capture. To overcome the ILs' limits and meanwhile take their advantages, the mixed amine + IL + H2O solutions as CO2 capture absorbent were investigated in a CO2 absorption/desorption loop setup. It was found that with an increase in IL concentration, the viscosity of the mixed solution rose while the energy required for absorbent regeneration decreased. In addition, no IL loss was detected and the amine loss per ton of captured CO2 was considerably lower than that of aqueous amine solution. The viscosity of the best candidate of 30 wt% MEA + 40 wt% [bmim][BF_4] + 30 wt% H2O is close to the value of aqueous amine solution, indicating that the ionic liquid disadvantage of high viscosity can be overcome for absorbent delivery of CO2 capture.

1. Introduction

Room-temperature ionic liquids (ILs) have been proposed as a potential candidate for CO2 capture in the last few years [1]. In order to overcome some of the limitations of ILs as CO2 capture media, meanwhile, still taking the advantageous of their existing physical properties, mixed IL-amine solutions are employed to be co-capture agents[2-4]. Considering intractable tars due to amine/IL solutions corresponding CO2 adducts, absorbents of amine + IL + H2O systems were proposed by Ahmad et al. [5]. It suggested that amine + IL + H2O system might be an attractive CO2 capture media with the advantages

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of low viscosity and high CO₂ absorption rate. However, it should be necessary and interesting to investigate the performance of an absorption-desorption loop using amine + IL + H₂O system as CO₂ capture media. Herein, the CO₂ capture performances of the amine + IL + H₂O system in continuous CO₂ absorption and desorption were investigated in this study. The viscosities and regeneration energy of absorbents of MEA + [bmim][BF₄] + H₂O with different compositions were analysed. Considering the CO₂ absorption rate and the solubility of the CO₂-carbamate salts in IL, four absorbents of MEA / TEA + [hmim][Tf₂N] / [bmim][BF₄] + H₂O with different concentrations were tested in an absorption-desorption loop system with a continuous operation of 15 days.

2. Experimental

The specifications of the analysis methods and the set-up absorption-desorption loop system for CO₂ capture in this study the system were described in our previous work [6]. Four campaigns of amine + IL + H₂O absorbent solutions were conducted to study the CO₂ capture performances of absorbents with different concentrations. The exact operating parameters were presented in Table 1. The feed gases of four campaigns are in the composition range of flue gas from coal-fired power plant.

Table 1. Experimental conditions.

<table>
<thead>
<tr>
<th>Items</th>
<th>MEA wt%</th>
<th>TEA wt%</th>
<th>[hmim][Tf₂N] wt%</th>
<th>[bmim][BF₄] wt%</th>
<th>H₂O wt%</th>
<th>CO₂ vol%</th>
<th>Flue gas flow rate Nm³ h⁻¹</th>
<th>Solution flow rate mL min⁻¹</th>
<th>Operating time h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campaign 1</td>
<td>30</td>
<td>0</td>
<td>70</td>
<td>0</td>
<td>0</td>
<td>12.5</td>
<td>0.01</td>
<td>1</td>
<td>360</td>
</tr>
<tr>
<td>Campaign 2</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>90</td>
<td>5</td>
<td>12.5</td>
<td>0.01</td>
<td>5</td>
<td>360</td>
</tr>
<tr>
<td>Campaign 3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>90</td>
<td>5</td>
<td>12.5</td>
<td>0.01</td>
<td>5</td>
<td>360</td>
</tr>
<tr>
<td>Campaign 4</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>30</td>
<td>12.5</td>
<td>0.01</td>
<td>1</td>
<td>360</td>
</tr>
</tbody>
</table>

3. Results and discussion

3.1. Solvent loss

With the absorption desorption loop system running, there was no obvious loss of [hmim][Tf₂N] or [bmim][BF₄] detected in four campaigns. It is contributed by the low saturated vapor pressure and excellent heat stability of IL [7]. During CO₂ absorption by amine, MEA / TEA losses mainly caused by evaporation and degradation. The total MEA / TEA losses were plotted as a function of operation time as shown in Fig. 1. (a). The MEA loss in Campaigns 1 increased dramatically with the system running. Carbonate formed by MEA reacting with CO₂ is not soluble in [hmim][Tf₂N] at the absorber operation temperature of 50°C. The carbonate precipitated from MEA + [hmim][Tf₂N] solution is too thick to flow in the CO₂ capture system. As shown in Fig. 1. (a), TEA and MEA losses increased with the system running. In Campaign 4, for 30 wt% MEA + 40 wt% [bmim][BF₄] + 30 wt% H₂O, MEA loss was 1.16 per ton of captured CO₂, respectively. The saturated vapor pressure of the mixed absorbent decreased with the addition of [bmim][BF₄] [8], resulting in low evaporation of absorbent. The addition of IL ([bmim][BF₄]) to amine aqueous solution can reduce the absorbent loss.

3.2. CO₂ capture

In order to explore CO₂ removal capacities of the mixed absorbents, the CO₂ absorption efficiencies of four campaigns as a function of operation time were examined, as shown in Fig.2.(b). In Campaign 1, for 30 wt% MEA+70 wt% [hmim][Tf₂N], CO₂ capture efficiency was above 90% during the first 8 days and
then decreased to 18.6% at the end of operation. In Campaign 2, CO₂ absorption efficiency decreased gradually and kept around 50% over the whole operation time. The reaction rate of TEA with CO₂ is relatively lower than that of MEA. Although the TEA loss was low as shown in Fig.1(a), its CO₂ capture efficiency decreased gradually. It was attributed that water loss in Campaign 2 was much more than TEA, and TEA removals CO₂ by CO₂ hydration. In Campaign 3, CO₂ removal efficiency decreased along with the MEA loss. In Campaign 4, CO₂ capture efficiency was the highest among all of the campaigns and kept above 90% within 15 days’ operation.

![Graph](image1.png)

![Graph](image2.png)

Fig. 1. (a) MEA/TEA losses as a function of operation time; (b) CO₂ removal efficiencies as functions of operation time.

3.3. Viscosities and regeneration energies of the solutions

The viscosities of 30 wt% MEA solutions with different concentrations of [bmim][BF₄] were measured as a function of temperature (see Fig. 2(a)). The viscosities of the solutions decreased gradually with an increase in temperature. Thus, high temperature benefits absorbent transportation with a low mechanical energy requirement. Simulations were carried out to calculate the thermal energy at the strippers for absorbents of MEA + [bmim][BF₄] + H₂O with different compositions using the Aspen Plus (version 13.1). The electrolyte-NRTL model was used to describe the MEA-H₂O-CO₂ system thermodynamically. The parameters for this calculation are based on experimental conditions, as shown in Table 1. Viscosity at absorber operation temperature of 50°C and regeneration energy required of 30 wt% MEA + [bmim][BF₄] + H₂O solution as a function of [bmim][BF₄] mass fraction was illustrated in Fig. 3. (b). With an increase in concentration of [bmim][BF₄], the energy demand of the solution decreased and meanwhile the solution viscosity increased. As shown in Fig. 2. (b), the [bmim][BF₄] concentration of 40% was roughly chosen as an optimal value by weighing the thermal energy requirement in stripper and the viscosity at absorber operation temperature of 50°C.

4. Conclusion

The mixed amine + IL + H₂O solutions as CO₂ capture absorbent were investigated in a CO₂ absorption / desorption loop setup. It was found that the 30 wt% MEA + 40 wt% [bmim][BF₄] + 30 wt% H₂O is most likely the best candidate in this case considering the viscosity related to the mechanical energy for absorbent transportation and required energy for CO₂ desorption. In addition, no IL loss was detected and the amine loss per ton of captured CO₂ was considerably lower than that of aqueous amine solution. The viscosity of the best candidate of 30 wt% MEA + 40 wt% [bmim][BF₄] + 30 wt% H₂O is close to the value of aqueous amine solution. Thus, the mixed IL-amine solution showed great potential in
post-combustion CO₂ capture with the advantages of low viscosity and energy required by CO₂ desorption. In addition, a key feature of the mixed IL-amine solution different from conventional aqueous amine solution is that the viscosity of the mixed IL-amine solution is sensitive to temperature. So controlling the temperature of the mixed IL-amine absorbent is important during the operation of CO₂ capture system.

Acknowledgements

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References

Biography

Jie Yang is a Ph.D student in East China University of Science and Technology, under the supervision of Prof. Jerry Yan and Prof. Shan-Tung Tu. Jie Yang’s research interests are CO2 capture process intensification and energy efficient extraction of lipids from algae.