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CO_2 capture with complex absorbent of ionic liquid, surfactant and water

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ABSTRACT

A new kind of high efficiency and low cost CO_2 complex absorbent was studied. Through innovative research, imidazolium-based ionic liquid was mixed with an aqueous solution of a non-ionic surfactant. The absorption ability of each complex absorbent with different concentrations was tested under a condition of 20 °C, from 0.1 to 0.6 MPa. The absorption capacity of CO_2 in absorbents increases with increasing pressure and concentrations of ionic liquids. Different aqueous ionic liquid–surfactant solutions had different CO_2 absorption, and the sequence was as follows: X-100 > TWEEN 80 > PEG 400. [emim] [OTf] was more likely to absorb CO_2 than the other four ionic liquids. All of the complex absorbents had good absorption properties. The best combination was made up of 5% TWEEN 80, 10% [emim] [OTf] and water, which could capture 0.798 mol L^{-1} CO_2 at 0.6 MPa while pure water could only capture 0.439 mol L^{-1} under the same conditions. Through computer numerical simulations, the experimental data could be well fitted with Henry's law and Langmuir isothermal adsorption equation. After multiple absorption and regeneration, the absorption capacity of the complex absorbent was reduced by less than 5%. It could be expected to be a new type of CO_2 capture absorbent.

Introduction

Climate warming caused by CO_2 has become one of the top concerns around the world [1]. It is important to control and reduce CO_2 emission. At present, amine compounds absorption is widely used in industry with the advantages of a high absorption effect. On the contrary, high energy consumption, serious equipment corrosion and secondary pollution caused by solvent evaporation are the drawbacks of the method [2]. Ionic liquids, as a new type of absorbent, have excellent physical and chemical properties. It is found that the absorption effect of ionic liquids for CO_2, SO_2 and H_2S are excellent.

Research on ionic liquids has focused on conventional ionic liquids and functionalized ionic liquid. Conventional ionic liquids can be divided into imidazole salt, ammonium salt, sulfonic acid salt and pyrrole salt, etc. [3]. The most common type is imidazole ionic liquids with low viscosity and good flowability [4]. Imidazole ionic liquids containing anion such as BF_4^-, PF_6^- and Tf_2N^- are investigated frequently regarding their absorption capacity of CO_2. The absorption of CO_2 of ten different kinds of imidazole salt ionic liquids with temperatures of 25, 40 and 60 °C was investigated [5,6]. The pressure was in the range of 1–15 MPa. They came to a conclusion that absorption capacity of different anion under the same temperature and pressure with the same cation was in the order of $[NO_3] < [DCA] < [BF_4] < [PF_6] < [TfO] < [Tf_2N] < [methide]$. In addition, the absorption of CO_2 in different ionic liquids with different carbon chain length was also investigated [7,8]. The results showed that the increase of carbon chain was conducive to the absorption. For conventional ionic liquids such as imidazole ionic liquids, the absorptivity for CO_2 was less than 0.1 mol(CO_2)/mol IL(ionic liquid) [9], resulting in functionalized ionic liquid. In 2002, ionic liquid containing amino [NH_2p-bim]BF_4 was synthesized for the first time by Bates et al. [10]. The absorptivity for CO_2 was almost 0.5 mol(CO_2)/mol IL. Due to the introduction of functional groups such as amino and amino acid, functionalized ionic liquids have better absorption performance, but higher viscosity and costs.

Although ionic liquid showed an excellent absorption property, the high viscosity and costs make it only suitable for laboratory researches. The mixture liquid of ionic liquid and water was used to absorb CO_2 [11]. The result showed that the aqueous solution of ionic liquids was also good at absorbing CO_2. In order to reduce the cost and viscosity while guaranteeing the capture effect at the same time, non-ionic surfactant was added to aqueous solution of

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Nomenclature

C_g absorption capacity of solution, mol L^{-1}
n_g amount of substance of CO_2, mol
ρ density of CO_2, g L^{-1}
P pressure of CO2, Pa
T temperature of CO2, °C
V volume of absorption vessel, mL
C_{CO_2} absorption capacity of solution, mol L^{-1}
K_H correlation coefficient of Henry's law, mol/(L Pa)
a correlation coefficient of Langmuir equation
k correlation coefficient of Langmuir equation

ionic liquids in this article. Experiments about the CO_2 capture effect of the combination solution were carried out at 20 °C with the pressure ranged from 0.1 to 0.6 MPa. Henry's law and Langmuir isothermal adsorption equation were used to verify the reliability of the data. The purpose of the experiments was to introduce a new type of CO_2 absorbent with high efficiency and low cost.

Experiment

Experimental materials and equipments

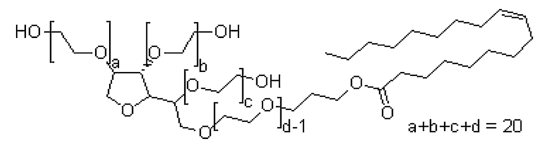
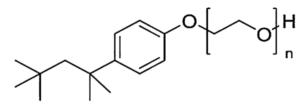
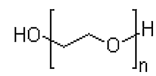
The five ionic liquids were purchased from LinZhou KeNeng Material Technology Co., Ltd. (China). The three non-ionic surfactants were purchased from NanJing WanQing Chemical Glassware Instrument Co., Ltd. (China). The purity of the purchased ILs and surfactants, as well as the molar weight, and the density are listed in Table 1. The structures of non-ionic surfactants are shown in Table 2.

The equipments used in the experiments include GSH-0.4L high-pressure reaction tank, GSH-0.4L high-pressure gas tank, DZF-6050 vacuum oven, ZNHW temperature control device, ZHQ-250ml dry bottom electric sets, HJ-3 constant temperature magnetic stirrer and 2XZ-8 sliding vane rotary vacuum pump.

Preparation of the combination solution

Considering the economic feasibility and practicality, the combination solution was prepared with low concentration. Each surfactant of TWEEN 80, X-100 and PEG-400 was mixed with water to prepare 150 mL solution with the concentrations of 5% and 10%, respectively. Each of the ionic liquids was mixed with various surfactants to prepare 150 mL mixed solutions, respectively. The concentration of the ionic liquids was 5% and 10%, respectively, which was the same for surfactant. The obtained solution was put into magnetic stirrer stirring for 10 min to ensure it adequately dissolved. All the experiments were carried out in the same laboratory, the environment temperature maintained at 20 °C.

Table 2
Structures of non-ionic surfactants.

<table>
<tr><th>Name</th><th>Structure</th></tr>
<tr><td>TWEEN 80</td><td>
</td></tr>
<tr><td>X-100</td><td>
</td></tr>
<tr><td>PEG 400</td><td>
</td></tr>
</table>

CO_2 absorption and regeneration

The absorption of CO_2 was carried out by the apparatus shown in Fig. 1. It consisted mainly of a gas cylinder, a vacuum pump, a gas chamber (0.4 L), a stainless steel absorption chamber (0.4 L) with a magnetic stirrer, a pressure sensor with an accuracy of 0.1 kPa in the experimental pressure range and a temperature controller. The temperature of the absorption chamber was set through temperature controller. In a specific experiment, 150 mL combination solution was put into the absorption chamber and heated to a set temperature. Valve 1 was closed, Valves 2 and 3 were switched to open, and the entire system was then evacuated to vacuum to remove the air in the experimental instrument. We waited 5–10 min, vacuumed again, repeated the process 3–5 times until the instrument display data no longer changed. If the display data was not zero, the value was written down as "zero point". Then valve 3 was closed and valve 1 opened to let CO_2 into the gas storage chamber from the cylinder, and then passed into the absorption chamber. After reaching the set pressure, valve 2 was closed, and the initial pressure recorded while the pressure was stable on the display. Then turn on the magnetic stirrer, combination solution started to absorb gas. When the pressure reading remained stabilized and unchanged for 40 min, the system can be considered to have reached equilibrium absorption, and then the equilibrium pressure was recorded. After the absorption experiment, the solution was placed into the vacuum chamber for 120 min and then used to test regeneration ability.

The absorption capacity was calculated according to volume change of the gas chamber and absorption chamber, pressure change, temperature and "zero point". The absorption capacity C_g is defined as:

Table 1
Samples used in this work.

Name	Abbreviation	M (g mol^{-1})	Purity (%)
1-Butyl-3-methylimidazolium hexafluorophosphate	[bmim] [PF_6]	284.18	≥99
1-Ethyl-3-methylimidazolium trifluoromethanesulfonate	[emim] [OTf]	260.23	≥97
1-Butyl-3-methylimidazolium acetate	[bmim] [OAc]	198.26	≥97
1-Hexyl-3-methylimidazoliumbis (trifluoromethylsulfonyl)imide	[hmim] [NTf_2]	330.37	≥99
1-Butyl-3-methylimidazolium tetrafluoroborate	[bmim] [BF_4]	226.02	≥99
t-Octyl phenoxy poly ethoxy ethanol	X-100	646.85	CP
Polyethylene glycol sorbitan monooleate	TWEEN 80	428.6	CP
Macrogol 400	PEG 400	400	CP