International Journal of Greenhouse Gas Control 55 (2016) 55–59

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

Evaluation of effectiveness of highly concentrated alkanolamine solutions for capturing CO_2 in a rotating packed bed

Hsing-Ju Ma, Yu-Shao Chen*

Department of Chemical Engineering, Chung Yuan University, Chung-Li, 320, Taiwan

ARTICLE INFO

Article history:
Received 4 August 2016
Received in revised form 17 October 2016
Accepted 8 November 2016
Available online 15 November 2016

Keywords:
Rotating packed bed
CO_2 capture
Chemical absorption
Alkanolamines

ABSTRACT

The capture of CO_2 by single and mixed alkanolamine solutions of monoethanolamine (MEA), 2-methylamino-ethanol (MMEA) and piperazine (PZ) with total alkanolamine concentrations from 30 to 100 wt% was conducted in a rotating packed bed (RPB). The effects of rotational speed, gas flow rate and composition of the absorbent were investigated. Experimental results showed that increasing the alkanolamine concentration and the rotational speed up to 1800 rpm effectively improved the CO_2 removal efficiency. However, the removal efficiency decreased as the gas flow rate increased. MMEA solutions exhibited a higher removal efficiency than MEA because MMEA reacts faster with CO_2 than MEA. The alkanolamines that were mixed with PZ were more effective in capturing CO_2 than single alkanolamine solutions. The height of transfer unit (HTU) decreased as the alkanolamine concentration and rotational speed increased, but increased with the gas flow rate. A CO_2 removal efficiency of 99.4% and an HTU of 0.74 cm were obtained using absorbent that contained 80 wt% MMEA and 20 wt% PZ at a rotational speed of 600 rpm, a liquid flow rate of 0.1 L/min, a gas flow rate of 30 L/min and a temperature of 313 K. The high removal efficiency and low HTU value reveal that an RPB has great potential for CO_2 capture from a gas stream using an absorbent with a high alkanolamine concentration.

1. Introduction

Carbon dioxide is one of the main greenhouse gases, which cause global warming. Reducing CO_2 emission from industrial sources, such as fossil fuel power plants, has become important in solving the problem of global warming. Therefore, many CO_2 capture and storage techniques have been developed to reduce CO_2 emissions, and chemical absorption is generally regarded as one of the most effective for removing CO_2 from the flue gas of power plants. Over the years, numerous investigations have focused on developing a more efficient and economic absorbent, and have examined various alkanolamines, including primary, secondary, tertiary, and sterically hindered amines and their mixtures, as absorbents. Additionally, a large volume is usually required for conventional gas-liquid contactors, such as packed columns and spray columns, for CO_2 capture, owing to their low mass transfer efficiency. Accordingly, novel gas-liquid contactors for CO_2 absorption must be developed.

Ramshaw and Mallinson (1981) proposed the rotating packed bed to improve the rate of mass transfer between gas and liquid. The liquid flows rapidly and chaotically, and is dispersed into thin films and tiny droplets as it passes through the packing under the influence of a centrifugal force. Therefore, the mass transfer efficiency increases substantially as the thickness of the boundary layer declines and the gas-liquid interfacial area increases. The mass transfer coefficient in an RPB has been provided to be one or two orders of magnitude higher than that in a conventional packed column (Ramshaw and Mallinson, 1981; Chiang et al., 2009), indicating that the size and cost of the equipment can be significantly reduced. Exploiting the remarkable mass transfer efficiency in an RPB, various gas-liquid contact processes have been reported, including the absorption of volatile organic compounds (VOCs), O_3, H_2S and NO from a gas stream, and the stripping of oxygen and VOCs from water (Chen and Liu, 2002; Sung and Chen, 2012; Lin and Su, 2008; Qian et al., 2010; Zhang et al., 2012; Peel et al., 1998; Gudena et al., 2012).

For CO_2 capture in a rotating packed bed, various alkanolamine solutions including monoethanolamine (MEA), 2-amino-2-methyl-1-propanol (AMP), methyl- diethanolamine (MDEA), 2-(2-aminoethylamino)ethanol (AEEA), diethanolamine (DEA) and diethylenetriamine (DETA) have been investigated for use as absorbents (Lin et al., 2003; Tan and Chen, 2006; Jassim et al., 2007; Yi et al., 2009; Cheng and Tan, 2009; Yu et al., 2012, 2014; Lin and Kuo, 2016; Sheng et al., 2016). Owing to the short residence time

* Corresponding author.
E-mail address: yschen@cycu.edu.tw (Y.-S. Chen).

http://dx.doi.org/10.1016/j.ijggc.2016.11.009
1750-5836/

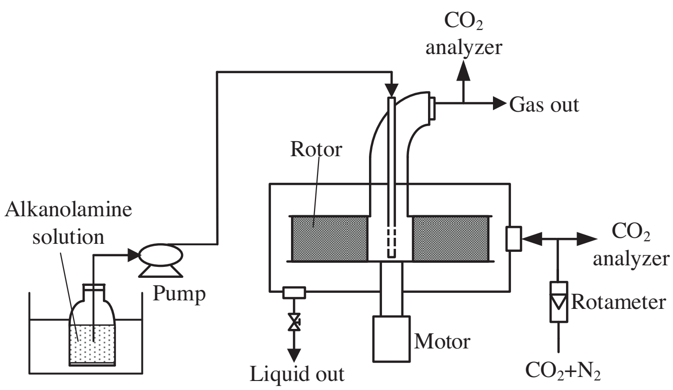

Fig. 1. Experimental setup for CO_2 absorption.

in an RPB, alkanolamines that have a high reaction rate with CO_2, such as MEA, AEEA and DETA, are suggested to be used. Piperazine (PZ) has recently been identified as an effective promoter owing to its high reaction rate with CO_2, and adding PZ into an alkanolamine solution increases the capture efficiency (Tan and Chen, 2006; Cheng and Tan, 2009; Yu et al., 2012; Sheng et al., 2016). Increasing the alkanolamine concentration also directly increases the reaction rate and absorption capacity. However, in a conventional packed column, the use of highly concentrated alkanolamine solution is usually limited by the viscosity of the liquid and corrosion. The viscosity of the liquid has less effect on mass transfer in an RPB than in a packed column because the liquid flow is accelerated in a centrifugal field (Chen et al., 2005; Chiang et al., 2009). Furthermore, the use of construction material such as stainless steel to prevent corrosion is more practical in an RPB because an RPB is significantly smaller than a packed column. Jassim et al. (2007) studied the absorption of CO_2 in an RPB using MEA solutions with concentrations from 30 to 100 wt% and found that the absorption efficiency was proportional to the concentration of alkanolamine. Increasing the concentration of alkanolamine not only increases the CO_2 capture efficiency, but also reduces the regeneration energy of the absorbent. Abu-Zahra et al. (2007) proposed that a 9% reduction of the regeneration energy was achieved as the concentration of an MEA solution increased from 30 wt% to 40 wt. The objective of this study is to examine CO_2 capture performance in an RPB with alkanolamine solutions of MEA, 2-methyl-amino-ethanol (MMEA), and PZ with a total alkanolamine concentration from 30 to 100 wt%. The effects of rotational speed, gas flow rate and composition of the alkanolamine solution on the CO_2 removal efficiency and the height of transfer unit (HTU) were investigated.

2. Experimental

MEA with a purity of 98% and PZ with a purity of 99% were purchased from Alfa. MMEA with a purity of 98% was purchased from Sigma-Aldrich. Nitrogen gas with 10 vol% CO_2 was purchased from Minyang Gases (Taiwan). All chemicals were used as received.

Fig. 1 presents the experimental setup for CO_2 capture in an RPB. The rotating packed bed comprised a rotor that was driven by a motor and a stationary housing. The inner and outer radii of the rotor were 2.25 and 6 cm, respectively, and the axial height was 1.8 cm. The packing was wire mesh with a specific surface area and porosity of 1229 1/m and 0.93, respectively. The rotor was operated from 600 to 2400 rpm, which generates 17–266 times the gravitational force based on the arithmetic mean radius. The rotor, stationary housing and packing were made of 304 stainless steel. The absorbents were single or mixed alkanolamines, including MEA, MMEA, MEA/PZ and MMEA/PZ, with a total alkanolamine concentration from 30 to 100 wt%. Table 1 presents the viscosity of the absorbents. The viscosity of the alkanolamine solutions were measured by a capillary viscometer. The prepared absorbent was maintained at 313 K using a water bath and introduced into the RPB through a metering pump. The absorbent entered the bed from the distributor, sprayed toward the inner edge of the packing region and passed through the rotor under the influence of the centrifugal force. The liquid then splashed onto the static housing before exiting at the bottom. The CO_2-N_2 gas stream with a CO_2 concentration of 10 vol% was introduced from the static housing, came into contact countercurrently with the absorbent in the rotor, and was expelled through the pipe at the center of the bed. The liquid flow rate was maintained at 0.1 L/min and the gas flow rate was varied from 30 to 70 L/min. The CO_2 concentrations in the inlet and outlet gas streams were measured by an NDIR CO_2 analyzer (Polytron 8720, Drager).

Table 1
Viscosity of alkanolamine solutions at 313 K.

Alkanolamine solution	Viscosity (mPa s)
100 wt% MEA	12.8
80 wt% MEA + 20 wt% PZ	12.0
64 wt% MEA + 16 wt% PZ	13.8
48 wt% MEA + 12 wt% PZ	9.2
24 wt% MEA + 6 wt% PZ	4.1
100 wt% MMEA	10.4
80 wt% MMEA + 20 wt% PZ	8.9
64 wt% MMEA + 16 wt% PZ	14.2
48 wt% MMEA + 12 wt% PZ	10.2
24 wt% MMEA + 6 wt% PZ	4.4

3. Results and discussion

In this investigation, the absorption of CO_2 by aqueous solutions of MEA, MMEA, MEA/PZ and MMEA/PZ in an RPB was studied. The effects of the concentration of alkanolamine, the rotational speed and the gas flow rate on the CO_2 removal efficiency (E) and the HTU were examined. The E and HTU values were calculated using the following equations (Yu et al., 2012).

$$E = \frac{C_i - C_o}{C_i} \times 100\% \quad (1)$$

$$\mathrm{HTU} = \frac{r_o - r_i}{\ln\left(\frac{C_i}{C_o}\right)} \quad (2)$$

In Eq. (1), C_i and C_o are the CO_2 concentrations in the inlet and outlet gas streams. In Eq. (2), r_i and r_o denote the inner and outer radii of the rotor. The CO_2 loading, representing the mole of the CO_2 absorbed per mole of alkanolamine, was also calculated. During absorption, the CO_2 concentration in the outlet gas stream was observed to reach a steady value in 5 min.

Figs. 2 and 3 present the removal efficiencies of CO_2 by absorption using MEA/PZ and MMEA/PZ, respectively, in an RPB. The total alkanolamine concentration ranged from 30 to 100 wt% and the weight ratio of MEA or MMEA to PZ was kept at 4. The effect of the total alkanolamine concentration on the CO_2 removal efficiency at a liquid flow rate of 0.1 L/min, a rotational speed of 600 rpm and a temperature of 313 K was tested. Experimental results revealed that increasing the gas flow rate from 30 L/min to 70 L/min reduced the CO_2 removal efficiency. Increasing the gas flow velocity can reduce the mass transfer resistance because doing so makes the gas boundary layer thinner. However, increasing the gas flow rate introduced more CO_2 into the system and reduced the contact time between the gas and liquid in the RPB. The obtained results indicated that reducing the thickness of the gas boundary layer has an insignificant effect on CO_2 absorption. Experimental results also showed that increasing the gas flow rate increased