CHEMICAL ENGINEERING TRANSACTIONS Volume 17, 2009
Editor Sauro Pierucci

DOI: 10.3303/CET0917282

Carbon Dioxide Absorption into Mixed Amines in a Cross-Flow Rotating Packed Bed

Chia-Chang Lin[1,2] and Yong-Wen Chen[1]
[1]Department of Chemical and Materials Engineering, Chang Gung University
259 Wen-Hwa 1st Road, Kwei-Shan, Taoyuan, Taiwan 333, R.O.C
[2]Pollution Prevention Group, Green Technology Research Center, Chang Gung University
259 Wen-Hwa 1st Road, Kwei-Shan, Taoyuan, Taiwan 333, R.O.C

This study investigates the feasibility of applying a cross-flow rotating packed bed (RPB) to absorb carbon dioxide (CO_2) by mixed amine solutions from gaseous streams. The cross-flow RPB has an inner radius of 2.4 cm, an outer radius of 4.4 cm and an axial height of 12.0 cm. Wire mesh was used as packings. Rotor speeds ranged from 600 to 1800 rpm, providing 14~123 equivalent gravitational force. The removal efficiency of CO_2 was determined at various values of operating parameters, including the rotor speed, gas flow rate, mixed amine flow rate, and absorbent type. Our experimental results demonstrated that the removal efficiency of CO_2 increased with the rotor speed and mixed amine flow rate, however, decreased with the gas flow rate. Furthermore, CO_2 removal efficiency using PZ/MEA was superior to those using MEA and AMP/MEA. Consequently, PZ/MEA could be used in a cross-flow RPB for the removal of CO_2 from the gas stream with higher flow rate owing to its high efficiency and its low cost.

1. Introduction

Ramshaw and Mallinson (1981) first presented that the concept of intensifying mass transfer was to establish a dramatically more rapid regeneration of the interface between gas and liquid phases. To attain this concept, they took advantage of centrifugal force to contact gas and liquid in a high centrifugal field by rotating doughnut-shaped packing element. Thus, a rotating packed bed (RPB) was developed for enhancing distillation and absorption efficiency. This novel technology was referred to as "Higee" (an acronym for high gravity). Under RPB operation, thin films and tiny droplets generated owing to a rigorous centrifugal acceleration (2000~10000 m/s^2) could provide an enhancement in the gas-liquid mass transfer. Furthermore, the RPB could be operated higher gas and/or liquid flow rates owing to the low tendency of flooding relative to that in the conventional packed bed. Therefore, the gas-liquid mass transfer would frequently be enhanced by a factor of 10~100 and the dramatic reduction in the size of the equipment would be achieved, thereby reducing the capital and operating costs (Ramshaw, 1983). The RPB has been applied in a variety of applications

Please cite this article as: Lin C.C. and Chen Y.W., (2009), Carbon dioxide absorption into mixed amines in a cross-flow rotating packed bed, Chemical Engineering Transactions, 17, 1687-1692 DOI: 10.3303/CET0917282

such as distillation (Lin et al., 2002), absorption (Lin et al., 2003), stripping (Lin and Liu, 2006), and ozone oxidation (Lin and Liu, 2003).

Although the gas absorption performance of a cross-flow RPB has been examined, the experimental results were isopropyl alcohol (IPA) absorption by water (Lin et al., 2006). The previous work (Lin and Chen, 2007) has applied a cross-flow rotating packed bed (RPB) to the removal of carbon dioxide (CO_2) using absorption with NaOH solution. The experimental results indicated that MEA could provide the highest removal efficiency of CO_2. Based on these results, to increase the CO_2 removal efficiency, the mixed amine solutions are considered to be the absorbent. Therefore, the objective of this work is to elucidate the removal of CO_2 from gaseous streams by absorption with mixed amine solutions in a cross-flow RPB. PZ/MEA and PZ/AMP are adopted as the model mixed amine solutions in this work. The results in this work could provide further insight into the feasibility of applying a cross-flow RPB to the removal of CO_2 from gaseous streams.

2. Experimental

Fig. 1 presents the experimental setup for absorbing CO_2. The CO_2 concentration in the inlet CO_2-N_2 stream was set at 10 % (mole fraction). During normal operation, the CO_2-N_2 stream traveled axially from the bottom of the packing owing to the pressure drop. At the same time, the prepared mixed amine solution was introduced from the tank into the inner edge of the packing through a liquid distributor. mixed amine solution moved radially in the packing due to the centrifugal force and, then, exited the packing from the outer edge. Both CO_2-N_2 stream and mixed amine solution were in contact with the cross-flow mode within the RPB, in which CO_2 in the CO_2-N_2 stream reacted with mixed amine in the liquid stream. The exiting CO_2-N_2 stream, containing low CO_2 concentration, finally left the top of the packing, and, then, was discharged from the top of the RPB, while the CO_2-rich mixed amine solution was expelled from the bottom of the RPB.

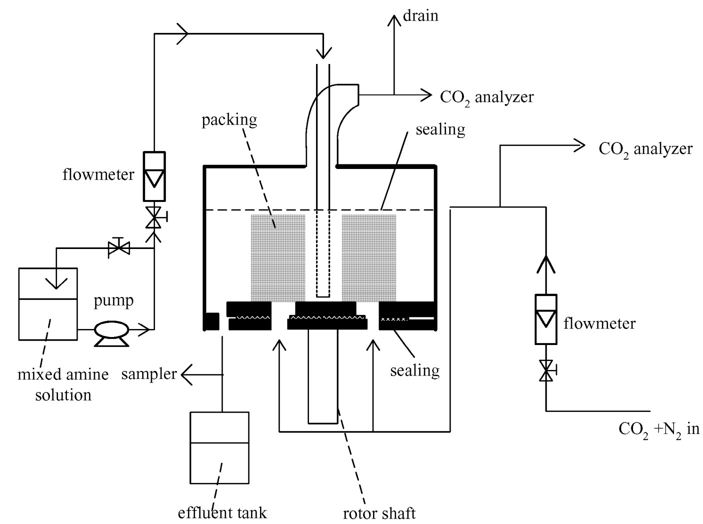

Fig. 1. Experimental setup of a cross-flow RPB for CO_2 absorption process.

The cross-flow RPB had an inner radius of 2.4 cm, an outer radius of 4.4 cm, and an axial length of 12 cm. Stainless wire mesh was used as packings having a configuration of interconnected filaments with a mean diameter of 0.22 mm and an average mesh diameter of 3 mm and arranged within the cross-flow RPB where gas and liquid were contacted with the cross-flow mode. Packings had a specific surface area of 677 m^2/m^3 and a voidage of 0.95. In general, the cross-flow RPB could be operated at the rotor speed of 600~1800 rpm, which provides 14~123 times gravitational force based on the arithmetic mean radius. During operation, the gas flow rate (axial direction) was varied at the range of 10~70 L/min and the liquid flow rate (radial direction) was varied at the range of 0.2~0.5 L/min. To present gas from bypassing the packing and keep the cross-flow operating mode, both sealings were adopted as shown in Fig. 1.

For most runs, a steady state was achieved within 10~15 min. The CO_2 concentrations in the inlet and outlet CO_2-N_2 streams were measured by an infrared (IR) CO_2 analyzer (Ploytron, Draeger Ltd). The reproducibility tests under almost all of the operating conditions were carried out in this study. The CO_2 concentration in outlet CO_2-N_2 streams was observed to be reproduced with a deviation of less than 5%. Material balance on the inlet and outlet of both the gas and liquid streams presented that the errors were within 10%. All experiments were conducted at an average temperature of 28 °C with atmospheric pressure.

3. Results and Discussion

The CO_2 removal efficiency in a cross-flow RPB is defined as follows.

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

where E is the CO_2 removal efficiency, and C_i and C_o are the concentrations of CO_2 in the inlet and outlet gas streams, respectively. The E values were measured at various values of the operation variables, including rotor speed (ω), gas flow rate (Q_G), mixed amine flow rate (Q_L), to estimate the CO_2 absorption performance of a cross-flow RPB.

Fig. 2 summarizes the E values as functions of the rotor speed from 540 to 1600 rpm for three absorbents (0.2M PZ/0.8M MEA, 1.0M MEA, 0.2M AMP/0.8M MEA). These rotor speeds provided a centrifugal acceleration from 109 to 955 m/s^2. At a particular gas flow rate and liquid flow rate, increasing the rotor speed enhanced the E values, as expected, for three absorbents. This phenomenon revealed that the centrifugal force further increased the mass transfer rate of CO_2 from the gas phase to the liquid phase during CO_2 absorption. Similar to a countercurrent-flow RPB (Lin et al., 2003), a cross-flow RPB also could offer an enhancement in the gas-liquid interfacial area and a reduction in the resistance of CO_2 mass transfer owing to that the thinner liquid films and/or the smaller droplets were induced by larger centrifugal force. Consequently, a cross-flow RPB should be considered to be an effective absorber for increasing CO_2 absorption. Also, PZ/MEA provided the highest E values owing to that the reaction rate of CO_2 with PZ/MEA was the highest. Moreover, the E values increased with mixed amine flow rate, however, decreased with the gas flow rate for three absorbents.

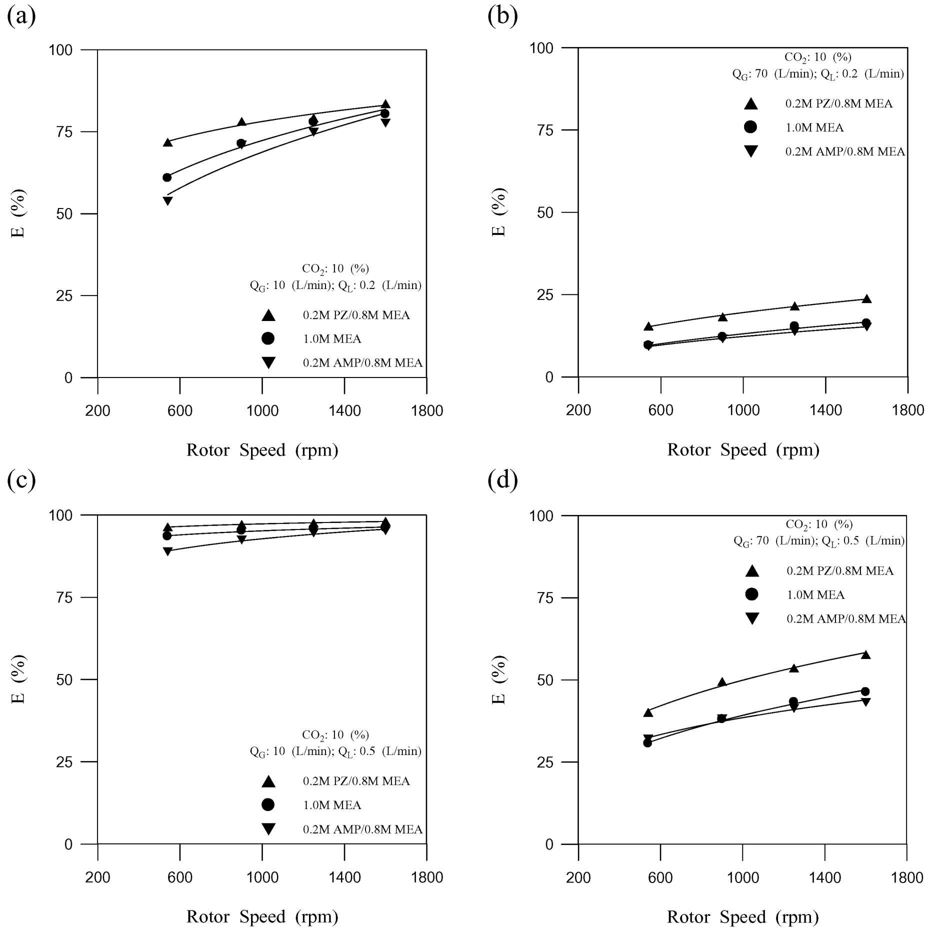

Fig. 2. Effect of rotor speed on E (a) Q_G = 10 L/min and Q_L = 0.2 L/min (b) Q_G = 70 L/min and Q_L = 0.2 L/min (c) Q_G = 10 L/min and Q_L = 0.5 L/min (d) Q_G = 70 L/min and Q_L = 0.5 L/min.

As shown in Fig. 2, it was noted that the E values was proportional to the rotor speed raised to the x power. The values of x depended on the gas flow rate, the mixed amine flow rate and the absorbent type as shown in Table 1. The x values at a low gas flow rate of 10 L/min Table 1 indicated that AMP/MEA offered the highest x values regardless of the liquid flow rate in the range of 0.2~0.5 L/min. This characteristic implied that for a low gas flow rate, the sensitivity of E to variations in the rotor speed for AMP/MEA was higher than those for other two absorbents. However, as the gas flow rate was increased to 70 L/min, this phenomenon was not observed, indicating that for a high gas flow rate, the sensitivity of E to variations in the rotor speed for MEA was higher than those for other two absorbents. For a given absorbent, the highest E value was found at a low mixed amine flow rate of 0.2 L/min and a high gas flow rate of 70 L/min, implying that the rotor speed could compensate the loss of removal efficiency induced by low mixed amine flow rate and high gas flow rate.

Table 1 Variation of exponent x with various operating conditions

Q_G (L/min)	Q_L (L/min)	x		
		0.2M PZ/0.8M MEA	1.0M MEA	0.2M AMP/0.8M MEA
10	0.2	0.131	0.263	0.339
10	0.5	0.016	0.026	0.066
70	0.2	0.403	0.509	0.461
70	0.2	0.331	0.386	0.280

4. Conclusion

This work has examined the absorption performance of a cross-flow RPB with the removal of CO_2 by mixed amine solutions from gaseous streams. The results were considered in relation with the removal efficiency, E values. As expected, increasing the rotor speed increased the E values; however, an optimum compromise between the consumption of energy (rotor speed) and the removal efficiency must be evaluated for industrial-scale applications.

According to the experimental results, CO_2 removal efficiency of increased with rotor speed and mixed amine flow rate, but decreased with an increase of gas flow rate. Moreover, CO_2 removal efficiency using PZ/MEA was superior to those using MEA and AMP/MEA. Consequently, PZ/MEA could be used in a cross-flow RPB for the removal of CO_2 from the gas stream with higher flow rate owing to its high efficiency and its low cost.

References

Lin C. C. and Chen B. C., 2007, Carbon Dioxide Absorption into NaOH Solution in a Cross-flow Rotating Packed Bed, J. Ind. Eng. Chem. 13, 1083-1090.

Lin C. C., Ho T. J. and Liu, W. T., 2002, Distillation in a Rotating Packed Bed, J. Chem. Eng. Jpn. 35, 1298-1304.

Lin C. C., Liu W. T. and Tan, C. S., 2003, Removal of Carbon Dioxide by Absorption in a Rotating Packed Bed, Ind. Eng. Chem. Res. 42, 2381-2386.

Lin C. C. and Liu W. T., 2006, Removal of an Undesired Component from a Valuable Product Using a Rotating Packed Bed, J. Ind. Eng. Chem. 12, 455-459.

Lin C. C. and Liu, W. T., 2003, Ozone Oxidation in a Rotating Packed Bed, J. Chem. Technol. Biotechnol. 78, 138-141.

Lin C. C., Wei, T. Y., Hsu S. K. and Liu, W. T., 2006, Performance of a Pilot-scale Cross-flow Rotating Packed Bed in Removing VOCs from Waste Gas Streams, Sep. Purif. Technol. 52, 274-279.

Ramshaw C. and Mallinson R. H., 1981, Mass Transfer Process, U.S. Patent 4,283,255.

Ramshaw C., 1983, Higee Distillation - An Example of Process Intensification, Chem. Engr. 389, 13-14.