ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 8, February 2015

Evaluation of Membrane Gas Absorption Performance by using Various of Liquid Absorbents

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Abstract*— Membrane gas absorption (MGA) can overcome the major drawbacks of the processes have been used commercially for the removal of CO_2. However, there are still many challenges in the operation of MGA in order to develop hydrophobic membrane and choose the best liquid absorbent to suit a whole range of promising MGA application, which is the main focus of this research. Performance in batch of MGA was carried out using deionized water, AMP and DEA as liquid absorbent. It was observed that the mass transfer rate of CO_2 increases with the liquid absorbent flow rate, gas feed flow rate, liquid absorbent concentration and CO_2 concentration at inlet gas. When the CO_2 concentration increases from 20 vol. % to 100 vol. %, CO_2 absorption using DEA was superior to AMP and deionized water.

Index Terms—**CO_2, liquid absorbents, MGA**

I. INTRODUCTION

Due to the enhanced greenhouse effect, Membrane Gas Absorption (MGA) has been considered to be a promising alternative to conventional and potential large scale application technology for the recovery and removal of CO_2 [1]. The various factors such as porosity, membrane dimension, liquid viscosity, chemical reaction on mass transfer in membrane gave the impact for the MGA performance [2,3]. In this study, performance of thin film composite (TFC) membrane for the absorption of CO_2 using liquid absorbents such as deionized water, DEA and AMP were study experimentally in MGA. Analysis of CO_2 removal in this system under various conditions such as liquid absorbents flow rate, gas feed flow rate, concentration of CO_2 at the inlet gas and liquid absorbent concentration.

II. MATERIALS AND METHODS

The TFC membranes (PDMS based on 0.1 µm PVDF) were used. Pure CO_2 and pure N_2 were mixed with a volume ratio of 10: 90, 20:80, 30:70, 40:60 or 100:0, which is in composition range of flue gas. In the experiment, the flow rate of the feed gas supplied from compressed gas cylinder was adjusted and controlled by Aalborg mass flow controllers, and then it was fed through up side of the membrane module. The experimental setup was schematically shown in Figure 1. Analysis of CO_2 removal in this system under various conditions such as liquid absorbents flow rate, gas feed flow rate, concentration of CO_2 at the inlet gas and liquid absorbent concentration.

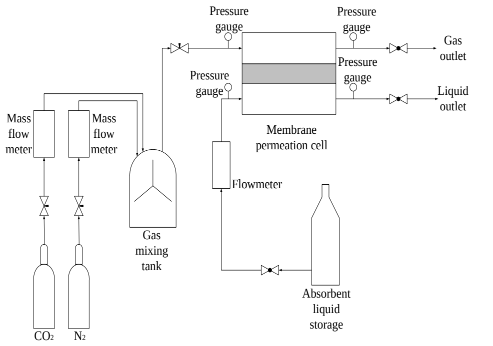

Fig 1: Schematic diagrams of MGA system

III. RESULT AND DISCUSSION

A. Effect of liquid absorbent flow rate

Liquid absorbent flow rate is perhaps the most important operating variable in the MGA system because in general it has an obvious influence on the mass transfer rate of CO_2. Figure 2 shows the experimental results of the mass transfer rate as a function of liquid absorbent flow rate (U_l) when using aqueous 1M DEA, 1M AMP solution and deionized water. The effects of liquid absorbents flow rate (from 25 to 80 ml/min) were studied by maintaining the total gas flow rate at 100 ml/min and CO_2 concentration was 20 vol.%.

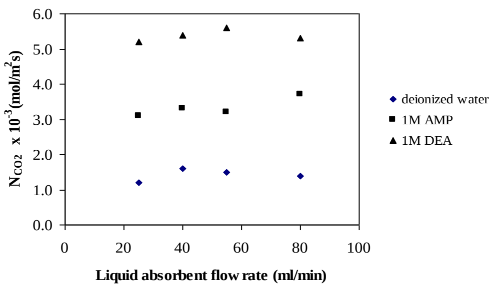

Fig 2: Effect of liquid absorbents flow rate on the mass transfer rate of CO_2 (U_g: 1 x 10^{-4} m^3/s; CO_2 volume fraction in feed gas: 20 vol.%; T_l: 30°C)

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It was observed that the mass transfer rate of CO_2 increases with the liquid flow rate. Similar behaviour for the water and some alkanolamines as liquid absorbent [4,5]. This was because that the boundary layer thickness of the liquid phase at the other side of the membrane decreased with increasing liquid flow rate, which leads to the decrease in the resistance of the liquid phase, and the increase in the mass transfer and diffusivity [1]. Similar trend was also reported for the mass transfer rate of CO_2 using aqueous amino acid salt solution, potassium taurate as liquid absorbent in a single fiber membrane contactor [6]. Other researchers also reported similar trends when using typical amines to absorb CO_2 in PP or PTFE membrane contactor [7,8,9]. It was also clearly showed that the mass transfer rate of CO_2 by aqueous DEA solution is higher than the other liquid absorbents. In general, the mass transfer rate of CO_2 was higher than 5.73 x 10^{-3} mol/m^{2}s using DEA, but the maximum mass transfer rate using AMP was 3.91 x 10^{-3} mol/m^{2}s, and the maximum using deionized water is only attained at 1.56 x 10^{-3} mol/m^{2}s in the experiments. This showed that the relatively lower liquid flow rate can be selected to absorb CO_2 in MGA when using DEA as the liquid absorbent, which can reduce the potential to wet the membrane [10].

B. Effect of gas feed flow rate

The impact of inlet gas flow rate (U_g) on the mass transfer rate of CO_2 and is demonstrated in Figure 3. The effects of gas feed flow rate (from 50 to 120 ml/min) were studied by maintaining the total liquid absorbent flow rate at 25 ml/min and CO_2 concentration was 20 vol.%.

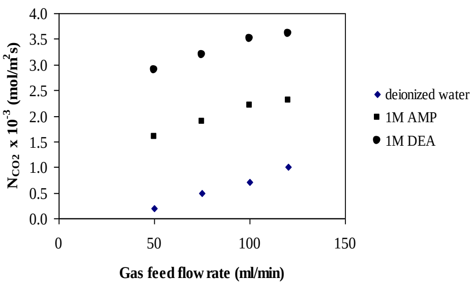

Fig 3: Effect of gas feed flow rate on the mass transfer rate of CO_2 (U_l: 2.5 x 10^{-5} m^3/s; CO_2 volume fraction in feed gas: 20 vol. %; T_l: 30^{o}C)

In Figure 3, the increase of gas flow rate could effectively enhance the CO_2 mass transfer, which was confirmed by experiments. When gas feed flow rate increased from 50 to 120 ml/min, the residence time of CO_2 in the MGA was reduced significantly. The same behaviour was reported by Yeon et al., 2005 when using a hybrid absorbent composed of 5 wt.% TEA and 5 wt.% MEA in a porous PVDF hollow fiber module. It could be explained that increasing flue gas flow rate can enhance the mass transfer in the gas phase, and thus, enhance the mass transfer through the membrane [1]. From the figure 3 also noticed that the mass transfer rate using DEA were higher than those using AMP and deionized water under the same conditions. This indicated that DEA was more suitable to absorb CO_2 in the MGA compared with AMP or deionized water when gas feed flow rate was frequently changed.

C. Effect of liquid absorbent concentration

Effect of CO_2 concentration at the flue gas inlet on the mass transfer rate of CO_2 is illustrated in Figure 4. The effects of CO_2 concentrations (from 10 to 100 vol.%) were studied by maintaining the total gas flow rate at 100 ml/min and liquid absorbent flow rate was 25 ml/min.

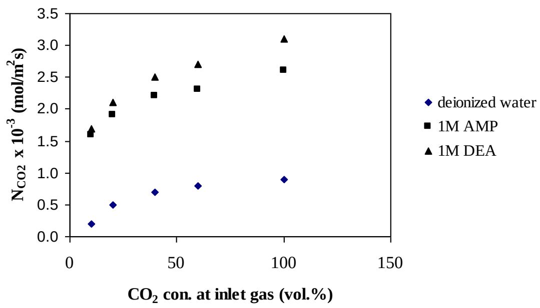

Fig 4: Effect of CO_2 concentration at inlet gas on the mass transfer rate of CO_2 (U_l: 2.5 x 10^{-5} m^3/s;U_g: 1 x 10^{-4} m^3/s; T_l: 30^{o}C)

When the CO_2 concentration increases from 20 vol.% to 100 vol.%, the mass transfer rate was increased from 2.13 x 10^{-3} mol/m^{2}s to 3.14 x 10^{-3} mol/m^2 s using aqueous DEA solution as liquid absorbent. This was because more CO_2 permeates through the membrane module when CO_2 concentration increases. The exciting fact that the performance of CO_2 absorption using DEA was superior to AMP and deionized water under the same conditions also can be expressed in Figure 4.

D. Effect of liquid absorbent concentration

The dependence of mass transfer rate of CO_2 on initial liquid absorbents concentration is illustrated in Figure 5. The effects of liquid absorbents concentration (from 1M to 3M) were studied by maintaining the total gas flow rate at 100 ml/min, liquid absorbent flow rate was 25 ml/min and CO_2 concentration was 20 vol.%. It was clearly shown that the mass transfer rate generally increases with the liquid absorbent concentration. Similar trends were observed by [6,7, 11]. This could be because that the active component absorbing CO_2 in the liquid boundary layer increases with the liquid absorbent concentration, which results in higher CO_2 solubility and lower liquid flow rate. At the same time, when the liquid absorbent concentration increased from 1M to 3M, the mass transfer rate showed the maximum value 6.32 x 10^{-3} mol/m^{2}s using 2M DEA, 2.12x 10^{-3} mol/m^{2}s using 2M AMP and 1.21 x 10^{-3} mol/m^{2}s using deionized water, respectively.

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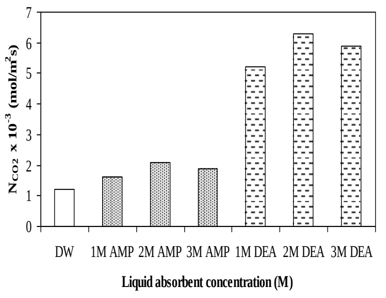

Fig 5: Effect of liquid absorbent concentration on the mass transfer rate of CO_2 (U_l: 2.5 x 10^{-5} m^3/s;U_g: 1 x 10^{-4} m^3/s; T_l: 30°C)

IV. CONCLUSION

In general, the mass transfer rate of CO_2 was higher than 5.73 x 10^{-3} mol/m^2s using DEA, but the maximum mass transfer rate using AMP was 3.91 x 10^{-3} mol/m^2s, and the maximum using deionized water is only attained at 1.56 x 10^{-3} mol/m^2s in the experiments. In term of gas feed flow rate, it could be explained that increasing flue gas flow rate can enhance the mass transfer in the gas phase, and thus, enhance the mass transfer through the membrane. When the CO_2 concentration increases from 20 vol.% to 100 vol.%, CO_2 absorption using DEA was superior to AMP and deionized water. Besides, the liquid absorbent concentration increased from 1M to 3M, the mass transfer rate showed the maximum value 6.32 x 10^{-3} mol/m^2s using 2M DEA and 2.12 x 10^{-3} mol/m^2s using 2M AMP.

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