

Effect of Liquid Flow Rate and Amine Concentration on CO₂ Removal from Natural Gas at High Pressure Operation in Packed Absorption Column

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Abstract. Greenhouse gas (GHG) emissions such as carbon dioxide (CO₂) and methane (CH₄) from oil and natural gas operation at offshore platforms have significant contribution to global warming. The reduction of these GHG emissions is possible through CO₂ capture technology. This study reports the absorption performance of monoethanolamine (MEA) for the removal of CO₂ from natural gas (NG) at high pressure conditions. The absorption experiments were performed in an absorption column packed with Sulzer Metal Gauze Packing at 5.0 MPa operating pressure. The absorption performance was evaluated in terms of CO₂ removal (%) with liquid flow rate ranging from 1.81 to 4.51 m³/m².h and MEA concentration of 1.0 - 4.0 kmol/m³. It was found that CO₂ removal (%) had increased with increasing liquid flow rate and MEA concentration.

Introduction

The oil and gas industry contributes to the greenhouse gas (GHG) emissions through flaring and venting of unwanted sub-quality natural gas. The flare and vent is absolutely necessary in oil and gas production for safe disposal and to reduce the risk of fire and explosion at the offshore platform. However, flaring produces largely carbon dioxide (CO₂) emissions while venting produces largely methane (CH₄) emissions [1]. The emissions of these two GHG have to be reduced and properly managed to avoid further negative impacts to the environment.

As offshore oil and natural gas production increases worldwide, this industry should make the effort to reduce CO₂ and CH₄ emissions by developing an effective GHG capture technology for offshore platforms. Sub-quality natural gas that contains high CO₂ concentration can be processed using CO₂ capture technologies instead of wasting this valuable gas via flaring and venting to the atmosphere. Thus, the purified natural gas can be further commercialized and utilized in commercial applications.

The CO₂ capture technologies include physical and chemical absorption, adsorption, as well as membrane and cryogenic separation. Among these technologies, chemical absorption is the most preferred approach for CO₂ removal due to its high reactivity. For flue gas treatment, researches in CO₂ removal using alkanolamines have been actively conducted at atmospheric pressure with low CO₂ concentration (< 15%) [2-10]. The most commonly used alkanolamines for this purpose are monoethanolamine (MEA), diethanolamine (DEA), methyldiethanolamine (MDEA) and 2-amino-2-methyl-1-propanol (AMP). However, the performance of chemical solvents at high pressure operations, specifically for natural gas purification, is still limited and has to be further explored.

In this paper, the performance of CO₂ absorption from CO₂/NG gas mixture using MEA solvent is reported in terms of CO₂ removal (%) along the height of the column. CO₂ removal (%) was determined by conducting experiments at various liquid flow rates and MEA concentrations. In this study, experiments were conducted with CO₂ concentration of 20% and operating pressure of 5.0 MPa in a bench scale absorber packed with Sulzer Metal Gauze Packing.

Materials and Methods

Chemical

Monoethanolamine (MEA) (99% purity) was purchased from Acros Brand. CO₂ (99.99% purity) used in this study was purchased from Air Product Malaysia, while NG with 97% CH₄, 2% CO₂ and 1% heavier hydrocarbon was supplied by Petronas Dagangan Bhd. All materials were used as received without further purification.

Equipment and Procedures

The absorption experiments were performed in a 2.040 m high and 0.046 m inside diameter (ID) column which was packed with Sulzer Metal Gauze Packing (Sulzer Chemtech Pte Ltd, Winterthur, Switzerland). The surface area of the structured packing is approximately 500 m²/m³. The column and structured packing were made of 316 stainless steel. The absorption column consists of 6 sampling points at different column levels for the measurement of gas concentration profiles.

The schematic diagram of the experimental set up is shown in Fig. 1. Prior to the experiments, the desired gas composition of CO₂ and NG was prepared by setting the flow rate of CO₂ and NG using each of the mass flow controller. The mixed gas was compressed and stored in a high pressure gas vessel. The mixed gas was then introduced into the bottom of the packed absorption column at the desired flow rate through a gas flow controller.

These experiments were conducted at 5.0 MPa. The pressure in the absorber was controlled using a back pressure regulator which was placed at the absorber outlet. The liquid absorbent was pumped into the absorber at the desired flow rate using a high pressure liquid pump and it was introduced from the top of the column to create a counter-current contact between the gas and liquid. The CO₂ in the gas phase was then absorbed into the liquid. The treated gas left the column at the top while the CO₂ rich solution, leaving from the bottom of the column, was collected in a storage tank.

Each absorption experiments were operated until steady-state conditions were reached. CO₂ concentrations at the inlet, outlet and sampling points along the column were measured using CO₂–CH₄ IR gas analyzer (Fuji Electric Instrument). The gas concentration at different levels along the column were sampled by switching the sampling point from one port to another, and readings were taken after a steady state for each level was reached.

The percentage of CO₂ removal is calculated using the following equation;

$$\text{CO}_2 \text{ removal} = \frac{y_b - y_a}{y_b} \times 100\% \quad (\text{Eq. 1})$$

The y_a and y_b represent the mole fraction of component CO₂ in bulk gas at the outlet and inlet of the column, respectively.

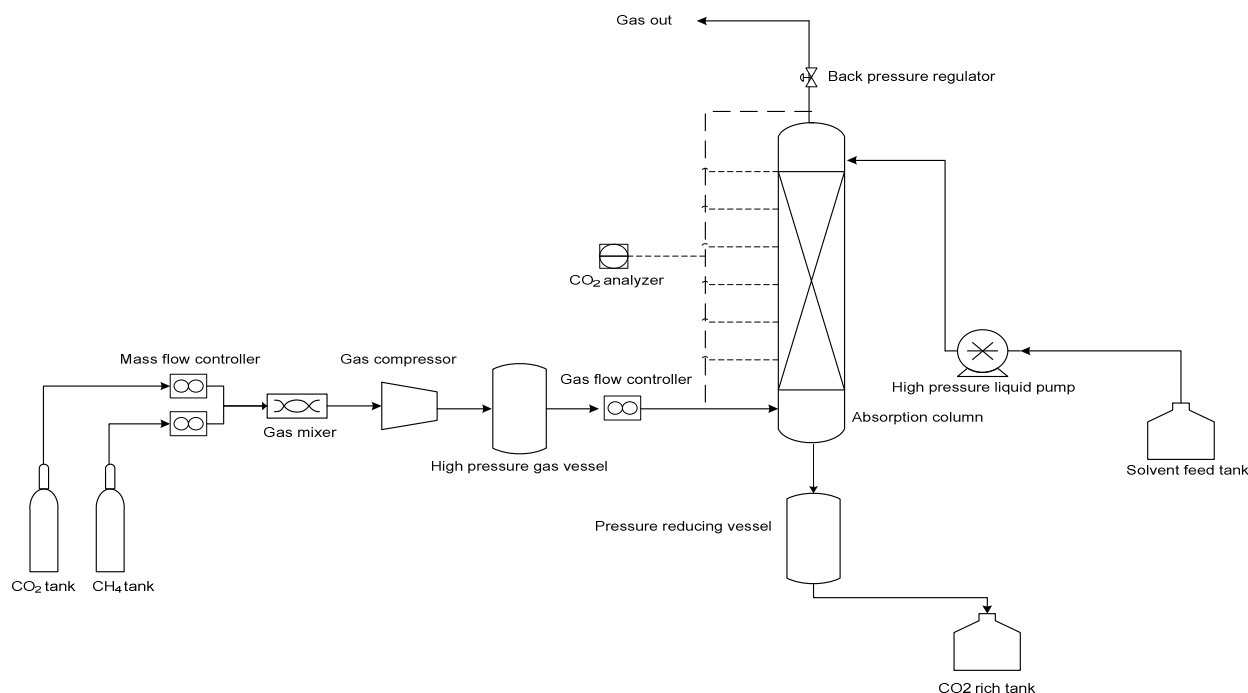


Fig. 1 Schematic diagram of the experimental set up

Results and Discussion

As shown in Fig. 2, the percentage of CO₂ removal increases from 34.68% to 87.27% when the liquid flow rate was increased from 1.81 to 4.51 m³/m².h. It is believed that at high liquid flow rate, the reaction between amine and CO₂ is enhanced by the larger amount of free amine molecules. Furthermore, higher liquid flow rate would increase turbulence within the column which would decrease the mass transfer resistance in the liquid phase. These observations corresponded well with CO₂ absorption studied at atmospheric operations [2, 4-9, 11]. Thus, it can be concluded that liquid flow rate has a significant effect on the percentage of CO₂ removal in CO₂ – MEA absorption at high pressure operation.

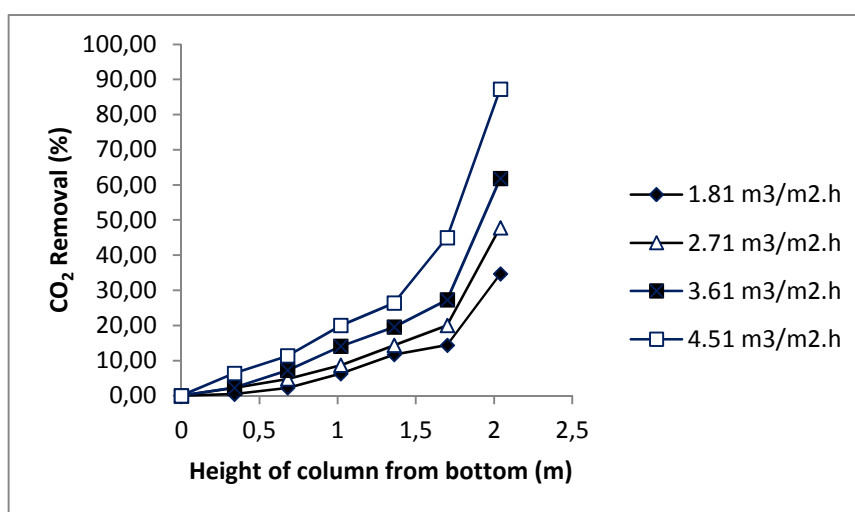


Fig. 2 Effect of Liquid Flow Rate on CO₂ Removal (%). (Gas flow rate: 19.72 kmol/m².h; 20% CO₂ in NG; [MEA] = 1.0 kmol/m³, $P = 5.0$ MPa; $T = 27^{\circ}\text{C}$)

Fig. 3 shows the effect of MEA concentration (1.0 – 4.0 kmol/m³) on the percentage of CO₂ removal. The percentage of CO₂ removal increases when MEA concentration was increased from 1.0

to 4.0 kmol/m^3 . This effect is due to the increasing amount of active MEA available in the liquid solution, which are ready to react with the dissociated CO_2 . The increased percentage of CO_2 removal at higher MEA concentrations may be attributed to the high enhancement factor (E) which consequently increases the liquid-side mass transfer coefficient. Similar trends have also been reported for CO_2 absorption studied at atmospheric operations [3, 5, 6, 9, 11].

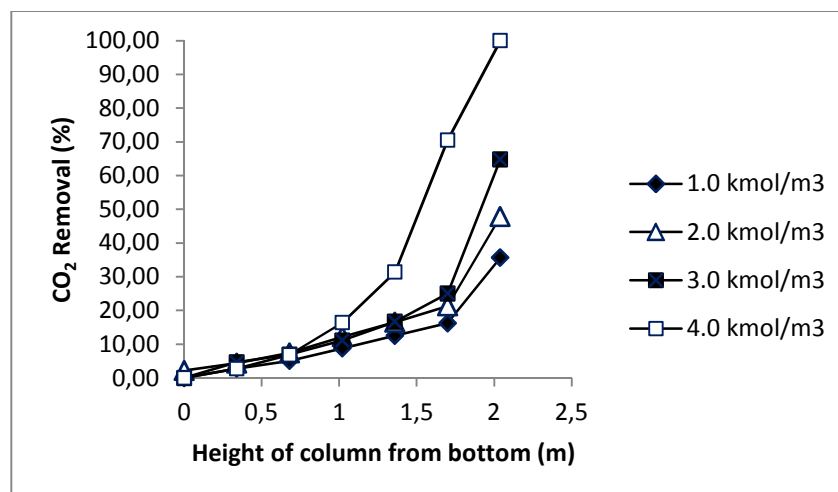


Fig. 3 Effect of MEA concentration on CO_2 Removal (%). (Gas flow rate: $28.18 \text{ kmol/m}^2\cdot\text{h}$; 20% CO_2 in NG; Liquid flow rate: $1.81 \text{ m}^3/\text{m}^2\cdot\text{h}$; $P = 5.0 \text{ MPa}$; $T = 27^\circ\text{C}$)

Conclusions

The removal of CO_2 from a gas mixture containing 20% CO_2 in NG at high pressure operation (5.0 MPa) was conducted for varying liquid flow rate ($1.81 - 4.51 \text{ m}^3/\text{m}^2\cdot\text{h}$) and MEA concentration ($1.0 - 4.0 \text{ kmol/m}^3$). The absorption was performed in a bench-scale absorption column packed with Sulzer Metal Gauze packing. The results showed that at high pressure condition, the CO_2 removal (%) increases with increasing liquid flow rate and MEA concentration. From these results, it can be concluded that the trend of the absorption performance at high pressure (5.0 MPa) is similar with the performance at atmospheric pressure. The results have shown that the CO_2 capture technology via chemical absorption may possibly be implemented at offshore platforms which would consequently reduce GHG emissions to the atmosphere.

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References

- [1] J. Kearns, K. Armstrong, L. Shirvill, E. Garland, C. Simon, J. Monopolis, Flaring & venting in the oil & gas exploration & production industry, International Association of Oil & Gas Producers (OGP), 2000.
- [2] A. Aroonwilas, P. Tontiwachwuthikul, Mass transfer coefficients and correlation for CO_2 absorption into 2-amino-2-methyl-1-propanol (AMP) using structured packing, Ind. Eng. Chem. Res., 37 (1998) 569-575.
- [3] A. Aroonwilas, P. Tontiwachwuthikul, High-efficiency structured packing for CO_2 separation using 2-amino-2-methyl-1-propanol (AMP), Sep. Purif. Technol., 12 (1997) 67-79.

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- [4] A. Aroonwilas, P. Tontiwachwuthikul, A. Chakma, Effects of operating and design parameters on CO₂ absorption in columns with structured packings, *Sep. Purif. Technol.*, 24 (2001) 403-411.
 - [5] A. Dey, A. Aroonwilas, CO₂ absorption into MEA-AMP blend: Mass transfer and absorber height index, *Energy Procedia*, 1 (2009) 211-215.
 - [6] K. Fu, T. Sema, Z. Liang, H. Liu, Y. Na, H. Shi, R. Idem, P. Tontiwachwuthikul, Investigation of Mass-Transfer Performance for CO₂ Absorption into Diethylenetriamine (DETA) in a Randomly Packed Column, *Ind. Eng. Chem. Res.*, 51 (2012) 12058-12064.
 - [7] A. Naami, M. Edali, T. Sema, R. Idem, P. Tontiwachwuthikul, Mass Transfer Performance of CO₂ Absorption into Aqueous Solutions of 4-Diethylamino-2-butanol, Monoethanolamine, and N-Methyldiethanolamine, *Ind. Eng. Chem. Res.*, 51 (2012) 6470-6479.
 - [8] T. Sema, A. Naami, P. Usubharatana, X. Wang, R. Gao, Z. Liang, R. Idem, P. Tontiwachwuthikul, Mass transfer of CO₂ absorption in hybrid MEA-methanol solvents in packed column, *Energy Procedia*, 37 (2013) 883-889.
 - [9] A. Setameteekul, A. Aroonwilas, A. Veawab, Statistical factorial design analysis for parametric interaction and empirical correlations of CO₂ absorption performance in MEA and blended MEA/MDEA processes, *Sep. Purif. Technol.*, 64 (2008) 16-25.
 - [10] Y. Artanto, J. Jansen, P. Pearson, G. Puxty, A. Cottrell, E. Meuleman, P. Feron, Pilot-scale evaluation of AMP/PZ to capture CO₂ from flue gas of an Australian brown coal-fired power station, *Int. J. Greenhouse Gas Control*, 20 (2014) 189-195.
 - [11] K. Maneeintr, R.O. Idem, P. Tontiwachwuthikul, A.G.H. Wee, Comparative Mass Transfer Performance Studies of CO₂ Absorption into Aqueous Solutions of DEAB and MEA, *Ind. Eng. Chem. Res.*, 49 (2010) 2857-2863.