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# Important Factors Affecting Carbon Dioxide Removal Efficiency By Using Extra-high Concentrated Monoethanolamine Solutions and High-Capacity Packings

A. Aboudheir, D. deMontigny, P. Tontiwachwuthikul*, and A. Chakma, Process Systems Laboratory, Faculty of Engineering, University of Regina, Regina, Saskatchewan, Canada S4S 0A2



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## Abstract
Experimental work is presented for the absorption of carbon dioxide ($CO_2$) into extra-high concentrated monoethanolamine solutions (MEA) using a pilot plant. The effect of a wide range of operating conditions on the removal efficiency is investigated. These operating conditions include ultra-high solvent concentration, packing type, liquid flow rate, gas flow rate, inlet gas composition, and solutions $CO_2$ loading. It was found that the absorption capacity of amine solutions is increases as its concentration increases, but not as great as might be expected, and a better removal efficiency of $CO_2$ can be achieved by using high-capacity packing.

## Introduction
The removal of carbon dioxide from raw natural gas is an essential step for meeting cleanup targets. The majority of raw gases contain a significant amount of $CO_2$ and often require treating in order to achieve a $CO_2$ cleanup target of less than 1% by volume (Astarita et al, 1983). Natural gas treating systems used to meet this target must have considerable flexibility in order to handle incoming fluctuations of raw gas rates and compositions. To investigate the main factors that affect $CO_2$ removal efficiency, a pilot plant study was conducted. In this experimental study, $CO_2$ was absorbed into MEA, the most commonly used chemical solvent in this field (Kohl and Nielsen, 1997). Results from this work will assist designers in selecting the appropriate system in this field.

In general, about five normal (30wt%) MEA solutions have been used as solvents for acid gas absorption (Strigle, 1987; and Kohl and Nielsen, 1997). On a pilot plant scale, Tontiwachwuthikul et al., 1992 reported detailed absorption data for a $CO_2$-MEA system using up to 18wt% MEA concentration. It is the aim of this paper to report, for the first time, new absorption data for MEA systems at ultra-high concentration, up to 54.0wt%, from pilot plant experiments. In addition, the other main factors affecting the absorption process were investigated. These include the packing type, gas flow rate, liquid flow rate, inlet gas composition, and solution $CO_2$ loading. The reported data and its analysis will be beneficial for designing new columns, operating existing columns, as well as for testing theoretical simulation models of gas absorption units.

## Experimental work
Absorption of $CO_2$ from air into MEA was performed in a pilot plant consisting of three identical absorption columns (2.40 m high and 0.101 m inside diameter) and a regenerator. The first and second columns were randomly packed with Pall Rings-16mm and IMTP#15 respectively, while the third column was packed with A4-structured packing. The absorption process was conducted in a counter-current mode at preset operating conditions. At steady state operation the gas concentration and the temperature profiles along the column were measured and recorded. As well, the outlet liquid composition was analyzed for its $CO_2$ loading.

The total number of measured data points from 56 experimental runs is 1078, which include 574 measured points of $CO_2$ gas concentration, 112 measured points of liquid composition, and 392 measured points of temperature. This data was obtained under a wide range of operating conditions which are: total MEA concentration from 3.0 to 9.0 kmol/m$^3$, $CO_2$ loading in the liquid feed from 0.0778 to 0.3526 mol $CO_2$/mol MEA, superficial liquid flow rate from 6.63 to 23.96 m$^3$/m$^2$ h, superficial gas flow rate from 28.05 to 65.46 kmol/m$^2$ h, feed $CO_2$ concentration from 4.96 to 20.3%, and three types of packing materials. Due to the large number of data points obtained in this work, the detailed experimental data are not pub-

* To whom correspondence should be addressed

lished as part of this paper but are available in tabular form and can be requested from the authors.

## Results and Discussion

The choice of amine concentration for $CO_2$ absorption is usually made on the basis of operating experience. Based on historical corrosion-concerns in alkanolamine gas treating plants, DuPart et al., 1993 recommend a maximum MEA concentration of 20wt%. However, higher amine concentrations can be used when corrosion inhibitors are used in the solution and when the $CO_2$ is the only acid gas component to be treated. Typical concentrations of MEA range from 12wt% to 32wt% (Kohl and Nielsen, 1997). In this work, $CO_2$ absorption into MEA solutions has been investigated experimentally within this typical range and into ultra-high concentrations, up to 54wt%, of MEA solutions.

By increasing the amine concentration, its capacity will be enhanced as shown in Figure 1a. As a result, the required solution circulation will be reduced and, therefore, the plant operating cost. However, as shown in Figure 1b, the effect is not as great as might be expected. As the MEA concentration is increased from 18wt% to 30wt%, the $CO_2$ removal efficiency will be increased from about 91% to 96%, with 5% of enhancement achieved. Further increase in MEA concentration from 30wt% to 54wt%, will increase the removal efficiency from about 96% to 98%, with only 2% of enhancement achieved, even though at a higher MEA concentration the net $CO_2$ absorption per mole of MEA is less. There are two main reasons for this trend. First, the acid-gas vapor pressure is higher over more concentrated solutions at equivalent acid-gas/amine mole ratio (Kohl and Nielsen, 1997). Second, as shown in Figure 2a, when the same quantity of $CO_2$ is absorbed in a smaller volume of solution (In this case, the volume of solution is reduced from 15.25 $m^3/m^2$ h of 18wt% MEA to 7.40 $m^3/m^2$ h of 54wt% MEA), the heat of reaction results in a greater increase in temperature as shown in Figure 2b. This increase in temperature will increase the $CO_2$ vapor pressure over the solution.

Since packed columns for gas absorption can be packed either randomly or with structure packing, three different type of packings were tested experimentally for the $CO_2$-MEA absorption system. Figure 3 shows the effect of the packing type on the absorption rate. The IMTP#15 proves to have a higher absorption capacity than the Pall Rings-16mm packing where the $CO_2$ removal efficiency is enhanced from about 92% to 96% over the full-length of the column. Furthermore, the complete removal of $CO_2$ was achieved using A4-structured packing. This type of packing was found to have a superior absorption capacity with 100% removal efficiency achieved in only three-quarter of the column height. Mainly, the higher interfacial area available during the absorption process can explain the high absorption capacity gained.

The effect of changing liquid flow rate, gas flow rate, $CO_2$% in the feed, and solution loading on the column performance is shown in Figures 4 to 7. First, when the liquid flow rate is increased gradually within the range from 6.63 to 16.95 $m^3/m^2$ h, the absorption rate and the absorption capacity of the column increase as shown in Figure 4. This is due to a higher liquid mass transfer coefficient, effective interfacial area, and concentrations of free absorbent. Second, by reducing the gas feed rate, the degree of $CO_2$ removal will increase as shown in Figure 5. This is directly related to the amount of available $CO_2$ in the gas stream. Third, the effect of $CO_2$ concentration in the feed on the absorption rate is presented in Figure 6. When the inlet $CO_2$ concentration is raised gradually from about 5% to 20%, the removal efficiency of $CO_2$ falls from approximately 100% to 79%. In this case, if high removal efficiency is required, the liquid flow rate and/or amine concentration should be increased and/or a higher packing-capacity should be utilized. Finally, when the loading is reduced from 0.3526 to 0.1736 mol $CO_2$/mol MEA, while keeping all other conditions approximately the same, the $CO_2$ removal efficiency is increased from about 73.0 to 95.0%. The increase is due to the availability of more free absorbent for reaction with the absorbed carbon dioxide. From these results, it can be concluded that the behavior of the stripping unit in the gas processing plant has a significant effect on the absorber unit efficiency. The more efficient the stripping system, the higher the removal efficiency in the absorber unit.

## Conclusion

On a pilot plant scale, detailed experimental measurements for concentration and temperature profiles were collected and analyzed for the absorption of $CO_2$ into ultra-high concentrated MEA solutions. The effect of the main operating conditions on the absorption process was investigated. The main findings are: (1) The absorption capacity of the amine is increased as its concentration increases, but not as great as might be expected because of the high acid-gas vapor pressure over the solution which increases as the concentration and the temperature of the solution increased. (2) A better removal efficiency of $CO_2$ can be achieved by using high-capacity packing. In addition, it was found that increasing the liquid flow rate would enhance the $CO_2$ removal efficiency. However, increasing the $CO_2$ loading, the inlet gas composition, and the inlet gas flow rate hinders the removal efficiency.

The data and its analysis are useful for designing new columns, operating existing columns, as well as for testing the theoretical models for simulation of gas absorption units.

## References


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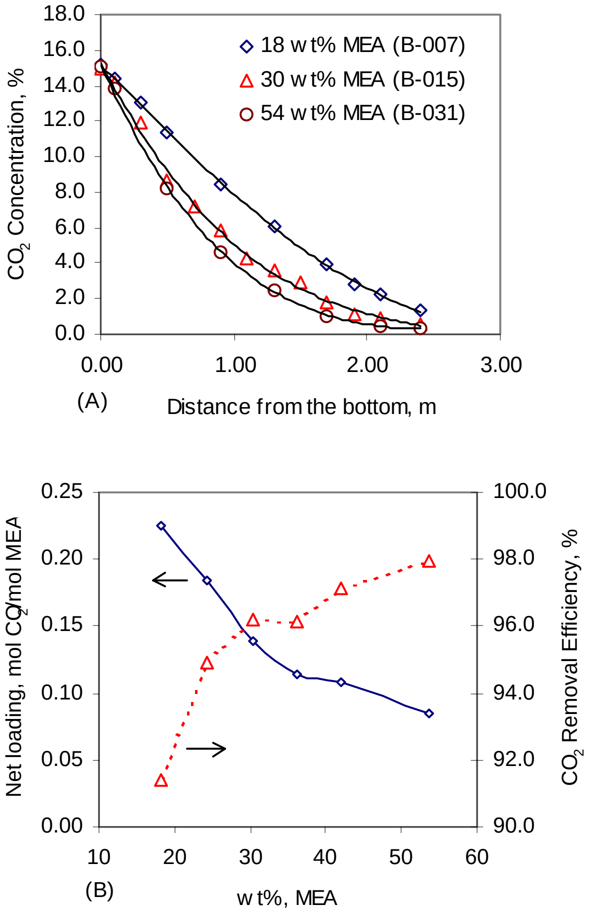


Figure. 1 Effect of absorbent concentration within the range of 18 to 54 wt%. Runs number are: B-007, B014, B015, B-026, B-029, and B-031.

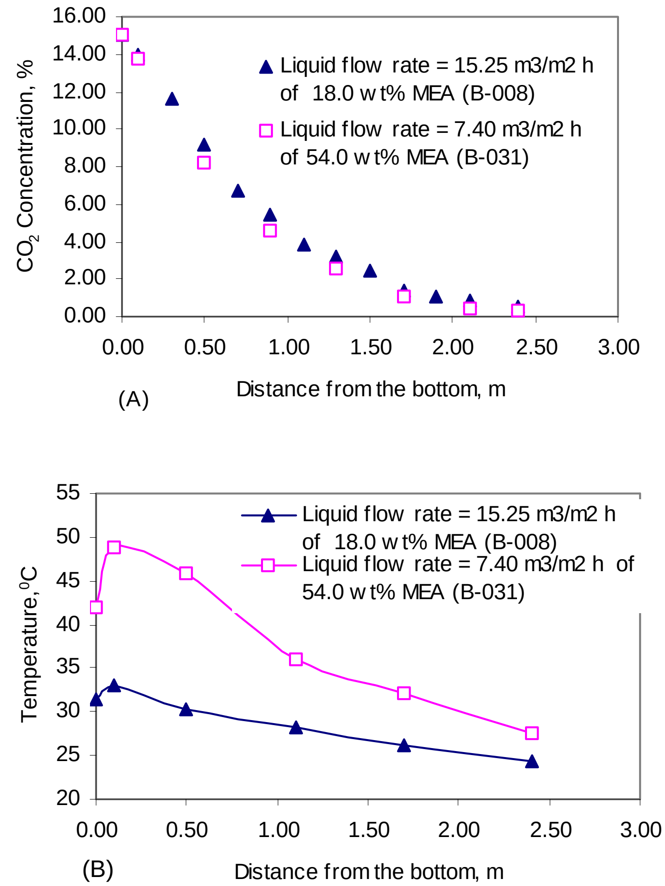


**Figure 2. The effect of absorbing the same quantity of CO2 in a smaller volume of solution on the temperature profile. Runs number: B-008 and B-031.**

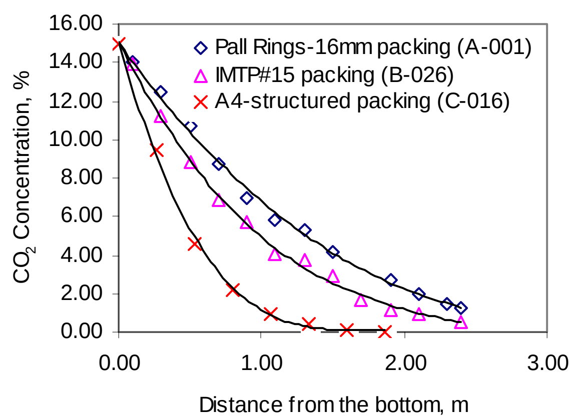


**Figure 3. Effect of packing type on the removal efficiency of CO2. Runs number: A-001, B-026, and C-016.**

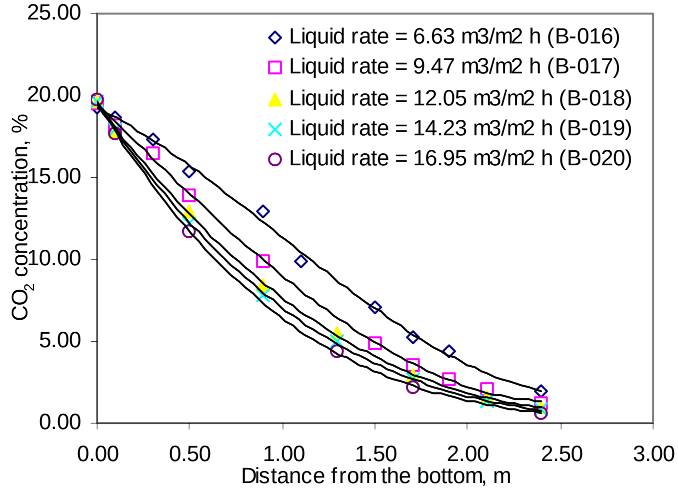


**Figure 4. Effect of liquid flow rate on CO2 absorption into MEA solutions.**

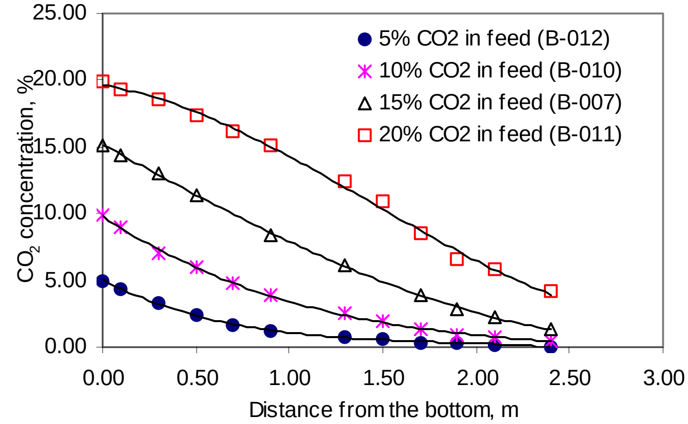


**Figure 6. Effect of gas $CO_2$ concentration on the absorption rate.**

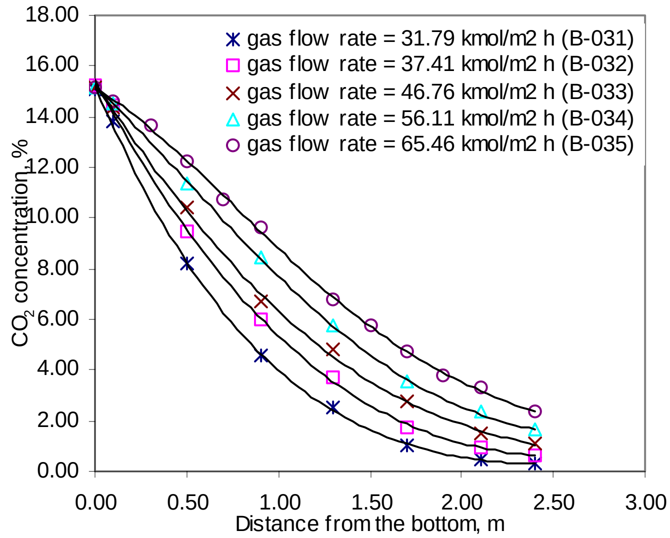


**Figure 5. Effect of gas flow rate on the CO2 absorption**

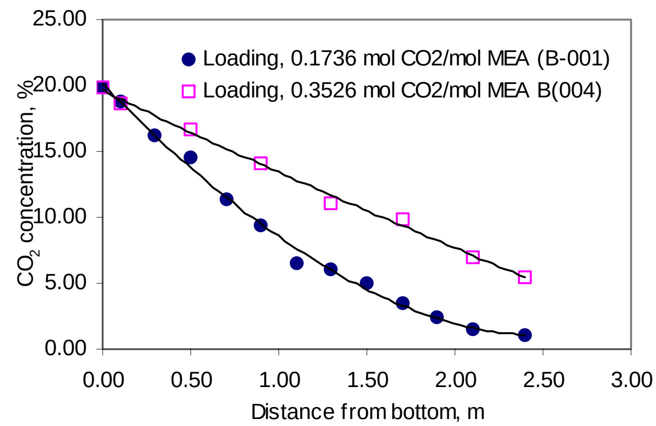


**Figure 7. Effect of CO2 loading on the absorption process**