

Absorption of Carbon Dioxide into Aqueous Solutions of Alkanolamines in a Wetted Wall Column with Film Promoter

Henry Rodriguez*, Lilian Mello, Wilson Salvagnini, José Luis de Paiva

Chemical Engineering Department, Polytechnic School, University of São Paulo
Av. Prof. Luciano Gualberto, travessa 3, 380-Cidade Universitária, CEP 05508-900
São Paulo, SP, Brazil
henry.flores@usp.br

The process for removing carbon dioxide from industrial gases can be achieved by absorption into aqueous solutions of alkanolamines. Mass transfer parameters in different alkanolamines solutions were investigated in a wetted wall column with a film promoter of thin stainless steel woven wire. The average overall volumetric mass transfer coefficient was measured at 25 °C, atmospheric pressure. The total gas flow rate at $2.8 \cdot 10^{-4}$ m³/s, with a composition of 10 % CO₂, was also measured in different liquid flow rates. The tested alkanolamines in the different experiments were monoethanolamine (MEA) and 2-amine-2-methyl-1 propanol (AMP). The absorption experiments were performed in individual alkanolamines aqueous solutions and their respective blends, aiming to combine the favorable features of individual alkanolamines while reducing the unfavorable features. The effective interfacial area of the column, a_c , was determined through the absorption of CO₂ diluted in air with an aqueous solution of NaOH, 2N, for different liquid flow rates. The results indicate that the average overall volumetric coefficients of mass transfer of the MEA and the mixture based on it are higher in relation to AMP. Moreover, this parameter is significantly affected by the behaviour of the film liquid flow rate provided by the film promoter, thus, affecting the efficiency of CO₂ removal.

1. Introduction

Over the years, the increase of the carbon dioxide concentration in the atmosphere has been identified as a major cause of global warming (McCann, 2009). Whereas CO₂ and NO_x, SO₂, and H₂S are produced in large scales by many major industries, in chemical, petrochemical and combustion processes; the removal of these gases has an important industrial and environmental role (Astarita et al., 1983)

One of the most widely employed absorbent for CO₂ removal are alkanolamines. These absorbents can be categorized into three groups: primary amines such as monoethanolamine (MEA) and diglicolamine (DGA); secondary amines, diethanolamine (DEA) and di-isopropanolamine (DIPA); and tertiary amines, methyldiethanolamine (MDEA) and triethanolamine (TEA) (Sakwattanapong et al., 2009).

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Recently, another group of alkanolamines has received great interest, the sterically hindered amines, e.g. 2-amino-2-methyl-1-propanol (AMP) because they require less energy for their regeneration. Moreover, the use of blended-alkanolamines has been gaining a great interest because of the possibility of combining the favorable features, e.g. high absorption capability, together with the unfavorable features, mainly related to thermal energy demand for regeneration (Aroonwilas and Veawab, 2004; Bougie and Iliuta, 2010).

At present, there are several technologies available for removing of gases such as absorption, adsorption, cryogenic methods and membrane separation, of which the chemical absorption is the most widely used (Kohl and Riesenfeld, 1985). In the literature, different types of gas – liquid contactors are used for studying this separation process. The CO₂ absorption tests were performed in aqueous alkanolamine solutions employing a laboratory scale wetted wall column with film promoter. This device was used originally as a falling-film evaporator to measure water evaporation rate, developed by Salvagnini and Taqueda (2004). This absorption system was evaluated by determining the main mass transfer parameters, namely the mass transfer overall volumetric coefficient, the effective area and the individual mass transfer coefficient of gas.

2. Experiment

A simplified schematic of the absorption system is shown in Figure 1.

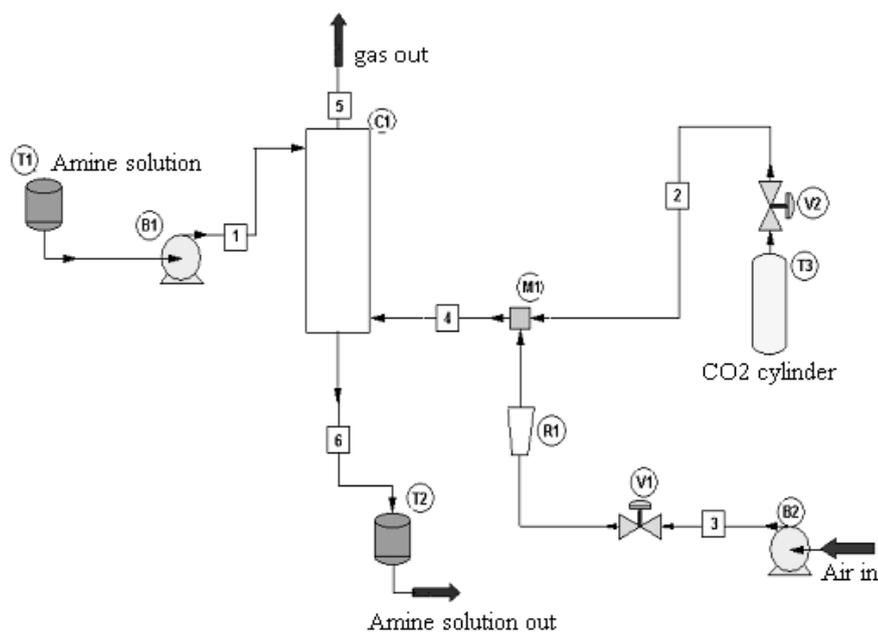


Figure 1: Schematic of the absorption system

C1, Absorption column; T1, feed tank of the amine solution; T2: receiving tank of the amine solution; T3, CO₂ cylinder; B1, peristaltic pump; B2, air compressor; M1, CO₂-air mixer; R1, rotameter for air; V1, V2, pressure regulating valve.

The absorption unit consists of two concentric glass tubes. The film promoter consisted of a metal mesh, 28 mesh, which was cut into pieces of a maximum height of 0.1 m and width equal to the circumference of the pipe. Each piece was shaped in a circular pattern and settled on the inner surface of the inner tube (i.d. 0.022 m and length 1.16 m).

The absorption column was operated countercurrent, in which tank T1 was filled with the liquid solution, and with the help of pump B1 was then pumped at a given flow rate to the column top and there was distributed through a device specifically designed to allow the overflow of the liquid. Moreover, the air flow rate was measured by flowmeter, R1, in which the pure CO₂ (> 99.9 %) was injected; the gas mixture was introduced at the bottom of the column. The temperature of the absorption column was controlled through a water bath connected to a thermostatic chamber. The absorption tests were performed in aqueous solutions of MEA, 3 M; AMP, 2 M, and their respective blend, the molar ratio of 2:1, and total concentration 3 M.

The total concentration of alkanolamine was determined by titration with standard hydrochloric acid, 1 N, using methyl orange as indicator. The content of CO₂ in liquid samples was determined by means of a double end point titration using phenolphthalein and methyl orange, respectively. More information about the operating conditions is summarized in Table 1.

Table 1: Operating conditions of the absorption test runs

Operating pressure	Atmospheric: $94 \cdot 10^3$ Pa
Operating temperature	298.15 K
CO ₂ concentration	10 % mol/mol
Liquid flow rate	$2.9 \cdot 10^{-7}$; $6.0 \cdot 10^{-7}$; $10.0 \cdot 10^{-7}$ m ³ /s
Air flow rate	$2.6 \cdot 10^{-4}$ m ³ /s

3. Results and Discussion

3.1 Mass Transfer Volumetric Coefficient of the Gas Phase – k_{GA}

The volumetric coefficient of mass transfer of the gas phase, k_{GA} , was determined by the absorption of SO₂ diluted in air (5 % mol/mol) in an aqueous solution of NaOH, 3 N. Due to the instantaneous reaction characteristic in the liquid phase, the resistance to mass transfer at this phase was considered negligible, thus the absorption process was completely controlled by the gas phase. In Figure 2, the experimental results of k_{GA} , in relation to the liquid flow rate are presented. Figure 2 shows that the parameter, k_{GA} , was significantly affected by the liquid flow rate, mainly due to increased interfacial area that is a function of the liquid flow rate.

3.2 Interfacial Area

The gas-liquid interfacial area was determined based on the chemical absorption method proposed by Danckwerts (1970) which is controlled through a liquid phase chemical reaction between CO_2 and NaOH , regarded as an irreversible reaction, rapid regime and pseudo-first order, being independent of the liquid phase hydrodynamic. The results of the interfacial area are shown in Figure 2.

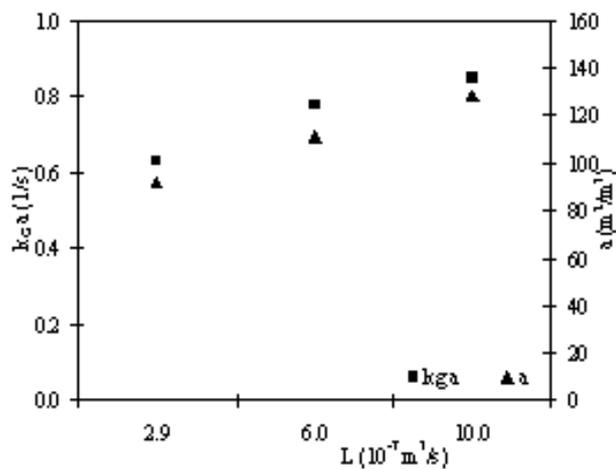


Figure 2: Effect of liquid flow rate on the interfacial area and the mass transfer coefficient of the gas phase

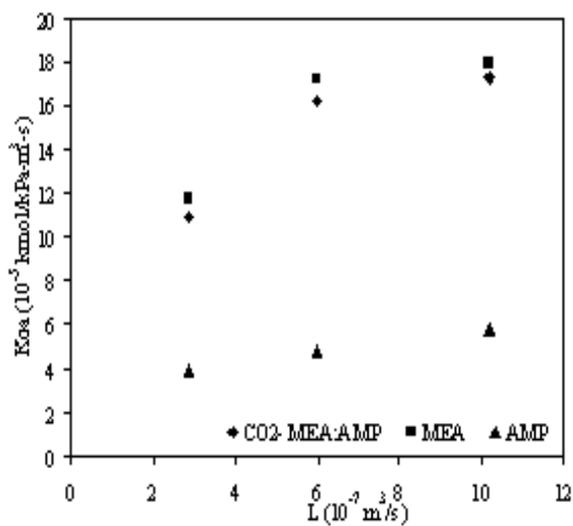


Figure 3: Effect of liquid flow on the average mass transfer volumetric coefficient

According to Figure 2, the values obtained for the effective interfacial area are: 92, 112, and 128 m^2/m^3 , being lower than the geometric area of the column, 182 m^2/m^3 . The results suggest that there is a strong correlation between the liquid flow rate and effective interfacial area. Moreover, it is inferred that by increasing the liquid flow rate, the steel wire mesh has higher irrigation, and thus a larger contact area available for mass transfer.

3.3 Absorption in Alkanolamines

In this study, the absorption experiments were performed in three different systems: CO_2 -MEA; CO_2 -AMP, and CO_2 -MEA: AMP. The experimental results of absorption performance are presented in function of the average mass transfer overall volumetric coefficient, K_{Ga} . This parameter is reported as a function of operating conditions of the process including: type of the absorbent and liquid flow rate.

According to Figure 3, the experimental results of the K_{Ga} , indicated a significant increase in function of liquid flow rate; this interference could be associated with an increase in interfacial area, which is a function of the liquid flow rate as shown in Figure 1. Moreover, according to results reported in the literature (Alper, 1990; Chakraborty et al., 1986; Choi et al., 2009) the reaction between CO_2 and amines: MEA and AMP are considered in rapid regime, irreversible reaction, and in this condition the enhancement factor is equal to the number of Hatta, which is a function of absorbent concentration, and therefore directly proportional to parameter K_{Ga} . Therefore, this parameter is affected by the performance of amine concentration along the column. Thus it can be observed that the liquid phase is the major factor for controlling the absorption process in these systems studied, under the performed experimental conditions.

4. Conclusions

The experimental results indicate that the interfacial area is significantly influenced by the liquid flow rate in the range studied.

The results of the overall mass transfer volumetric coefficient indicate that this parameter is a function of the liquid flow rate; this interference could be associated with the increase in the interfacial area.

With regard to the individual amine systems, the monoethanolamine was observed to have a best CO_2 absorption rate in relation to 2-amino-2-methyl-1-propanol.

Moreover, the MEA:AMP system had a higher absorption rate than the AMP individual system, probably due to a synergistic effect between the MEA and AMP, for the experimental conditions that were developed in the different tests.

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