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Comparative Study about Heat Transfer during the CO_2 Absorption in Alkanolamines

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This research analyses the absorption process of carbon dioxide in aqueous solutions of diethanolamine, with focus on the thermal effects related to the process. Absorption experiments were performed at room temperature, in two bubble columns (methacrylate and steel) operating in batches with respect to the liquid phase. The variables considered were the amine concentration within the range of 0.5-2.0 M, and the gas flow-rate. The temperature inside the column was measured using thermocouples and the superficial temperature was measured by an infrared camera. From the results, it is deduced that the process takes place in a non isothermal regime, and infrared thermography demonstrated being an useful and reliable tool for research in this area.

1. Introduction

Interest in the recovery of CO_2 from flue gas has been growing in the last decade. As a result, the technologies of CO_2 capture are priority to world scale. These technologies are developed mainly in a post-combustion stage. For the carbon dioxide removal, the absorption into alkanolamines continues being the most used technique in the industry. In this sense, monoethanolamine (MEA) and diethanolamine (DEA) are the most common amines used, although the utilization of tertiary amines is rising. Also some efforts have been made in the absorption process using Ammonia as the liquid phase (González et al., 2009). One of the most important considerations involved in the design of gas-absorption columns, is to determine if temperature varies or not along the length of the column because of heat effects. In the CO_2 removal by absorption in alkanolamines, several authors (Verma, 2002; Dhotre et al., 2005; Deckwer, 1980) have concluded that, at reduced partial pressures, the thermal effects can be considered negligible and can be disregarded. Nevertheless, if the absorption is carried out at high partial pressures of CO_2, these effects appear to be considerable (Camacho et al., 2000). It will therefore be useful to study the heat transfer in these systems, where the chemical reaction is associated to heat transfer.
Taking this into account, in this research the absorption process of carbon dioxide in aqueous solutions of DEA was studied focusing on the thermal effects related to the process. The absorption experiments were performed in two bubble columns operating in batches respect to the liquid phase. The variables considered were the amine concentration within the range of 0.5-2.0 M, and the gas flow-rate. The temperature data

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were registered in two different ways: collected using direct contact thermocouples and monitored with a non direct contact infrared camera.

2. Experimental Section

2.1 Gas-liquid contact device

A bubble column has been selected as the gas-liquid contact device for the absorption study at the laboratory, operating at room temperature. Two different columns (Figure 1) were designed (different in both dimensions and constructive material), to compare the results obtained. The first column was built in methacrylate 0.3 cm thick, 60 cm height and square-cross section 6 cm side (volume 2.16 l). Methacrylate is an insulating material (thermal conductivity 0.19 $W \cdot m^{-1} \cdot K^{-1}$). The second column was built in stainless steel 0.2 cm thick, 100 cm height and square-cross section 6 cm side (volume 4.20 l). Steel is a good heat conductor (thermal conductivity 45 $W \cdot m^{-1} \cdot K^{-1}$). A scheme diagram of the experimental set-up is showed in Figure 2. Experiments in the methacrylate column showed that a higher column will be needed to let the gas flow regime achieve an acceptable working regime.

2.2 Temperature Data Acquisition

The collection of temperature values was performed in two ways: a direct contact way (thermocouples) and an indirect contact way (infrared thermography).
Eight type K thermocouples (high resistance to corrosion, application range from 223 K to 483 K) were settled in both columns for getting temperature measurements within the liquid phase. Each side of the column was fitted with a thermocouple in turn, so that the 8 thermocouples were distributed throughout the system (2 on each side). The thermocouples were connected to a data acquisition device, sending the measurements to a computer. In the methacrylate column the layout of the thermocouples was as follows: the first was located over the base at 12 cm height, with a separation between thermocouples about 6 cm in the axial direction. The penetration depths of each thermocouple range from 1 to 5 cm taking as reference one of the sides of the column. In the steel column the layout is similar: the first was located 10 cm over the base, and the separation between thermocouples was 10 cm in the axial direction. The penetration depths of each thermocouple range from 1 to 5 cm.
Infrared thermography is a technique for non-destructive testing (Maldague, 2001). This technique allows measuring the infrared radiation emitted from the outer surface of the bubble column. So this thermal radiation is turned into thermal maps in real time, which could be used for monitoring the CO_2 absorption process with amines. Each experience was monitored using FLIR ThermaCAM E300, obtaining thermograms minute by minute from the beginning of each process and analyzing them with Flir ThermaCAM Reporter software. The outer superficial temperature over the stainless steel column was measured using Scotch 33 electrical tape with a known emissivity of 0.97 (Voilt, 2003).

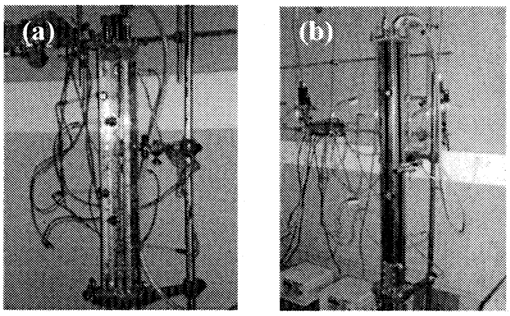

Figure 1: Photographs of both bubble columns: methacrylate (a) and stainless steel (b).

Through the thermograms the different superficial thermal gradients can be studied, due to the high thermal sensibility of these cameras. The use of infrared thermography provides a real knowledge of the reaction progress without interfering on it.

2.3 Gas circuit

The gas used in the absorption process is pure CO_2 from a bottle with pressure regulators. Gas is passed through a humidifier containing water inside in order to humidify it at the working temperature and prevent possible humidification within the column. Then the CO_2 is circulated through a flow meter connected to a flow controller Brooks 0154, allowing the operation flow being set to the desired value. The CO_2 enters the column through its base by a diffuser plate with three holes of 4 mm diameter each. The gas leaves the column through a hole on the top, measuring the outflow with a bubblemeter and eliminating it directly to the atmosphere.

2.4 Liquid phase

Aqueous diethanolamine (DEA) solutions in different concentrations (0.5 M, 1 M and 2 M) have been used as the liquid phase of the absorption process.

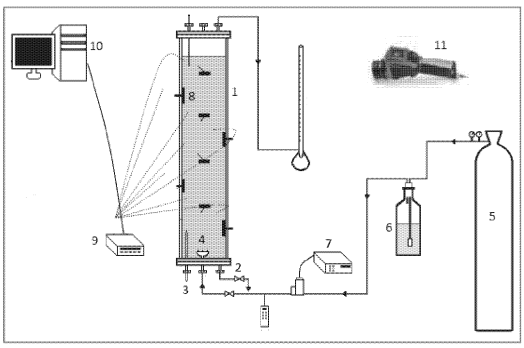

Figure 2: Scheme diagram of the experimental set-up: 1. Bubble column; 2. Liquid inflow; 3. Thermometer; 4. Porous plate; 5. Pressurized CO_2 source; 6. Humidifier; 7. Mass flow controller; 8. Type K thermocouples; 9. Data-acquisition equipment; 10. Computer; 11. IRT Camera.

3. Results and Discussions

In function of the carried out experiments with both columns (methacrylate and steel) is deduced that the absorption takes place in a non isothermal regime. In all the studied gas-liquid systems, for a certain gas flow-rate and concentration of amine, the temperature varied along time and along the column height (Figure 3).

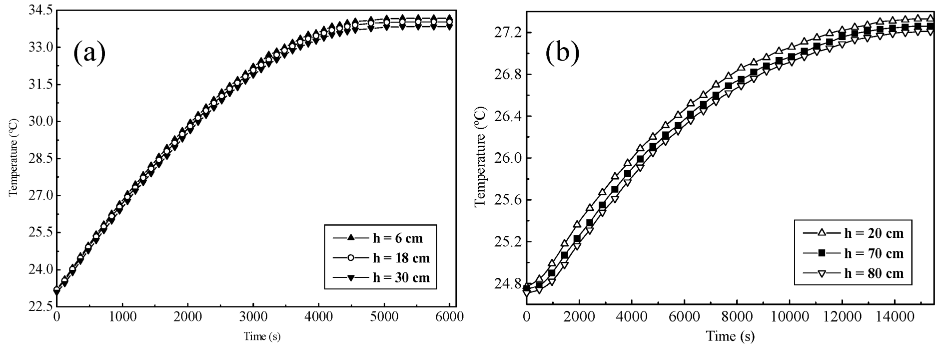

Figure 3: Time dependence of the temperature at different heights of the column for a [DEA]=2.0 M: (a) methacrylate; (b) steel.

This behavior is more relevant at high amine concentrations, in the methacrylate column (Figure 4), but in the steel column the temperature drop is constant for the different amine concentrations (Table 1). Note that in the methacrylate column the temperature values are almost the same independently of the height.

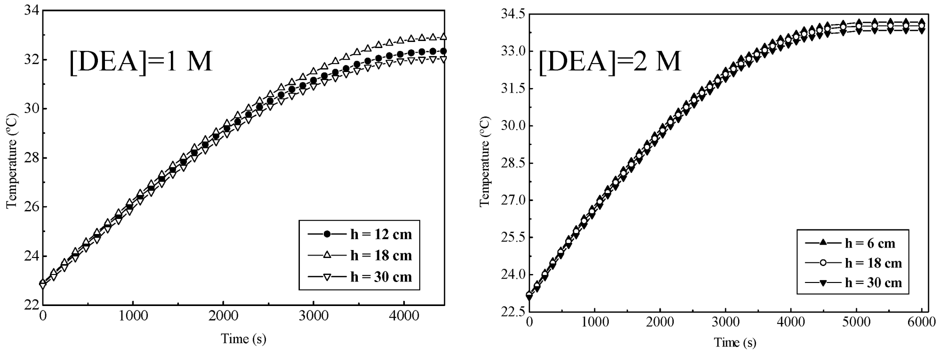

Figure 4: Time dependence of the temperature at different amine concentrations.

On the other hand, in the methacrylate column it was deduced (Tamajón, 2009) that the inner temperature is always higher than the outer surface temperature, and the temperature drop is higher when the measurement point is farther to the wall. This behavior is similar for all the studied systems. In the steel column the outer surface temperature is also lower than the inner temperature inside the column, as shown in the thermal images (Figure 5) from the initial time to the end of the exothermal reaction. Therefore both columns have a similar behavior (Tables 1 and 2).

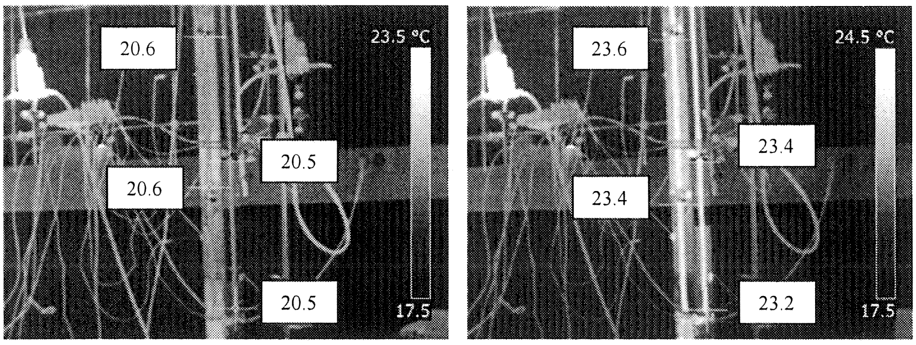

Figure 5: Thermograms with initial and final temperatures over the surface of the steel column, [DEA] = 0.5 M.

Table 1: Temperature data by thermocouple measuring (inner temperature)

	Methacrylate column			Stainless steel column		
[DEA] (mol · l^{-1})	t_0 (°C)	t_{max} (°C)	Δt (°C)	t_0 (°C)	t_{max} (°C)	Δt (°C)
0.5 M	22.97	26.42	3.45	20.51	23.81	3.30
1.0 M	19.41	26.13	6.72	21.06	23.66	2.60
2.0 M	18.90	29.78	10.88	24.75	27.25	2.50

Table 2: Temperature data by thermal image analysis (outer temperature)

	Methacrylate column			Stainless steel column		
[DEA] (mol · l^{-1})	t_0 (°C)	t_{max} (°C)	Δt (°C)	t_0 (°C)	t_{max} (°C)	Δt (°C)
0.5 M	22.80	26.10	3.30	20.51	23.51	3.00
1.0 M	19.45	25.70	6.25	21.00	23.65	2.65
2.0 M	19.15	29.20	10.05	24.60	27.05	2.45

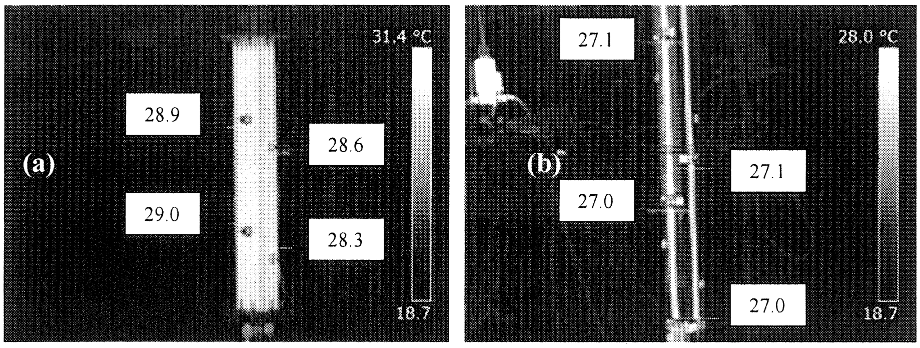

Figure 6: Comparative of two thermograms of both columns (a, methacrylate; b, steel) with final temperatures over the surface of the column, [DEA] = 2.0 M.

Finally, a comparative about two thermograms from both bubble columns is showed in Figure 6. Despite the initial temperature in the methacrylate column is lower (Table 2), it was checked that the temperature variation has been higher in this case due to the thermal conductivity of the steel, higher than the methacrylate conductivity. Therefore the amount of heat lost through the wall is higher in the steel column.

4. Conclusions

A comparative study about heat transfer in both columns has been made. From the results obtained it is deduced that the absorption takes place in a non isothermal regime. In all the studied gas-liquid systems, for a certain gas flow-rate and concentration of amine, the temperature varies along time, radial distance and along the column height. On the other hand, due to the methacrylate low thermal conductivity, the heat conduction through the wall can be disregarded in the first column; however it is a relevant parameter in the steel column. The infrared thermography allows us to obtain outer surface temperatures that describe a similar variation to the registered by thermocouples.

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