

Carbon dioxide absorption in non Newtonian fluids using a bubble contactor

Diego Gómez-Díaz, José M. Navaza, L. C. Quintáns-Riveiro, B. Sanjurjo
Department of Chemical Engineering, University of Santiago de Compostela.
c/ Lope Gómez de Marzoa s/n. E-15782. Santiago de Compostela. A Coruña. Spain.

Gas-liquid mass transfer has been investigated in a bubble column using non-Newtonian media and pure carbon dioxide as absorbent and gas phase, respectively. The volumetric mass transfer coefficient has been measured under different operational conditions for the gas/liquid system analysed in this work. The non-Newtonian media used were in all cases aqueous solutions of κ -carrageenan. The influence of rheological properties, polymer concentration and gas flow-rate upon the mass transfer rate has been studied.

Keywords: absorption, non-Newtonian, carbon dioxide.

1. Introduction

Bubble reactors (columns and stirred vessels) have a wide range of applications in the chemical, biochemical and pharmaceutical industries (Lee and Tsui, 1999) due to the effective contact of a gas with a liquid to carry out chemical or biochemical reactions. The transfer of gas into a liquid is often the rate-limiting step. Most of the liquid phases employed in these processes are non-Newtonian fluids, as in the food industries, for instance. Several studies (Vlaev et al, 1994; Miura and Kawase, 1997) have analysed the effect caused by the presence of different polymers on the absorbent phase.

The behaviour of these non-Newtonian liquids is studied on the basis of the apparent viscosity variations. Some studies proved the important effect upon the mass transfer caused by the apparent viscosity of the liquid phase (Jiao et al, 1998; Álvarez et al, 2000). For this reason, it is necessary to include the rheological behaviour in a serious study concerning the modelling of the absorption process. A variation on the stirring rate and/or the gas flow-rate could also produce a change in the physical properties of the absorbent phase, since the viscosity of the non-Newtonian liquid is a shear rate dependent (Metzner and Otto, 1957; Nakanoh and Yoshida, 1980).

Parameters of gas/liquid contactors such as mass and heat transfer coefficients are usually correlated in relation to viscosity by means of using the apparent viscosity (Álvarez et al, 2000). The local shear rate in such systems cannot be calculated. Therefore, it is necessary to use an effective shear rate with a corresponding effective viscosity. These liquids (polymers aqueous solutions) are usually shear thinning and they have rheological properties similar to real industrial media, like fermentation broths and liquid suspensions of small particles.

2. Materials and Methods

The aqueous solution employed as liquid absorbent phase has been produced using different quantities of κ -carrageenan supplied by Fluka (CAS number 11114-20-8). The solutions were prepared by mass using a balance with a precision of $\pm 10^{-7}$ kg. Bi-distilled water has been employed to prepare the absorbent phases.

Rheological studies were performed using an Anton Paar DV-1P digital thermostated rotational viscosimeter based in two coaxial cylinders. The polymer concentrations employed in the present study have been included, for polymer aqueous solutions, in a range of 0 - 10 g·L⁻¹.

The studies of carbon dioxide mass transfer to liquid phases were carried out using the experimental set-up and methodologies employed by our team (Gómez-Díaz et al, 2006) in previous works related to absorption processes. The gas/liquid contactor used in these studies has been a cylindrical bubble column (internal diameter = 7 cm; height = 100 cm), made of methacrylate with a volume of 2.4 litres.

3. Results and Discussion

The polymer solutions employed in present work show shear thinning behaviour that corresponds to a non-Newtonian and pseudoplastic fluid (see figure 1). The viscosity decreases when the shear rate increases, and the same behaviour is observed in all solutions. The experimental data were fitted to Ostwald's law and suitable fits have been obtained and the experimental results show that the behaviour index, n , for κ -carrageenan aqueous dispersions, has values minor than 1. Therefore, we can confirm that these solutions show a pseudoplastic behaviour.

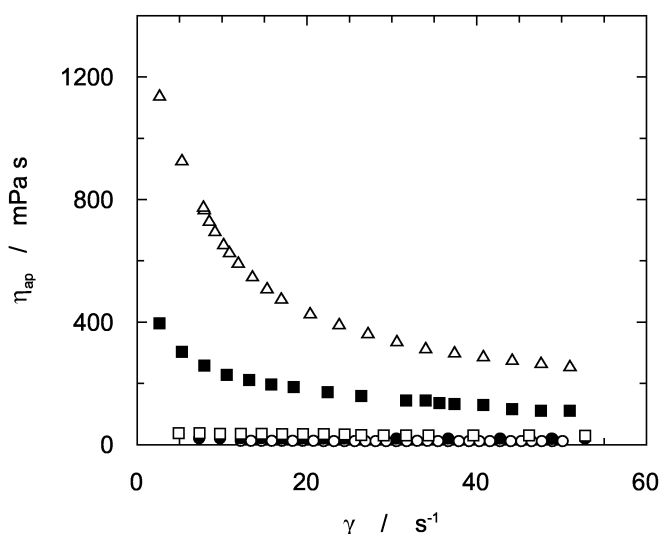


Figure 1. Influence of polymer concentration upon the rheological behaviour. (○) 2 g·L⁻¹, (●) 4 g·L⁻¹, (□) 6 g·L⁻¹, (■) 8 g·L⁻¹, (△) 10 g·L⁻¹.

Since different studies have proved the influence of physical properties upon the mass transfer processes, more specifically upon the viscosity, it is necessary to improve the understanding of the absorption process, which must be analysed considering the viscosity of the liquid phase present in the vessel. The viscosity value depends significantly on the shear rate and then, in the bubble column, the shear rate and viscosity must be calculated for each experimental conditions.

The procedure to determine the volumetric mass transfer coefficient is based on the measurements of the amount of gas absorbed per unit time and per unit of liquid phase according to equation 1.

$$\frac{dC}{dt} = K_L \cdot a \cdot (C^* - C) \quad (1)$$

where C^* is the interfacial concentration of gas at equilibrium (i.e. the solubility of the gas in the liquid phase) and C (the concentration of gas in the bulk liquid) is calculated from the experimental absorption rate data.

In relation to the influence produced by the presence of different quantities of polymer in the liquid phase, figure 2 shows that an increase in the polymer concentration produces a decrease in the volumetric mass transfer coefficient. Similar results have been obtained in previous studies by our team and by other researchers (Gómez-Díaz and Navaza, 2004; Tecante and Choplin, 1993) employing different systems formed by aqueous solutions of polymers.

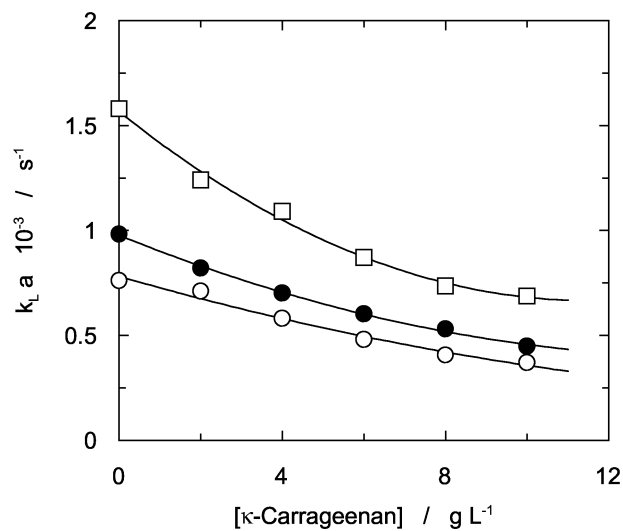


Figure 2. Influence of polymer concentration and gas flow-rate upon the volumetric mass transfer coefficient. (○) 18 L·h⁻¹; (●) 24 L·h⁻¹; (□) 30 L·h⁻¹.

Two opposite effects or mechanisms have been described in literature for falling films systems when polymer solutions are present and these effects act simultaneously. The slip effects produce an augmentation in the absorption rate, whereas the influence of elasticity on the mass transfer processes produces a reduction in the absorption rate. According to Mashelkar (1984), the overall effect seems to be the reduction on the mass transfer rate. In our present work, the elasticity effect is more important and a clear reduction in mass transfer rate is observed, due to the kind of contactor employed.

In relation to the effect of the gas flow-rate upon the value of the volumetric mass transfer coefficient, figure 2 also shows the behaviour observed for this system. An increase in the value of the gas flow-rate also produces an increase on the mass transfer rate. This figure shows that this increase is observed for all the experimental conditions analysed in the present work. At the same time, the previously observed influence of viscosity (related to the polymer concentration in the liquid phases) upon the volumetric mass transfer coefficient in figure 2 is corroborated with the values obtained for the mass transfer coefficient at different gas flow-rates. Figure 3 shows a complete vision of the influence of polymer concentration and gas flow-rate upon the volumetric mass transfer coefficient. The increment of both variables produces opposite effects: positive for gas flow-rate and negative for polymer concentration.

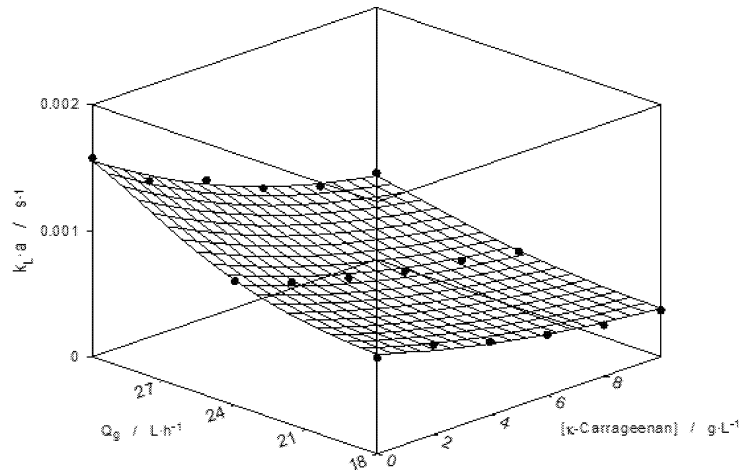


Figure 3. Effect of polymer concentration and gas flow-rate upon the volumetric mass transfer coefficient.

References

- Lee, S. Y. and Y. P. Tsui, 1999, *Chem. Eng. Prog.* 23.
- Vlaev, S. D., M. Valev and R. Popov, 1994, *J. Chem. Eng. Japan* 27, 723.
- Miura, H. and Y. Kawase, 1997, *Chem. Eng. Sci.* 52, 4095.
- Jiao, Z., Z. Xueqing and Y. Juntag, 1998, *Biotechnol. Tech.* 12, 729.
- Álvarez, E., B. Sanjurjo, A. Cancela and J. M. Navaza, 2000, *Chem. Eng. Res. Des.* 78, 889
- Metzner, A. B. and R. E. Otto, 1957, *AIChE J.* 3; 3.
- Nakanoh, M. and Y. Fumitake, 1980, *Ind. Eng. Chem. Res.* 19, 190.
- Alvarez, E., J. M. Correa, C. Riverol and J. M. Navaza, 2000, *Int. Commun. Heat Mass. Transfer* 27, 93.
- Tecante, A. and L. Choplin, 1993, *Can. J. Chem. Eng.* 71, 859.
- Gómez-Díaz, D. and J. M. Navaza, 2004, *J. Chem. Technol. Biotechnol.* 79, 1105.
- Mashelkar, R.A., 1984, *AIChE J.* 30, 353.

