Gas Holdup and Volumetric Mass Transfer Coefficient in Bubble Columns with Dilute Alcohol Solutions

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Applications of bubble columns in different fields of chemical industry and in diverse gas-liquid systems has shown that their behavior often depends very strongly on the nature of the liquid phase. The liquid phase in bioreactions and in coal liquefaction, which are important areas of bubble column use, can be simulated fairly well with dilute alcohol solutions (Schügerl et al., 1977). However, the literature offers a limited quantity of the information on this subject. Schügerl et al. investigated gas holdup in these systems for relatively low superficial gas velocities. They proposed an empirical correlation for the prediction of gas holdup. Oels et al. (1978) observed a significant increase of gas holdup in alcohol solutions, which is in accordance with the results of Schügerl and his coworkers. Higher gas holdup in alcohol solutions was also observed by Hikita et al. (1980). Kelkar et al. (1983) investigated the effect of the addition of aliphatic alcohols on gas holdup and noted an increase of the gas holdup with an increase of alcohol chain length. As the decrease of surface tension in the presence of alcohols was not sufficient to explain the increase of the gas holdup, they supposed that in the presence of alcohols the bubbles become more rigid and hence have low rise velocities, resulting in a bubble flow regime up to the superficial gas velocities of 0.08–0.10 m/s.

As for gas holdup, the literature provides a very limited amount of data for the volumetric mass transfer coefficient (k_La) in dilute alcohol solutions. Schügerl et al. (1977), Oels et al. (1978), and Voigt and Schügerl (1979) measured the mass transfer coefficient in aqueous alcohol solutions. The effect of addition of alcohols on k_La was explained by means of coalescence promoting and hindering properties of the liquid medium. These authors did not propose any correlation for prediction of k_La.

Experimental

Experiments were carried out in a glass bubble column of 0.10 m ID and 2.50 m tall, with a single sparger of 4 mm ID. Air was always used as a gas phase, and for the liquid phase solutions of water and various alcohols were used: methanol, ethanol, *i*-propanol, and *n*-butanol. The concentration of all solutions was 0.5%; for methanol and butanol, 1% aqueous solutions were also used. Gas holdup was measured by the simple hydrostatic head method. The concentration of dissolved oxygen was measured by oxygen electrode. All experiments were carried out at room temperature, 23°C ± 2°.

Results and Discussion

Experimental results for gas holdup, ϵ_g, are shown in Figure 1. ϵ_g increases with the increase of gas superficial velocity and depends significantly on the type of alcohol added. The gas holdup increases in the order water < methanol < ethanol < *i*-propanol < *n*-butanol, which is in agreement with the observations of other authors (Schügerl et al., Oels et al., Kelkar et al.). We obtained lower values of ϵ_g than these authors, which can be explained by the use of a less efficient gas sparger in our column. By comparison of their own experimental data with various existing correlations for the prediction of gas holdup, Kelkar et al. showed that none can be used successfully for prediction of ϵ_g in dilute alcohol solutions. Considering the equation of Schügerl et al. to be inconvenient since it involves the bubble diameter, a quantity that is more difficult to measure than the gas holdup itself, Kelkar et al. correlated their results by empirical correlation comprising superficial gas velocity and number of carbon atoms in the straight chain. They found that the influence of the alcohol concentration, i.e., the surface tension, is negligible and hence it was not included in their correlation.

Our results, shown in Figure 2, suggest that the concentration of alcohol has a definite effect on the gas holdup. We correlated our data by means of the relatively simple correlation of Hughmark (1967), which involves liquid density *and surface tension;* it is by these properties that the effect of alcohol concentration is included. We extended the original Hugmark correlation by a

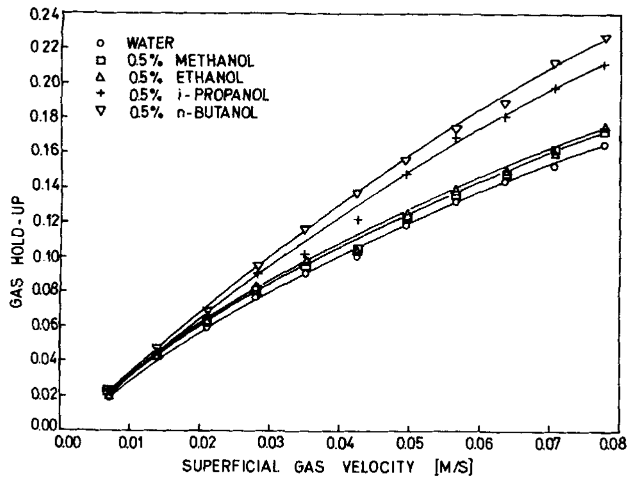

Figure 1. Effect of type of alcohol on gas holdup.

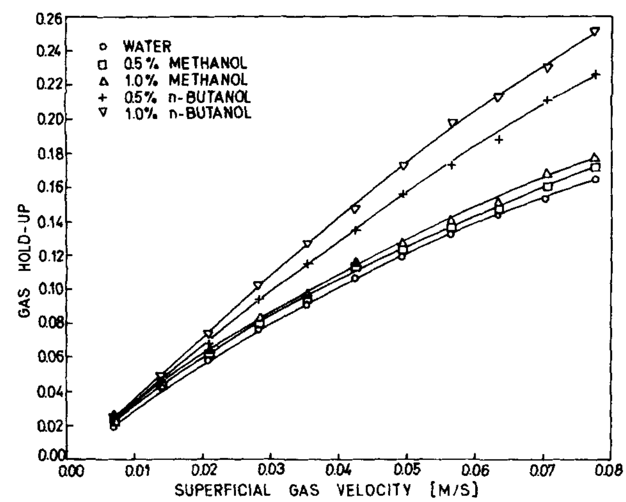

Figure 2. Effect of concentration of alcohol solution on gas holdup.

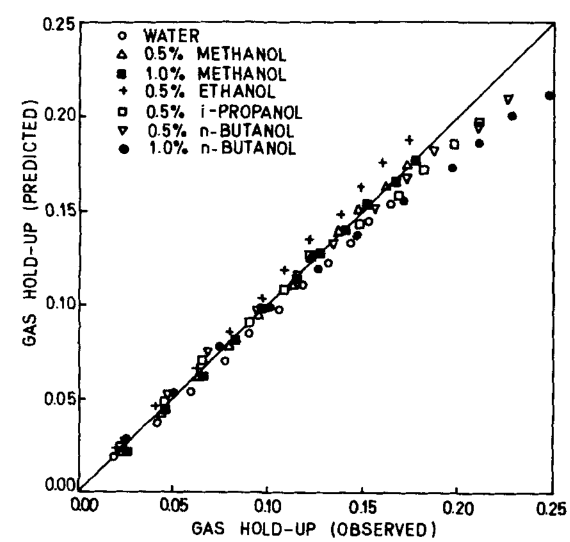

Figure 3. Comparison of calculated and observed ϵ_G values.

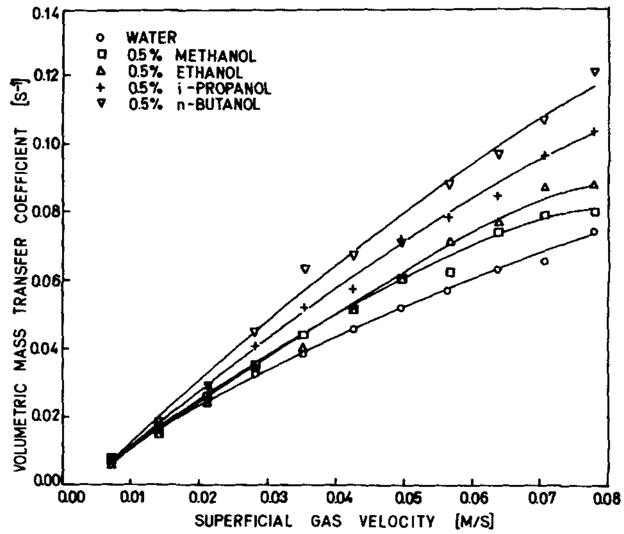

Figure 4. Effect of type of alcohol on volumetric mass transfer coefficient.

term that comprises the number of carbon atoms in the straight chain and obtained the following equation

$$\epsilon_g = \frac{1}{2 + \dfrac{0.35}{U_g}\left(\dfrac{\rho_L}{1,000}\cdot\dfrac{\sigma}{0.072}\right)^{1/3}} \cdot (1 + C_N)^{0.167} \qquad (1)$$

This equation enables the estimation of the gas holdup in bubble columns with dilute alcohol solutions; terms are defined in the Notation. The proposed equation correlates our experimental data with an average error of ±5.4%, Figure 3. It should be noted that in a boundary case, when $C_N = 0$, this correlation becomes the original Hughmark equation.

The experimental results shown in Figures 4 and 5 show that the addition of alcohols has the same effect on the volumetric mass transfer coefficient as on the gas holdup, i.e. the increase in the number of C atoms in the straight chain and the concentra-

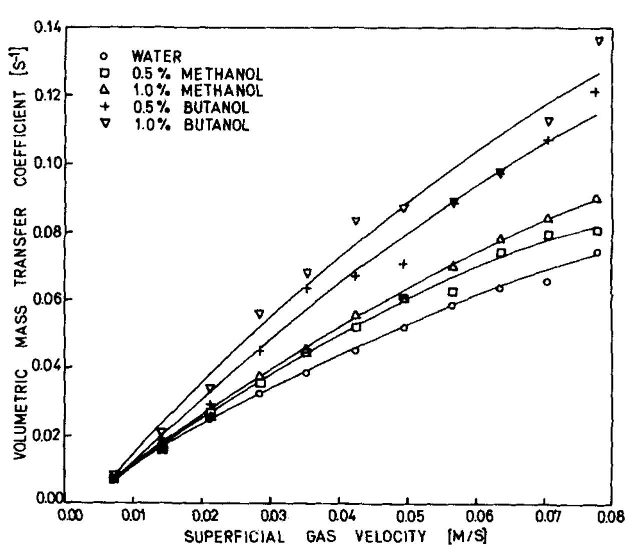

Figure 5. Effect of concentration of alcohol solution on volumetric mass transfer coefficient.

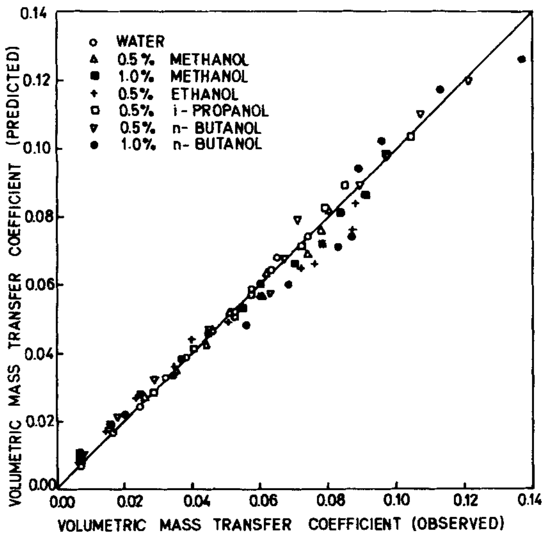

Figure 6. Comparison of calculated and observed k_La values.

tion of alcohols causes an increase of k_La. The observed behavior is in accordance with the findings of Schügerl et al., Oels et al., and Voigt and Schügerl. The difference in the measured values of k_La can be explained by the difference in the type of gas sparger used. These authors did not propose any correlation for their experimental results. Experimental data for the volumetric mass transfer coefficient presented in this note were correlated by the corrected equation of Akita and Yoshida (1973). This equation includes all liquid physical properties and was obtained for the same type of gas sparger as that used in our column (single-hole sparger). We correlated our k_La data by the equation:

$$k_La \frac{d_c^2}{D_L} = 0.961 \cdot \epsilon_g^{1.1} \left(\frac{\nu_L}{D_L}\right)^{0.5} \left(\frac{g d_c \rho_L}{\sigma}\right)^{0.62} \left(\frac{g d_c^3}{\nu_L^2}\right)^{0.31} \qquad (2)$$

with an average error of ±8.20%, Figure 6.

The experimental results and the proposed correlations reported in this note should promote a better understanding of the behavior of bubble columns in systems with dilute aliphatic alcohol solutions.

Notation

C_N = number of carbon atoms
d_c = column diameter, m
D_L = liquid phase diffusivity, m^2/s
g = acceleration of gravity, m/s^2
k_La = volumetric mass transfer coefficient, s^{-1}
U_G = superficial gas velocity, m/s

Greek letters

ϵ_G = gas holdup
ν_L = kinematic viscosity of liquid phase, m^2/s
ρ_L = density of liquid phase, kg/m^3
σ = interfacial tension, N/m

Literature cited

Akita, K., and F. Yoshida, "Gas Holdup and Volumetric Mass Transfer Coefficient in Bubble Columns," *Ind. Eng. Chem. Process Des. Dev.*, **12,** 76 (1973).

Hikita, M., S. Asai, K. Tanigawa, K. Segawa, and M. Kitao, "Gas Holdup in Bubble Column," *Chem. Eng. J.*, **20,** 59 (1980).

Hughmark, G. A., "Holdup and Mass Transfer in Bubble Columns," *Ind. Eng. Chem. Process Des. Dev.*, **6,** 218 (1967).

Kelkar, B. G., S. P. Godbole, M. F. Honath, Y. T. Shah, N. L. Carr, and W.-D. Deckwer, "Effect of Addition of Alcohols on Gas Holdup and Backmixing in Bubble Columns," *AIChE J.*, **29,** 361 (1983).

Oels, U., J. Lücke, R. Bucholz, and K. Schügerl, "Influence of Gas Distributor Type and Composition of Liquid on the Behavior of a Bubble Column Bioreactor," *Ger. Chem. Eng.*, **1,** 115 (1978).

Schügerl, K., J. Lücke, and U. Oels, "Bubble Column Bioreactors," *Adv. Biochem. Eng.*, **7,** 1 (1977).

Voigt, J., and K. Schügerl, "Absorption of Oxygen in Countercurrent Multistage Bubble Columns. I," *Chem. Eng. Sci.*, **34,** 1221 (1979).

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