THE BULLETIN OF OKAYAMA UNIVERSITY OF SCIENCE No.37 A pp.179-182 (2001)

Gas Holdup, Gas-Liquid Interfacial Area and Mass Transfer in an External-Loop Airlift Bubble Column with a Porous Plate

Toshiro MIYAHARA, Toshiyuki UMEDA and Yasuharu AKAGI

Department of Applied Chemistry,
Faculty of Engineering
Okayama University of Science,
Ridaicho 1-1, Okayama 700-0005, Japan

(Received November 1, 2001)

Key Words: Gas Holdup, Gas-Liquid Interfacial Area, Mass Transfer, Airlift Bubble Column, Porous Plate

The effect of porous plate geometry on gas holdup, gas-liquid interfacial area and mass transfer in an external-loop airlift bubble column was experimentally examined using an air-water system. Gas holdup can be well correlated with the drift flux correlation, irrespective of porous plate geometry, whereas that for the porous plate is a little smaller than that for either a single hole plate or a perforated plate. The Sauter mean bubble diameter affecting the gas-liquid interfacial area is smaller than that for a perforated plate. Therefore, a correlation equation for the Sauter mean bubble diameter is proposed following the results of Okada *et al.* (1996) and Miyahara *et al.* (1999). The specific gas-liquid interfacial area is also correlated for a porous plate on the basis of the result by Miyahara *et al.* (1997), in which it was larger than that for a perforated plate. In addition, it is found that the liquid-phase volumetric mass transfer coefficient is larger than that for a perforated plate, and the correlation is modified for a porous plate based on the results of Okada *et al.* (1996) and Miyahara *et al.* (1999). Further, a modified correlation for the mass transfer coefficient for a porous plate is proposed based on the results reported by Miyahara *et al.* (1997).

Introduction

The simple construction, low power requirements and low shear characteristics of airlift reactors have led to their widespread and diverse application in the chemical and biotechnological industries (Chisti, 1989; Siegel and Robinson, 1992).

Previous investigators reported the performance of external-loop airlift reactors depended not only on operating parameters (Bello *et al.*, 1984), but also on geometric parameters (Popovic and Robinson, 1987; McManamey *et al.*, 1984). However, only a few studies on the effect of plate geometry on the characteristics of an external-loop airlift bubble column have been reported.

The aim of this paper is to examine the effect of plate geometry, especially porous plate geometry, on the characteristics of an external-loop airlift bubble column following the previous study on the effect of a single hole and a perforated plate on the characteristics of fluid flow and mass transfer presented by the authors (Miyahara *et al.*, 1999).

1. Experimental

A description of the experimental apparatus and procedure has already been presented in the previous papers (Okada *et al.*, 1996; Miyahara *et al.*, 1997, 1999). The airlift column was constructed from a transparent acrylic resin tube (I.D. 0.14 m). A porous plate was placed at the riser bottom as a gas sparger. In this study, five types of porous plates were used to study the effect of porous plate geometry on the characteristics of fluid flow and mass transfer. All of the plates examined were made of brass (5-mm thickness). Plate geometry details are shown in **Table 1**. The liquid and gas were distilled water and air, respectively.

Table 1 Geometry of porous plates

Plate	Mean hole diameter d_H [μm]	Voidage F [%]	Plate thickness T [mm]	Particle diameter d_p[μm]	Remarks
P-150	400	45	5	1000	
P-120	300	43	5	828	Porous
P-100	230	40	5	575	plate
P-70	165	38	5	461	(Brass)
P-20	90	33	5	243	

2. Results and Discussion

2.1 Gas holdup

The Zuber and Findlay (1965) drift flux model has been frequently used to predict the gas holdup in airlift reactors. In this model, it is assumed that the drift velocity (defined as the difference between the velocity of a bubble in the bubbly flow and the average volumetric flux density of the gas-liquid mixture) is constant, independent of the gas holdup, and is equal to the terminal rise velocity of a single bubble in an infinite medium. With these assumptions, the following equation for the gas holdup in the riser can be obtained in terms of the superficial gas velocity and superficial liquid velocity in the riser.

$$\frac{U_G}{\varepsilon_G} = C_1(U_G + U_L) + C_2 \qquad (1)$$

According to these results, we obtain the correlation shown in **Fig. 1**, which is irrespective of porous plate geometry, where C_1 is 0.99 and C_2 is 0.540. The value of C_2 is a little larger than that (C_2=0.411) obtained by Okada *et al.* (1996) and Miyahara *et al.* (1999) for perforated plates and single hole plates. This is probably due to the fact that the bubbles are smaller compared with those for a single hole plate and a perforated plate. As a comparison, the correlation of gas holdup for a perforated plate and a single hole plate (Okada *et al.*, 1996; Miyahara *et al.*, 1999) is shown as a dashed line in the same graph.

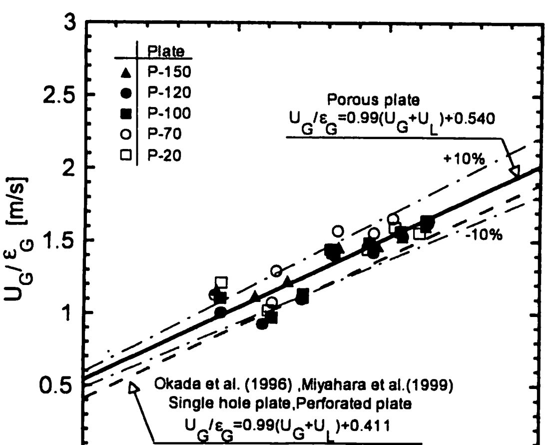

Fig. 1 Correlation of gas holdup based on the drift flux model

2.2 Gas-liquid interfacial area

Figure 2 shows the correlation of the specific gas-liquid interfacial area, a_R, for porous plate. The value a_R is obtained from the equation $a_R = 6\varepsilon_G / d_{VS}$. In Fig. 2, a_R for a porous plate is obtained using linear regression as

$$a_R = C_3 \varepsilon_G^{0.973} \sigma^{-0.766} \mu_a^{-0.192} \qquad (2)$$

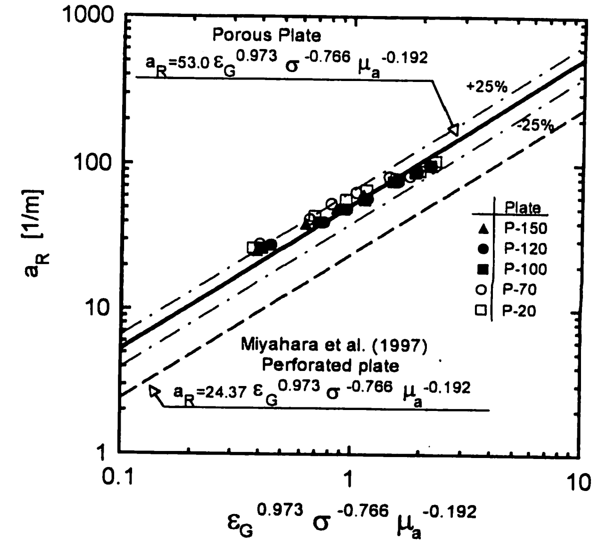

Fig. 2 Correlation of the gas-liquid interfacial area

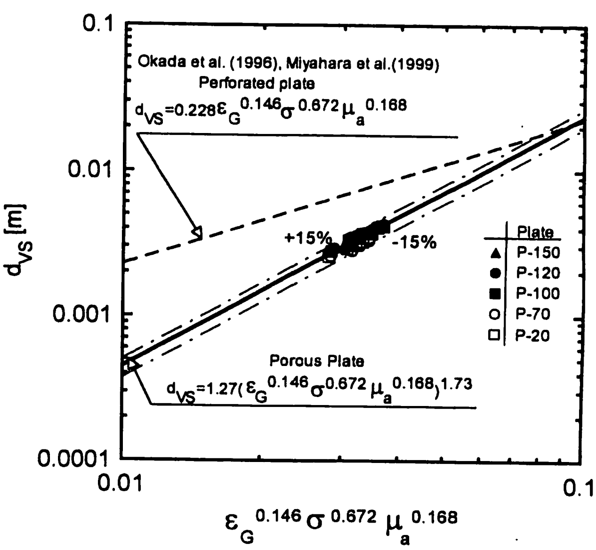

Fig. 3 Correlation of the Sauter mean bubble diameter

Where C_3 is 53.0 and $0.01 \le \varepsilon_G \le 0.1$, $0.047 \le \sigma \le 0.0724$ N/m and $0.001 \le \mu_a \le 0.047$ Pa·s. Equation (2) fits the data within an error range of about 25 %, regardless of porous plate geometry. The gas-liquid interfacial area for a porous plate is larger than that for a perforated plate (C_3=24.37) (Miyahara *et al.*, 1997), probably owing to the smaller bubbles. To confirm this fact, the Sauter mean bubble diameter was examined and the correlation is shown in **Fig. 3**, where the Sauter mean bubble diameter for a porous plate is smaller compared with that for a perforated plate (Okada *et al.*, 1996; Miyahara *et al.*, 1999). This phenomenon may be due to the smaller hole size of porous plate.

2.3 Mass transfer characteristics

Figure 4 shows the correlation of the gas-liquid volumetric mass transfer coefficient based on the results of Okada *et al.* (1996) and Miyahara *et al.* (1999). All of the data are well correlated, regardless of porous plate geometry, by the following equation.

$$k_L a_R = C_4 \left(\frac{U_G}{d_{VS}} \right)^{1.11} \quad (3)$$

Where C_4 is 1.05×10^{-3}. C_4 for a perforated plate is 1.69×10^{-3}, which is also shown in the same graph as a dashed line. Although we do not show them in this paper, $k_L a_R$ values for porous plates become larger than those for perforated plates at the same superficial gas velocity, whereas the Sauter mean bubble diameter for porous plates becomes smaller than that for perforated plates, as shown in Fig. 3, probably leading to the difference in C_4 between porous and perforated plates.

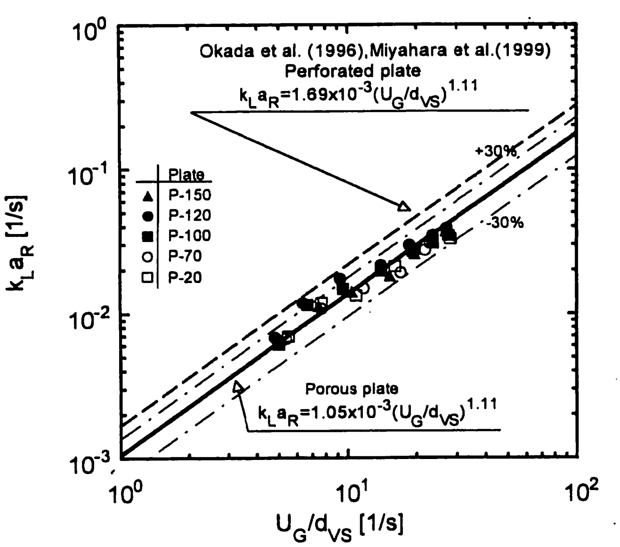

Fig. 4 Correlation of the liquid-phase volumetric mass transfer coefficient

Figure 5 shows the correlation of the Sherwood number containing the mass transfer coefficient obtained from the volumetric mass transfer coefficient and specific gas-liquid interfacial area as a function of the Scmidt number, the Reynolds number and the Morton number, and the following equation is obtained.

$$Sh / Sc^{0.5} = 2 \times 10^{-3} \left(Re \cdot M^{0.15} \right)^3 \quad (4)$$

Where, $100 \le Re \le 4000$ and

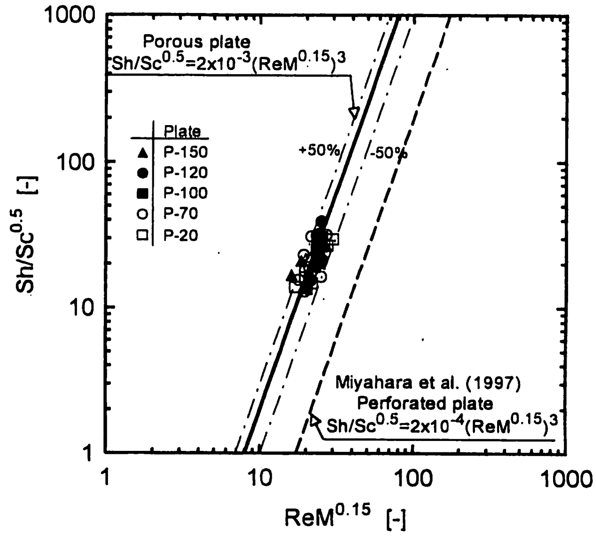

Fig. 5 Correlation of the mass transfer coefficient

$2.58 \times 10^{-11} \le M \le 7.59 \le 10^{-5}$. Equation (4) roughly expresses all of the data. The dashed line in the same graph is for a perforated plate using data previously obtained by Miyahara *et al.* (1997). From the figure, it is found that the mass transfer coefficient for a porous plate is larger compared with that for a perforated plate. This is probably due to the increase in partial pressure of the transfer component within a bubble because of the smaller bubble diameter.

Nomenclature

a_R	= specific gas-liquid interfacial area per unit dispersion volume, m^2/m^3
C_1	= constant in Eq. (1)
C_2	= constant in Eq. (1), m/s
C_3	= constant in Eq. (3), $kg^{0.958} m^{-1.192} s^{-1.74}$
D_L	= liquid-phase molecular diffusivity, m^2/s
d_H	= mean hole size of porous plate, m
d_p	= particle diameter of porous plate, m
d_{VS}	= Sauter mean bubble diameter, m
F	= voidage of porous plate
g	= gravitational acceleration, m/s^2
k_L	= liquid-phase mass transfer coefficient, m/s
$k_L a_R$	= liquid-phase volumetric mass transfer coefficient, 1/s
M	= Morton number ($=g\mu_a^4/(\rho_L \sigma^3)$)
Re	= Reynolds number ($=d_{VS} U_s \rho_L / \mu_a$)
Sc	= Scmidt number ($=\mu_a/(\rho_L D_L)$)
Sh	= Sherwood number ($=k_L d_{VS}/D_L$)
T	= plate thickness, m
U_G	= superficial gas velocity, m/s
U_L	= superficial liquid velocity, m/s
U_s	= slip velocity, m/s

ε_G = gas holdup
μ_a = apparent viscosity, Pa · s
ρ_L = density of liquid, kg/m^3
σ = surface tension, N/m

Literature cited

Bello, R. A., C. W. Robinson and M. Moo-Young; "Liquid Circulation and Mixing Characteristics of Airlift Contactors," *Can. J. Chem. Eng.*, **62**, 573-577 (1984)

Chisti, M. Y.; Airlift Bioreactors, Elsevier Applied Science, London and New York (1989)

Okada, K., Y. Nagase and Y. Akagi; "Effect of Packed Bed on Mass Transfer in External-Loop Airlift Bubble Column," *J. Chem. Eng. Japan*, **29**, 582-587 (1996)

Siegel, M. H. and C. W. Robinson; "Application of Airlift Gas-Liquid-Solid Reactors in Biotechnology," *Chem. Eng. Sci.*, **47**, 3215-3229 (1992)

Miyahara, T., H. Hamanaka, T. Takino and Y. Akagi; "Gas Holdup, Gas-Liquid Interfacial Area and Mass Transfer Coefficient in External-Loop Airlift Bubble Column Containing Low Density Particles," *J. Chem. Eng. Japan*, **30**, 958-961 (1997)

Miyahara, T., H. Hamanaka, T. Umeda and Y. Akagi; "Effect of Plate Geometry on Characteristics of Fluid Flow and Mass Transfer in External-Loop Airlift Bubble Column," *J. Chem. Eng. Japan*, **32**, 689-695 (1999)

Zuber, N. and J. A. Findlay; "Average Volumetric Concentration in Two-Phase Flow Systems," *Trans. ASME, J. Heat Transfer*, **87**, 453-468 (1965)