Influences of Suspended Fine Particles on Gas Holdup and Mass Transfer Characteristics in a Slurry Bubble Column

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Introduction

The slurry bubble column has frequently been used in industrial practices such as biochemical reaction, hydrogenation of liquid petroleum fractions, coal liquefaction, Fischer-Tropsch synthesis, and removal of air pollutants (Deckwer et al., 1974; Kara et al., 1982; Sada et al., 1983). Numerous studies have been directed toward the influence of suspended particles on the performance of slurry bubble columns. The gas holdup, which is one of the most important operating parameters in bubble dispersed contactors, has been found to decrease with increasing solid loading, particle size, or particle density. In our earlier article (Sada et al., 1984) the influences of suspended particles on the gas holdup in a slurry bubble column were quantitatively evaluated. Almost all of the existing investigations cited above have dealt with coarse particles above about 50 μm, and these particles have been found to have negligible effect on the gas holdup as long as their concentration is low.

However, the effects of fine particles smaller than 10 μm, which are very often used as catalysts or solid reactants, on the behavior of bubble dispersed contactors have not been understood yet, especially for low solid loadings. Sharma and his coworkers, for instance, observed considerable increases in gas-liquid interfacial area and volumetric mass transfer coefficient by suspending a small amount of fine particles. They concluded that such increases were caused by the bubble coalescence hindering effects of fine particles (Chandrasekaran and Sharma, 1977; Sharma and Mashelkar, 1968). Similar observations have been obtained elsewhere (Kara et al., 1982; Sada et al., 1983, 1984). In contrast to these findings, Quicker et al. (1984) recently argued that fine particles did not affect the bubble formation at all while the solid concentration was as low as 1 wt. %, and concluded that an observed increase in the volumetric mass transfer coefficient by suspending a small amount of fine activated carbon particles might be due to an increase in the liquid-side mass transfer coefficient through adsorption transportation of carbon particles.

The above contradictory conclusion may be the result of differences in the experimental systems used.

In the present work, slurries with suspended fine particles (whose size is smaller than 10 μm) of lower than 1 wt. % were used to provide an insight into the solid-bubble interaction in a bubble column. The liquid property and gas sparging system as well as the particle size were varied; the effects of these variables on the gas holdup and the volumetric liquid-side mass transfer coefficient were determined experimentally and are here discussed quantitatively.

Experimental

All of the measurements were made at 293 K and atmospheric pressure. The column, which was the same one used in the previous work (Sada et al., 1984), was made of transparent MMA resin cylinder. Its diameter and height were 7.8 and 150 cm, respectively. Two types of gas distributor were used, a perforated plate with 37 holes of 1 mm dia. and a sintered porous plate of 0.1 mm glass particles. The bubble columns were operated batchwise with respect to the slurry phase and continuously with respect to the gas phase. The height of slurry phase free of gas bubbles was 62 cm. Suspended particles were aluminium oxide ($d_p < 3$ μm, $\rho_p = 3.85$ g/cm^3), calcium hydroxide ($\bar{d}_p = 7$ μm, $\rho_p = 2.24$ g/cm^3), and calcium carbonate, which was generated by sparging carbon dioxide into aqueous calcium hydroxide saturated solution. The filtrate from aqueous slurries of calcium hydroxide was charged in the column and then carbon dioxide was introduced at a flow rate of 2 cm^3/s for 2 h. The average particle size was estimated from a microphotograph to be about

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10 μm. To prepare finer particles, the filtrate in the column was agitated by introducing nitrogen at a superficial velocity of 5 cm/s and carbon dioxide was fed at a flow rate of 2 cm³/s simultaneously for 2 hr. Flocks of fine particles of about 1 μm in average size were obtained.

Gas and liquid holdups were determined by

$$\epsilon_G = (H_T - H_L)/H_T \tag{1}$$

and

$$\epsilon_L = 1 - \epsilon_G, \tag{2}$$

respectively, where H_L and H_T refer to the liquid height free of gas bubbles and the aerated liquid height, respectively.

The volumetric mass transfer coefficient was determined by

$$k_L^o a = \epsilon_L \{d \ln (C^* - c)/dt\} \tag{3}$$

where c refers to dissolved oxygen concentration in liquid which was measured continuously by a dissolved oxygen meter (Beckman, model 123301).

Results and Discussion

Gas holdups

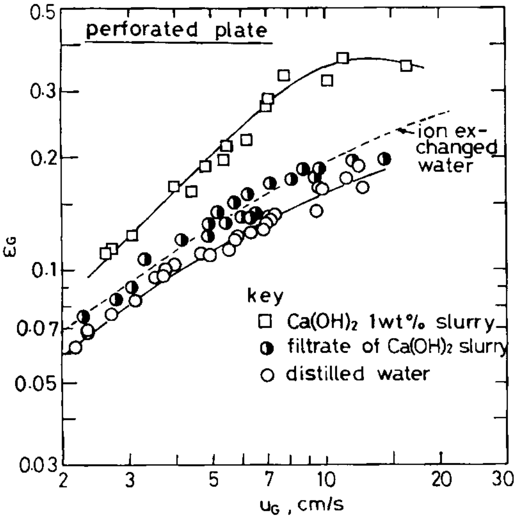

Figure 1. Gas holdups in 1 wt. % calcium hydroxide slurry, its filtrate, and distilled water.

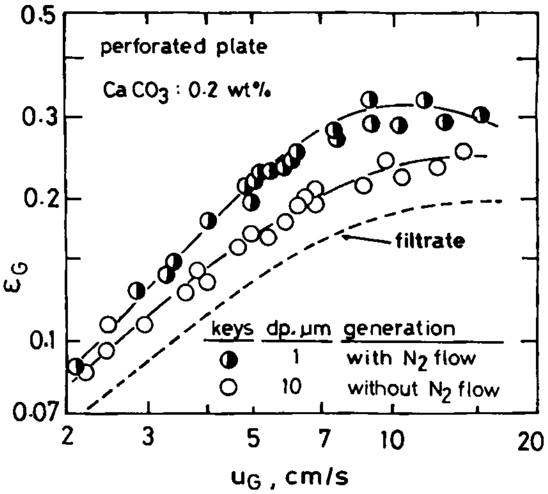

Figure 2. Gas holdups in the prepared calcium carbonate slurries.

Figure 1 shows gas holdups measured in the perforated plate equipped bubble column. The gas holdup for an aqueous calcium hydroxide saturated solution, which was prepared by filtering the calcium hydroxide slurry, was found to be higher than that for distilled water due to electrolyte in the filtrate. The only difference between the slurry of 1 wt. % calcium hydroxide and its filtrate is whether calcium hydroxide particles are present or not. Accordingly, higher values of ϵ_G for 1 wt. % slurry than those for the filtrate can be deduced to result from some function of suspended fine particles. The dotted line in Figure 1 represents the gas holdup for ion-exchanged water that was presented in the previous article (Sada et al., 1984) and is a bit increased compared with the corresponding data for distilled water. Figure 2 indicates gas holdups for aqueous slurries of prepared calcium carbonate. The gas holdups for such slurries were always higher than those for the filtrate of calcium hydroxide slurry. Besides, the slurry of finer particles gave higher gas holdups than that of larger particles. The solid concentrations in these two slurries are essentially the same and can be estimated to be 0.2 wt % from the stoichiometry of crystallization reaction. Thus, differences in the gas holdups for these two slurries may be caused by differences in particle size. Further, some experiments were performed with fine aluminium oxide particles ($d_p < 3$ μm) suspended in distilled water and aqueous sodium chloride solutions; the results are shown in Figure 3. The results for 0.1 wt. % aluminium oxide suspended slurries seem to be of interest. When aluminium oxide particles were suspended in distilled water, these particles did not exert any influence on ϵ_G. On the other hand, when these particles were suspended in electrolyte solutions ϵ_G was considerably increased, being independent of the concentration of electrolyte. In electrolyte solutions, bubbles were hindered from coalescing and as a result smaller bubbles with low rising velocity are generated. In distilled water, on the other hand, bubbles coalescence is promoted and larger bub-

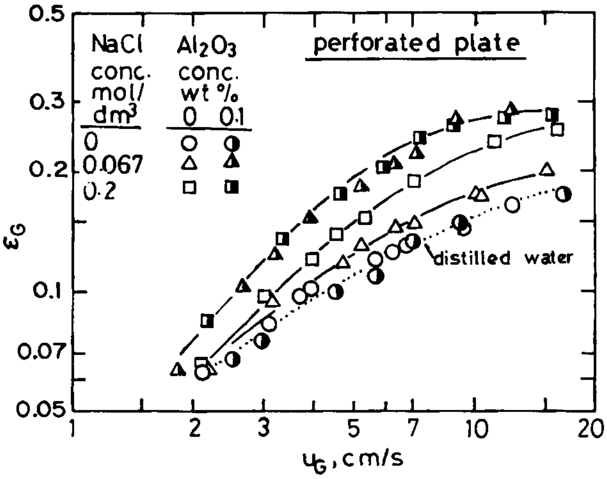

Figure 3. Influences of fine particles on the gas holdups in distilled water and electrolyte solutions.

bles with violent mobility are generated. The particles used in the present experiments were wettable ones, hence it is difficult to think that these particles gather excessively around the bubble surface. But these fine particles of a few microns are thought to disperse in the liquid film around the bubble as well as in the bulk liquid. In fact, we observed particles dispersed in the liquid film around the foams that were generated at the top of aerated column. It may be considered from such findings as well as the results depicted in Figure 3 that fine particles dispersed in the liquid films around bubbles prevent bubble coalescence, while the bubbles are tiny and rise gently.

To further confirm such a judgment, some experiments were performed using a bubble column equipped with a porous plate sparger. Generally, gas bubbles generated from a porous plate are very small, and ϵ_G in a porous plate equipped bubble column is higher than that in a perforated plate or single nozzle equipped bubble column when the gas flow rate is not so fast. Figure 4 shows the influence of aluminium oxide particles on the gas holdup when bubbles are generated from the porous plate. The gas holdup in such a bubble column is higher than that in a bubble column equipped with a perforated plate. It should be noted that even in distilled water, suspended aluminium oxide particles can increase the gas holdup when the porous plate is used as the gas sparger, and hence small bubbles are generated.

Volumetric liquid-side mass transfer coefficients

As $k_L^\circ a$ in a bubble column had been known to be strongly dependent on the gas holdup (Akita and Yoshida, 1974; Sada et al., 1984), the present results on $k_L^\circ a$ were plotted against ϵ_G instead of u_G and are shown collectively in Figure 5. The dotted line represents Eq. 4, which was given in the previous article (Sada et al., 1984) for ion-exchanged water.

$$k_L^\circ a = 0.24\,\epsilon_G^{0.9} \qquad (4)$$

The influences of electrolyte concentration and type of suspended solids on $k_L^\circ a$ are not found so significant, and the values of $k_L^\circ a$ for slurries are almost the same as those for electrolyte solutions without suspended solids, shown by the solid line in Figure 5. Hence, it is concluded from the present experiments that suspended solid particles do not exert any appreciable influence on the mass transfer coefficient k_L°.

Conclusion

The degree of influence of suspended particles on bubble column performance is considered to depend upon the particle size. Particles larger than 50 μm decreased ϵ_G with increasing concentration; at very low concentrations they exerted no appreciable influence on ϵ_G. Addition of particles smaller than 10 μm increased ϵ_G at very low concentrations only when small bubbles were generated, and the smaller the suspended particle was, the larger was ϵ_G. Such an increase in ϵ_G is presumably due to the bubble coalescence hindering action of fine particles dispersed in the liquid film around bubbles. The influences of electrolyte concentration and type of suspended particles on the relation of $k_L^\circ a$ vs. ϵ_G were not so significant, and the observed increase of $k_L^\circ a$ in low concentrations of fine particles was deduced to be due to an increase of a.

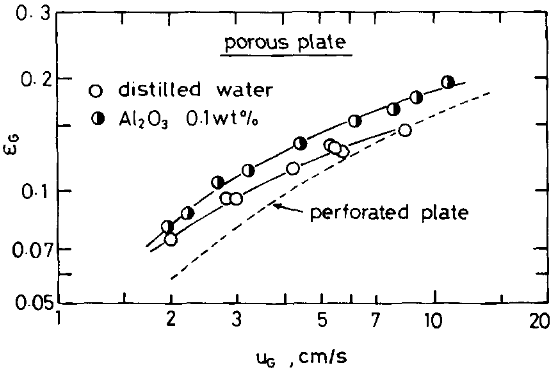

Figure 4. Influence of gas sparger on the gas holdup.

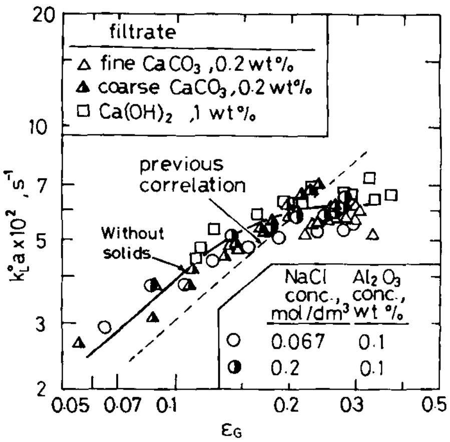

Figure 5. Influence of fine particles on the volumetric liquid-side mass transfer coefficient in electrolyte solutions.

Notation

a = specific gas-liquid interfacial area, m²/m³
c = concentration in liquid phase, mol/dm³
C^* = equilibrium concentration with gas phase, mol/dm³
d_p = diameter of solid particles, μm
H = dispersion height, m
k_L° = liquid-side mass transfer coefficient, m/s
$k_L^\circ a$ = volumetric liquid-side mass transfer coefficient, s^{-1}
t = time, s
u_G = superficial gas velocity, cm/s
w = solid concentration in slurry, wt. %
ϵ = phase holdup
ρ_p = solid density, g/cm³

Subscripts

G = gas phase
L = liquid phase
T = total

Literature Cited

Akita, K., and F. Yoshida, "Bubble Size, Interfacial Area, and Liquid-Phase Mass Transfer Coefficient in Bubble Columns," *Ind. Eng. Chem. Proc. Des. Dev.*, **13**, 84 (1974).

Chandrasekaran, K., and M. M. Sharma, "Absorption of Oxygen in Aqueous Solutions of Sodium Sulfide in the Presence of Activated Carbon as Catalyst," *Chem. Eng. Sci.*, **32**, 669 (1977).

Deckwer, W.-D., R. Burkhart, and G. Zoll, "Mixing and Mass Transfer in Tall Bubble Columns," *Chem. Eng. Sci.*, **29**, 2,177 (1974).

Kara, S., et al., "Hydrodynamics and Axial Mixing in a Three-Phase Bubble Column," *Ind. Eng. Chem. Proc. Des. Dev.*, **21**, 584 (1982).

Quicker, G., A. Schumpe, and W.-D. Deckwer, "Gas-Liquid Interfacial Areas in a Bubble Column with Suspended Solids," *Chem. Eng. Sci.*, **39**, 179 (1984).

Sada, E., H. Kumazawa, and C. H. Lee, "Chemical Absorption in a Bubble Column Loading Concentrated Slurry," *Chem. Eng. Sci.*, **38**, 2,047 (1983).

Sada, E., et al., "Hydrodynamics and Mass Transfer Characteristics in a Three-Phase Bubble Column," *Ind. Eng. Chem. Proc. Des. Dev.* (1984).

Sharma, M. M., and R. A. Mashelkar, "Absorption with Reaction in Bubble Columns," *Inst. Chem. Eng. Symp. Ser.*, **28**, 10, London (1968).

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