MASS TRANSFER IN BUBBLE SLURRY COLUMN WITH STATIC MIXER IN DRAFT TUBE

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Introduction

A bubble slurry column can be used as a typical gas-liquid-solid three-phase reactor in which catalyst particles are suspended by the movement of gas bubbles without mechanical stirring. When a draft tube is immersed in the bubble column, gas is bubbled into the draft tube. Solid particles and liquid flow upwardly in the tube and downwardly in the annulus. Therefore, the minimum gas velocity for complete suspension of solid particles in the bubble column with draft tube is expected to be smaller than that without draft tube. Mass transfer rates could be promoted by a draft tube as reported in a previous paper[5].

Further, the presence of a static mixer or a motionless mixer has been found to be effective in enhancing rates of mass transfer from gas to liquid in some types of bubble columns, such as a bubble column with draft tube,[6] a conventional bubble column[7] and an external-loop column[2]. However, there are no publications on rates of mass transfer from liquid to solid.

In this paper, systematic investigations are reported for pressure drops, minimum gas velocities for complete suspension of particles, and rates of mass transfer from gas to liquid and from liquid to solid in a draft-tube bubble column with and without a static mixer.

1. Experimental

Figure 1 shows a bubble slurry column with a static mixer in a draft tube. The static mixer (manufactured by Noritake Co., Ltd.) was successively composed of right-hand (and left-hand) 90°-angle corrugated stainless steel sheets as shown in the details of Fig. 1. Two types of gas distributors (a single nozzle of 1 mm inside diameter and a plastic ball filter with many fine pores) were used.

If the draft tube was withdrawn, the column became a conventional bubble column.

A strong cation exchange resin (Amberlyst 15) was used as solid particles in the bubble column. The swollen resins were sieved in water and three fractions of particles—28–32 mesh, 20–24 mesh and 16–20 mesh—were used. The arithmetic means of the sieve openings were adopted as average diameters of particles: 0.55, 0.78 and 0.92 mm. Physical properties of resins were described elsewhere[8].

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2. Results and Discussion

2.1 Pressure drop

A manometer filled with water was connected to the gas inlet as shown in Fig. 1. The pressure drop due to gas flow through the gas distributor was determined by subtracting the height of water in the column, h_C, from the height difference in the manometer, h_M, that is, $(h_M - h_C)$ in Fig. 1. **Figure 2** shows the relations between pressure drop and gas velocity for both a single nozzle and a plastic ball. For the case of a plastic ball, the pressure drop appears immediately when the gas starts to flow and then

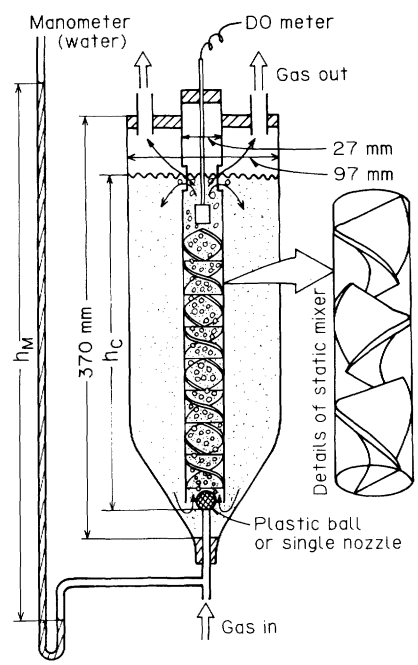

Fig. 1. Bubble slurry column with a static mixer in a draft tube

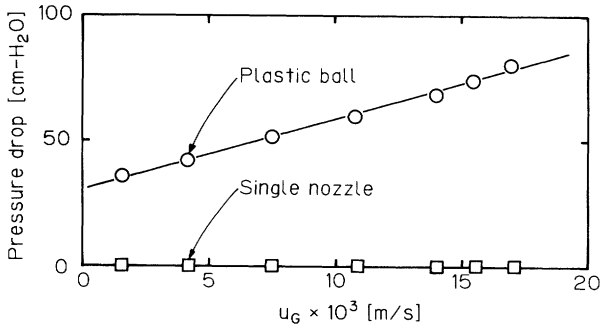

Fig. 2. Pressure-drop measurements

increases linearly with gas velocity. On the other hand, the pressure drop is almost zero under this experimental condition for the case of a single nozzle. Then the gas flow through very fine pores in the plastic ball is the main resistance. The presence of a static mixer showed almost no effect on the pressure drop.

2.2 Minimum gas velocity

The minimum superficial gas velocities for complete suspension of resins were determined by visual observation.

As shown in **Fig. 3**, the minimum gas velocity is increased as the fraction of solid particles increases.

The minimum gas velocity in a conventional column without draft tube is the highest for any solid fractions. When a draft tube is inserted, solid particles become easier to suspend.

It is seen from this figure, however, that the presence of a static mixer increases the minimum gas velocity, especially for the case of a single nozzle. This may be due to the turbulent movement of particles in the static mixer.

2.3 Gas-liquid mass transfer coefficient

The volumetric coefficient of mass transfer from gas to liquid was determined by the gassing-out method. At first, air was bubbled to saturate the distilled water in the column. Then, air was replaced by nitrogen gas and the experimental run started. The concentration of dissolved oxygen in the distilled water was measured with time by a DO meter.

The volumetric coefficient can be calculated from the following equation.

$$(ka)_{GL} = \ln(C_{L,0}/C_L)/t \qquad (1)$$

The value of $(ka)_{GL}$ was almost independent of time, t.

Figure 4 shows the log–log plots of $(ka)_{GL}$ and u_G for four cases. As the gas velocity increases, the volumetric coefficient is increased. The plastic ball can make very fine gas bubbles and then the value of $(ka)_{GL}$ is high. When a static mixer is inserted, these bubbles coalesce easily with each other and the coefficient becomes lower.

On the other hand, gas bubbles from a single nozzle

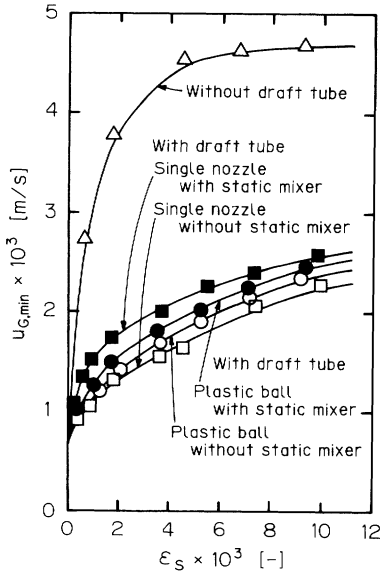

Fig. 3. Minimum gas velocity for complete suspension of resins ($d_p = 0.78$)

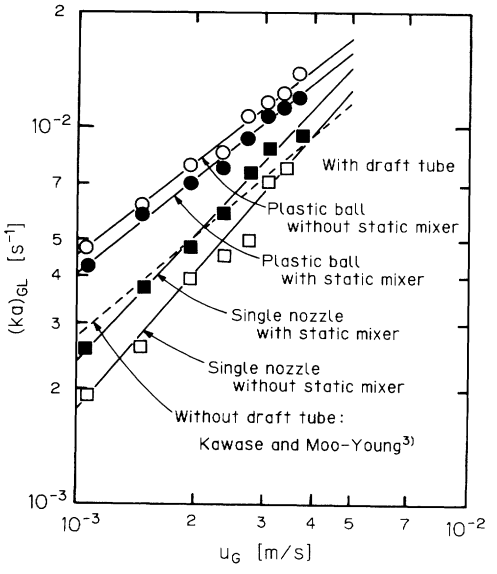

Fig. 4. Volumetric coefficients of gas-liquid mass transfer in bubble columns ($\varepsilon_s = 0$)

are rather large in the draft tube without a static mixer and the coefficient is the lowest of all cases considered. These large bubbles can be dispersed by a static mixer in the draft tube. Therefore, the presence of a static mixer can enhance mass transfer rates from gas to liquid by a standard deviation of 34% in the case of a single nozzle.

The dotted line in Fig. 4 indicates the result calculated from the correlation of Kawase and Moo-Young[3]. This is comparable with our cases of a single nozzle.

2.4 Liquid-solid mass transfer coefficient

This rates of ion exchange were measured by contacting Amberlyst 15 in the H^+ form with an

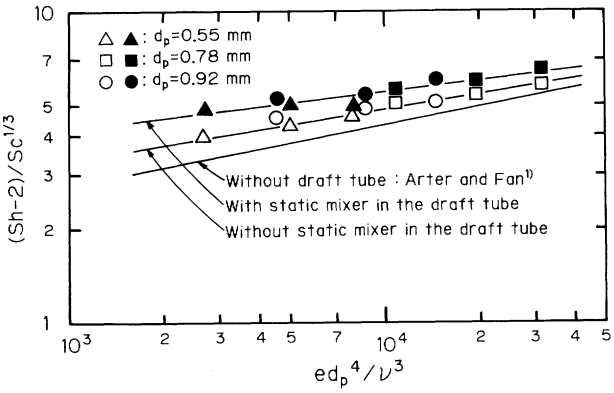

Fig. 5. Correlations of liquid-solid mass transfer coefficients in bubble columns

Table 1. Parameters in Eq. (3)

Type	a	b
Without draft tube (Arters and Fan[1])	0.695	0.200
Without static mixer in draft tube[5]	1.01	0.173
With static mixer in draft tube	1.68	0.133

aqueous solution of NaOH. The initial concentration of NaOH was 0.45 mol/m^3. The concentration of NaOH was measured continuously by an electric conductivity meter.

The mass transfer coefficient from liquid to solid in batch-wise operation could be calculated from the following equation.

$$k_{LS}=(V_L d_p/6V_{resin}t)\ln(C_{L,0}/C_L) \quad (2)$$

Since the values of k_{LS} were also independent of t, the resistance of intraparticle diffusion could be negligible[4].

Figure 5 shows a comparison between our data and published correlations. Experimental data can be well correlated with the following equation for three cases.

$$Sh=2+a(ed_p^4/\nu^3)^b Sc^{1/3} \quad (3)$$

The values of a and b in Eq. (3) are summarized in **Table 1**. The rates of mass transfer from liquid to solid could be accelerated about 20% by the presence of a static mixer in the draft tube. These rates were almost unaffected by the kind of gas distributor used—whether a single nozzle or a plastic ball.

Conclusion

It is evident from experimental results that the static mixer in a draft tube is effective in increasing the rate of mass transfer when a single nozzle is used as gas distributor to reduce pressure drop.

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Nomenclature

C_L	=	concentration of oxygen (or NaOH) in the liquid phase	[mol/m^3]
$C_{L,0}$	=	initial concentration of oxygen (or NaOH) in the liquid phase	[mol/m^3]
D_L	=	molecular diffusivity in liquid phase (2.6×10^{-9} m^2/s in this work)	[m^2/s]
d_p	=	diameter of particle	[m]
e	=	energy dissipation rate, $u_G g$	[m^3/s^3]
k_{LS}	=	liquid-solid mass transfer coefficient	[m/s]
$(ka)_{GL}$	=	volumetric coefficient of gas-liquid mass transfers	[$^{-1}$]
Sc	=	Schmidt number, ν/D_L	[m]
Sh	=	Sherwood number, $k_{LS}d_p/D_L$	[—]
t	=	time	[s]
u_G	=	superficial gas velocity based on the cross-sectional area of bubble column	[m/s]
V_L	=	volume of liquid phase	[m^3]
V_{resin}	=	volume of wet resin	[m^3]
ε_s	=	solid fraction in column	[—]
ν	=	kinematic viscosity	[m^2/s]

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