EFFECT OF SPARGED GAS ON MASS TRANSFER BETWEEN FINE PARTICLES AND LIQUIDS IN AN AGITATED VESSEL

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Introduction

In a previous paper,[1] we presented a new correlation for the mass transfer coefficient between solid particles and liquids in agitated vessels that was applicable over a wide range of particle size from 5 to 966 μm. This correlation is expected to be applicable also to the liquid-phase mass transfer around solid particles in gas-liquid-solid agitated systems, if the energy dissipation rate ε is evaluated as the sum of

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the gas and impeller contributions. The purpose of this note is to clarify the effect of gas sparging on the solid-liquid mass transfer in an agitated vessel.

1. Experimental

The agitated vessel was of 13.2 cm i.d. and was similar to that used in the our previous work.[1] The gas sparger was of single-nozzle type, and three nozzles of 0.1, 0.2 and 0.3 cm i.d. were used. The nozzle was attached at the center of the vessel bottom. The vessel was operated continuously with respect to the gas and batchwise with respect to the liquid. Air was used as the sparged gas, and the feed flow rate was $(16.1–235)\times 10^{-6}\,m^3/s$. The stirring speed of the impeller ranged from 1.67 to $6.67\,s^{-1}$. The liquid temperature was kept at 25°C. The solid-liquid mass transfer coefficients were measured with the same systems as used in the previous work[1]: the neutralization of $10^{-3}\,kmol/m^3$ NaOH solution with cation exchange resin of 23.0 μm, and the neutralization of $10^{-3}\,kmol/m^3$ HCl solution with anion exchange resins of 64.8 and 456 μm.

2. Results and Discussion

Typical results are shown in **Fig. 1**, where the observed Sherwood number *Sh* is plotted against the superficial gas velocity U_G. For strong mechanical agitation ($\varepsilon_M = 0.46\,m^2/s^3$) *Sh* is independent of U_G, and the effect of gas agitation is very small. On the other hand, for weak mechanical agitation ($\varepsilon_M = 0.013\,m^2/s^3$) *Sh* increases with U_G, indicating that the liquid is substantially agitated not only by the impeller but also by the gas. It should be noted that the nozzle diameter d_0 does not affect *Sh*.

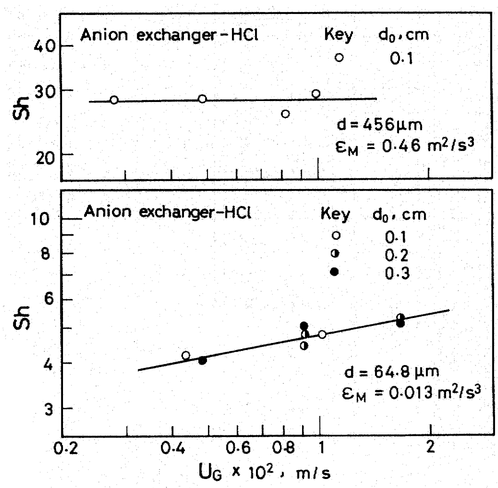

Fig. 1. Effect of superficial gas velocity on Sherwood number

In **Fig. 2**, all the present data are compared with our previous correlation[1] for gas-free agitated systems:

$$Sh = [2^{5.8} + \{0.61(\varepsilon^{1/3}d^{4/3}/\nu)^{0.58}Sc^{1/3}\}^{5.8}]^{1/5.8} \quad (1)$$

The energy dissipation rate ε in Eq. (1) was taken to be equal to the total energy dissipation rate ε_T:

$$\varepsilon_T = \varepsilon_M + \varepsilon_G \quad (2)$$

The energy dissipation rate ε_M by mechanical agitation, which decreases with increasing gas flow rate, was measured with a torsion dynamometer. The energy dissipation rate ε_G by sparged gas was taken as the energy required to overcome the static head. According to the conventional use in bubble columns,

$$\varepsilon_G = U_G g \rho_S/\rho_L \simeq U_G g \quad (3)$$

Here, the slurry density ρ_S may be approximated by liquid density ρ_L under the present experimental conditions in the dilute suspension ($\rho_S/\rho_L < 1.01$). The present data for all nozzle diameters were obtained for the range of $0.283 < (\varepsilon_T^{1/3}d^{4/3}/\nu) < 35.2$. As can be seen in Fig. 2, all the observed values of *Sh* are well correlated by Eq. (1) over the whole range from $\varepsilon_G/\varepsilon_T = 0$ to $\varepsilon_G/\varepsilon_T = 1$, that is, from the condition of no gas sparging to the condition of no mechanical agitation. This suggests that the ε_T value predicted from Eqs. (2) and (3) may be used for evaluation of the mass transfer coefficient from Eq. (1), and that the effect of kinetic energy of gas is insignificant for mass transfer between solid particles and agitated liquids.

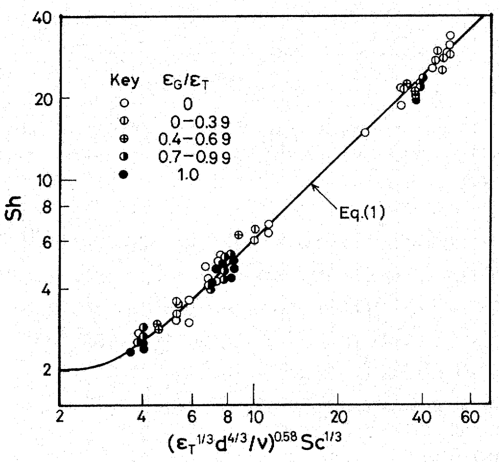

Fig. 2. Correlation of present experimental data

Figure 3 shows a comparison of Eq. (1) with other existing correlations (**Table 1**) in gas-sparged agitated vessels and bubble columns for $Sc = 300$, which corresponds to the average value under the present experimental conditions. For the specific power group in the range of $1 < (\varepsilon_T^{1/3}d^{4/3}/\nu) < 10$, Eq. (1) agrees approximately with the correlation of Sano *et al.*[4]. For $(\varepsilon_T^{1/3}d^{4/3}/\nu) > 1$, Eq. (1) also accords well with Marrone and Kirwan's correlation[2] covering only a narrow range of $0.3 < (\varepsilon_T^{1/3}d^{4/3}/\nu) < 5$. However, they evaluated the ε_G value as the sum of the contributions of the pressure drop through the gas sparger and the

Table 1. Previous correlations in gas-sparged agitated vessels and bubble columns

No.	Correlation	Investigators
1	$Sh=2+0.36(\varepsilon_T{}^{1/3}d^{4/3}/\nu)^{0.75}Sc^{1/3}$ (Agitated vessel)	Marrone and Kirwan (1986)[2]
2	$Sh=2+0.545(\varepsilon_T{}^{1/3}d^{4/3}/\nu)^{0.792}Sc^{1/3}$ (Bubble column)	Sänger and Deckwer (1981)[3]
3	$Sh=2+2.309(\varepsilon_T{}^{1/3}d^{4/3}/\nu)^{0.663}Sc^{0.178}$ (Bubble column)	Sänger and Deckwer (1981)[3]
4	$Sh=[2+0.4(\varepsilon_T{}^{1/3}d^{4/3}/\nu)^{3/4}Sc^{1/3}]\phi$ (Agitated vessel, Bubble column)	Sano *et al.* (1974)[4]

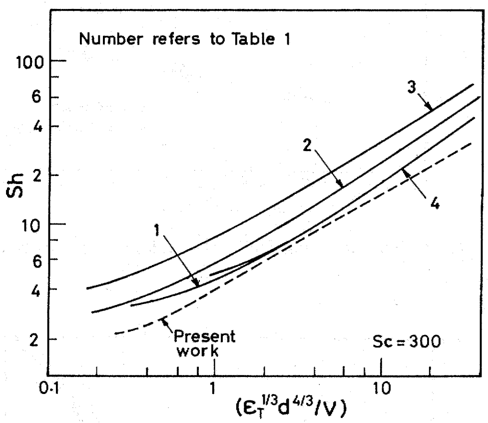

Fig. 3. Comparison of Eq. (1) with previous correlations for solid-liquid mass transfer in gas-sparged agitated vessels and bubble columns

head space of the vessel. This is unreasonable since the energy dissipation for gas flow through the sparger does not contribute to the agitation of liquid. The two correlations proposed by Sänger and Deckwer[3] yield substantially larger values of *Sh* over the whole range of the specific power group $(\varepsilon_T^{1/3}d^{4/3}/\nu)$.

Conclusion

Our previous correlation, Eq. (1) proposed for gas-free agitated systems, is also applicable to the prediction of solid-liquid mass transfer coefficients in gas-liquid-solid agitated systems, if the total energy dissipation rate ε_T is evaluated from Eqs. (2) and (3).

Nomenclature

D	= liquid-phase diffusivity	[m²/s]
d	= particle diameter	[m]
d_0	= nozzle diameter	[m]
k	= mass transfer coefficient	[m/s]
g	= acceleration of gravity	[m/s²]
Sc	= Schmidt number, ν/D	[—]
Sh	= Sherwood number, kd/D	[—]
U_G	= superficial gas velocity	[m/s]
ε	= energy dissipation rate per unit mass of liquid	[m²/s³]
ν	= kinematic viscosity of liquid	[m²/s]
ρ_L	= liquid density	[kg/m³]
ρ_S	= slurry density	[kg/m³]
ϕ	= shape factor of particles	[—]

〈Subscripts〉

G	= due to gas sparging
M	= due to mechanical agitation
T	= total

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