AMP를 첨가한 실리카 수용액의 점탄성이 이산화탄소의 물질전달에 미치는 영향

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Effect of viscoelasticity of aqueous colloidal silica solution on mass transfer of carbon dioxide with AMP

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Introduction

Gas-liquid mass transfer in non-Newtonian liquid is an important example of gas absorption in pseudoplastic flow relevant to industrial process such as a fermentation broth, slurry, and fluidized bed, et al. Variation of the volumetric liquid-phase mass transfer coefficient(k_La) in gas-dispersed systems consists of the variation of the mass transfer coefficient(k_L) and that of the specific gas-liquid interfacial area(a). The former could be correlated with the Reynolds and Schmidt numbers, which include liquid viscosity. It is likely that the latter varies not only with Newtonian liquid properties such as surface tension but also with some non-Newtonian and/or viscoelastic fluid properties.

There is little information about the effect of elastic properties on chemical absorption of gas in non-Newtonian liquid. Park et al.[1-3] presented the effect of elasticity of polyisobutylene (PIB) in the benzene solution of polybutene (PB) and PIB on absorption of CO_2 in w/o emulsion composed of aqueous solution as dispersed phase and benzene solution of PB and PIB as continuous phase in an agitation vessel. They showed that PIB accelerated the absorption rate of CO_2. It is considered worthwhile to investigate the effect of non-Newtonian rheological behavior on the rate of chemical absorption of a gas, where a reaction between CO_2 and reactant occurs in the aqueous phase.

In this study, as one of the series of studies about the effect of elastic properties on chemical absorption of gas in non-Newtonian liquid, the absorption rate of CO_2 was measured into aqueous nano-sized colloidal silica solution with 2-amino-2-methyl-1-propanol (AMP) to observe the effect of elasticity of the solution on the chemical absorption rate of CO_2, and compared with the theoretical value, which was estimated from the model based on the film theory accompanied by chemical reaction using the k_La, which was obtained by the empirical equation[3] for k_La of CO_2 in aqueous nano-sized colloidal silica solution.

Theory

The problem to be considered(Figure 1) is that a gaseous species A(CO_2) dissolves into the liquid phase and then reacts irreversibly with species B(AMP) according to

$$A + \nu B \rightarrow P \qquad (1)$$

Species B is a nonvolatile solute, which has been dissolved into the liquid phase prior to its introduction into the gas absorber. It is assumed that gas phase resistance to absorption is negligible by using pure species A, and thus the concentration of species A at the gas-liquid corresponds to equilibrium with the partial pressure of species A in the bulk gas phase.
The chemical reaction of Eq. (1) is assumed to be second-order as follows:

$$r_A = k_2 C_A C_B \qquad (2)$$

Under assumptions mentioned above, the conservation equations of species A and B based on the film theory with chemical reaction the film theory are given as follows:

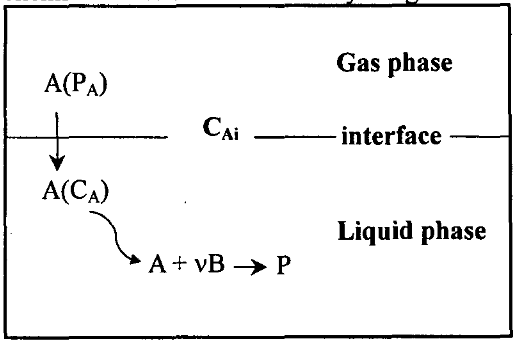

Fig. 1. Chemical absorption path of CO_2 into aqueous colloidal silica solution.

$$D_A \frac{d^2 C_A}{dz^2} = k_2 C_A C_B \tag{3}$$

$$D_B \frac{d^2 C_B}{dz^2} = \nu k_2 C_A C_B \tag{4}$$

Boundary and initial conditions to be imposed are

$$z = 0,\ C_A = C_{Ai}, \frac{dC_B}{dz} = 0 \tag{5}$$

$$z = z_L,\ C_A = 0, C_B = C_{Bo} \tag{6}$$

Eqs. (3) - (6) are put into the dimensionless form as follow:

$$\frac{d^2 a}{dx^2} = Mab \tag{7}$$

$$\frac{d^2 b}{dx^2} = rqab \tag{8}$$

$$x = 0\ ;\ a = 1, \frac{db}{dx} = 0 \tag{9}$$

$$x = 1\ ;\ a = 0, b = 1 \tag{10}$$

where $M = D_A k_2 C_{Bo} / k_L^2$, $a = C_A/C_{Ai}$, $b = C_B/C_{Bo}$, $x = z/z_L$, $q = \nu C_{Ai}/C_{Bo}$, $r = D_A/D_B$.

The enhancement factor (β) here defined as the ratio of molar flux with chemical reaction to that without chemical reaction is described as follows:

$$\beta = -\left.\frac{da}{dx}\right|_{x=0} \tag{11}$$

β in Eq.(11) is estimated by numerical solutions of Eq. (7) and (8) by the finite element method and used to predict absorption rate of CO_2 with chemical reaction.

Experimental

To get Deborah number(De), the rheological properties were measured from plots of shear stress and primary normal stress difference vs. shear rate by the parallel disk type rheometer(Ares, Rheometrics: diameter=0.05m, gap: 0.001m) in the range of silica concentration of 0 to 31 wt%.

Absorption experiments were carried out in an agitated vessel constructed of glass of 0.102 m inside diameter and of 0.157 m in height. The liquid phase was agitated with an agitator driven by a 1/4 Hp variable speed motor without agitation in gas phase because of pure CO_2 gas. A straight impeller with 0.034 m in length and 0.011 m in width was used as the liquid phase agitator, and located at the middle position of the liquid phase. The absorption rate of CO_2 was measured in the aqueous solution of silica of 0~31 wt%, AMP of 0~2 kmol/m^3, and the impeller speed of 50 rev/min at 25℃ and .101 MPa along the procedure similar to those reported elsewhere[3].

Results and Discussion

The measured values of De of colloidal silica solution increased with increasing the silica concentration in the range of 0 to 30 wt%. This means that silica solution is a non-Newtonian liquid with viscoelasticity.

The mass transfer coefficient(k_L) of CO_2 in aqueous colloidal silica solution was estimated by using the empirical equation correlating the relationship between k_La and the experimental variables in the non-Newtonian liquid as follows[3]:

$$k_L a d^2/D_A = 12.56(d^2 N\rho\rho/\mu^{0.48}(\mu\mu/_w)^{0.11}(1+39.4De)^{-0.43} \quad (12)$$

As shown in Eq. (12), k_L is affected by both viscosity and elasticity, and decreased with increasing silica concentration.

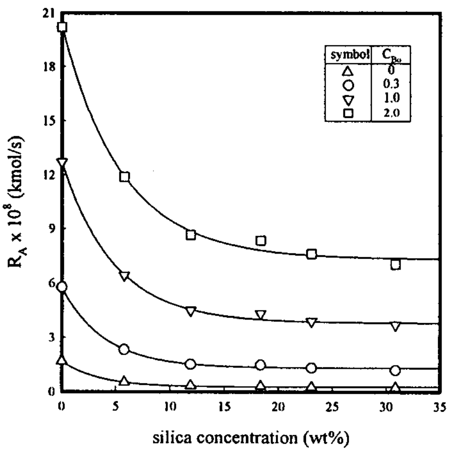

Fig. 2. Effect of silica concentration on absorption rate for various AMP concentrations.

Fig. 2 shows the plots of the absorption rate of CO_2 against the silica concentration for various AMP concentrations. As shown in Fig. 2, R_A decreases with increasing silica concentration, and increases with increasing AMP concentration.

To explain the trend of R_A as shown in Fig. 2, the dependence of variables such as k_La , β, and C_{Ai} on R_A is studied as mentioned below: The values of k_La were obtained from Eq. (12) using the physicochemical and rheological properties in the range of the silica concentration of 0-31 wt%, and plotted in Fig. 3. As shown in Fig. 3, k_La decreases with increasing the silica concentration. This result comes from the fact that the viscosity and De of the aqueous colloidal silica solution increase with increasing the concentration of silica as shown in Eq. (12).

The numerical solutions of the simultaneous differential equations (7) and (8) were obtained by the finite element method at given concentrations of silica and AMP using the physicochemical properties and k_L from Eq. (12), from which the value of β was estimated from Eq. (11). Fig. 4 shows the plots of β against the silica concentration for various AMP concentrations. As shown in Fig. 4, the values of β hold to be constant with increasing silica concentration and increase with increasing the AMP concentration.

From Eq. (12) and the results in Fig.2, 3, and 4, it might be said that decrease of R_A with increasing silica concentration was caused mainly by k_La rather than other variables; elasticity of the aqueous colloidal silica solution.

Conclusions

The measured rate of chemical absorption of carbon dioxide into the aqueous colloidal silica solution of 0-31wt% with AMP of 0-2 kmol/m^3 in a flat-stirred vessel with the impeller size of 0.034 m and its agitation speed of 50 rev/min at 25℃ and 0.101 MPa was compared

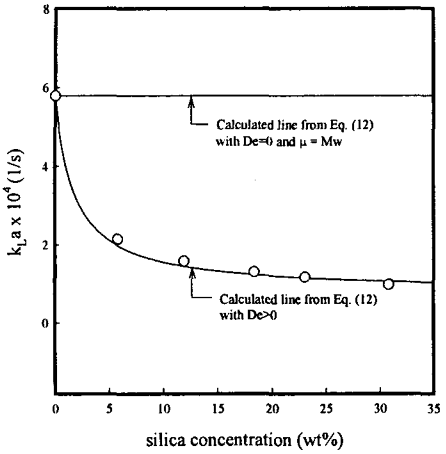

Fig. 3. Effect of silica concentration on k_La at d = 0.034 m and N = 50 rpm.

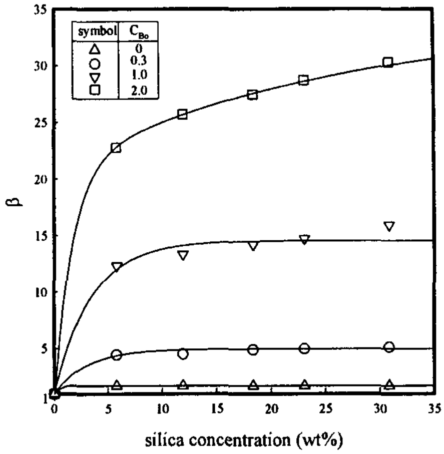

Fig. 4. Effect of silica concentration on enhancement factor for various AMP concentrations.

with that estimated from the model based on the film theory accompanied by chemical reaction using the value of k_La. The chemical absorption rate was decreased due to the reduction effect of k_La by elasticity of the aqueous colloidal silica solution. Value of k_La, which was used to estimate the enhancement factor, was obtained from the empirical equation.

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