DEA를 첨가한 PEO수용액에서의 이산화탄소의 물질전달

최병식, 박상욱*, 정혁인, 이준욱, 이재욱[1]
부산대학교 화학공학과
[1]서강대학교 화학공학과
(swpark@pusan.ac.kr*)

Mass transfer of carbon dioxide in aqueous PEO solution of DEA

Byoung-Sik Choi, Sang-Wook Park*, Hyuck-In Jung, Joon-Wook Lee, and Jae-Wook Lee[1]
Division of Chemical Engineering, Pusan National University
[1]Department of Chemical Engineering, Sogang University
. (swpark@pusan.ac.kr*)

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 polyiso butylene (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, the chemical absorption mechanism of CO_2 into an aqueous PEO solution with DEA is presented, and the measured absorption rates of CO_2 are compared with those obtained from the model based on the film theory with chemical reaction. The volumetric mass transfer coefficient from the empirical formula accompanied by Deborha number(De), which represents the elasticity of non-Newtonian liquid, is used to compare the elasticity with viscosity in the aqueous PEO solution having viscoelastic propertiy.

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(DEA) 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:

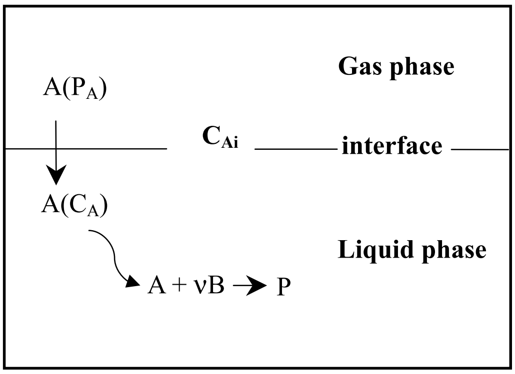

Figure 1. Chemical absorption path of CO_2 into aqueous PEO solution.

$$D_A \frac{\partial^2 C_A}{\partial z^2} = k_2\, C_A C_B \tag{3}$$

$$D_B \frac{\partial^2 C_B}{\partial z^2} = \nu k_2\, C_A C_B \tag{4}$$

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:

$$\frac{\partial^2 a}{\partial x^2} = M\, ab \tag{7}$$

$$\frac{\partial^2 b}{\partial x^2} = rq\, ab \tag{8}$$

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

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

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 a solution of Eq. (2) and (3) using a numerical analysis of FEMLAB method and used to predict absorption rate of CO_2 with chemical reaction.

EXPERIMENTAL

To get 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 PEO concentration of 10 to 30 kg/m^3.

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, 0.05, and 0.07 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 PEO of 0~30 kg/m^3, DEA of 0~2 kmol/m^3, and the impeller speed of 50-200 rev/min along the procedure similar to those reported elsewhere[3] at 25℃ and 101.3 kPa.

RESULTS AND DISCUSSION

The values of De of aqueous PAA solutions, which were obtained by the rheometer, increased with increasing the PEO concentration in the range of 10 to 30 kg/m^3. This means that the PEO solution is a non-Newtonian liquid with viscoelasticity.

The mass transfer coefficient(k_L) of CO_2 in aqueous PEO 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

$$k_L ad^2 / D_A = 12.56\left(d^2 N\rho/\mu\right)^{0.48}\left(1 + 8.33De^{1.31}\right) \tag{12}$$

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

To observe the effect of rheological properties of aqueous PEO solution on the rate of CO_2 absorption by comparison of elasticity with viscosity of PEO, the absorption rates of CO_2 into aqueous PEO solution were measured in the range of DEA concentration of 0–2 kmol/m^3. Figure 2 and 3 show the experimental R_A at PEO concentration of 10 and 30 kg/m^3 as symbol of circles under the typical conditions of N = 50 rpm and d = 0.034 m, respectively. The symbol of triangle represents R_A. As shown in these figures, R_A increases with increasing DEA concentration. And Ra in water is larger than that in aqueous PEO solution, because k_L in water is larger than that in the solution.

The solid lines in Fig. 2 and 3 are R_A estimated by Eq. (11), where k_L in water with $\mu = \mu_w$ and De = 0, k_L in aqueous PEO solution with De > 0, and k_L in aqueous PEO solution with De = 0 under assumption that the solution would act as a Newtonian liquid, respectively. As shown in Fig. 2 and 3, the estimated R_A in aqueous PEO solution with De > 0 is larger than that with De = 0. This means that the effect of the elasticity of the aqueous PEO solution on R_A is stronger than the effect of the viscosity, in other words, the elasticity of PEO accelerates the rate of absorption of CO_2.

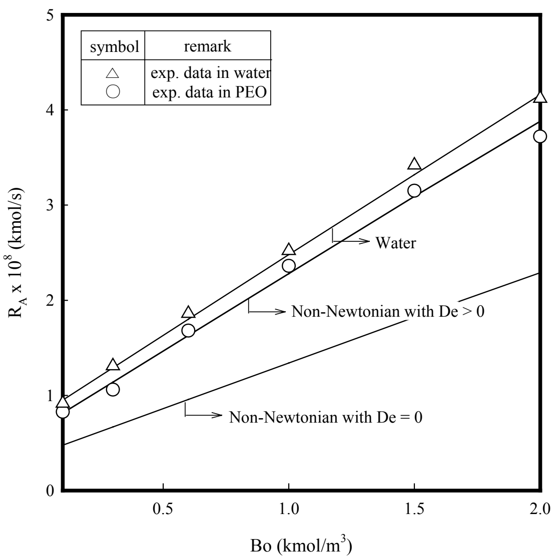

Fig.2. Comparison of elasticity with viscosity in aqueous PEO solution of DEA.(PEO=10 kg/m^3, d=0.034m, N=50rpm)

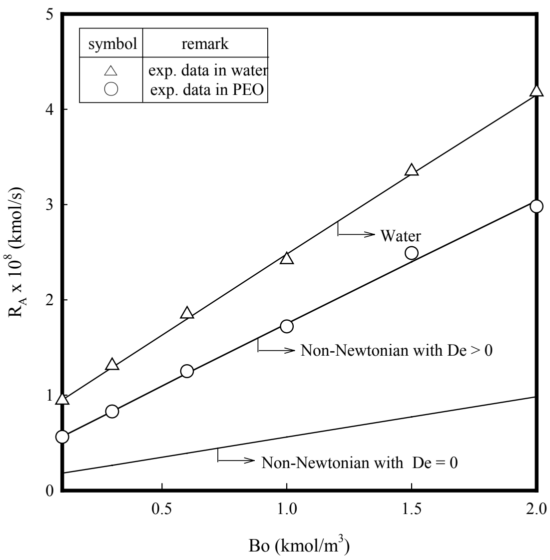

Fig.3. Comparison of elasticity with viscosity in aqueous PEO solution of DEA.(PEO=30 kg/m^3, d=0.034m, N=50rpm)

CONCLUSIONS

Rates of the chemical absorption of CO_2 in the aqueous solution of PEO at 10~30 kg/m^3 with DEA at 0~2 kmol/m^3 were measured in a flat-stirred vessel to get the influence of the rheological properties of PEO on the absorption rate under the experimental conditions such as the impeller size of 0.034, 0.05 and 0.07 m and the agitation speed of 50~200 rev/min at 25℃ and 101.3 kPa. The elastic property such as Deborah number of the aqueous PEO solution was considered to get an empirical correlation of the volumetric mass transfer
coefficient in the non-Newtonian liquid, which is used to estimate the enhancement factor for the chemical absorption. The elasticity of PEO accelerates the rate of absorption of CO_2 by the comparison of effect of the elasticity of the aqueous PEO solution on R_A with effect of the viscosity.

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