Facilitated Transport of Cr(VI) through a Supported Liquid Membrane with non-Newtonian Liquid

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Introduction

Because the dependence of shear stress on shear rate of a fluid in hydrodynamic system is different according to the type of the fluid, i.e., Newtonian or non-Newtonian fluid, and the mass transfer coefficient of a solute in one phase is in inverse proportional to the viscosity of its phase due to the inverse proportion of viscosity on diffusivity, the rheological properties such as Deborah number De, defined as the ratio of the characteristic material time to the characteristic process time, or Weissenberg number, Wi, defined as the ratio of the first normal stress difference to the shear stress, is taken into account to correlate the mass transfer coefficient in non- Newtonian fluid with that in Newtonian one. Mere use of the apparent viscosity of non-Newtonian fluids was not sufficient to obtain a unified correlation for k_La values in Newtonian and non-Newtonian fluids.

The present work was intended to obtain a unified correlation for membrane-side mass transfer coefficient (k_m) of Cr(VI) in the organic non-Newtonian fluids supported by microporous polymer, and to observe the effect of elasticity of non-Newtonian liquid on k_m. The particular system chosen for this study was extraction of Cr(VI) in toluene solutions of polybutene(PB) and PIB with varying the rheological properties.

Experimental

The supporting membrane was hydrophobic microporous polytetrafluoroethylene membrane with nominal thickness of 1.75×10^{-4} m, porosity of 0.7 and tortuosity of 1.353.

The polymer additives used in this study were PB with the mean molecular weight of 750 (Aldrich, U.S.A.) and PIB with the mean molecular weight of 1,000,000 (Aldrich, U.S.A.).

The experimental procedure to obtain the volumetric mass transfer coefficient of Cr(VI) was the same as those reported earlier (Park et al., 2001).

The rheological properties of the toluene solutions of PB and PIB were measured by the parallel disk type rheometer of the diameter of 0.05 m and the gap of 0.001 m (Ares, Rheome- trics, U.S.A.). The apparent viscosities of the toluene solutions of PB and PIB were measured using Ubbelohde viscometer at 25℃.

Results and Discussion

We assume that a power-law model, which has been widely used for shear-dependent viscosity, can be represented the non-Newtonian flow behavior of fluids.

$$\tau = K\gamma^{n}$$

$$N_1 = A\gamma^{b}$$

$$W_i = \frac{A}{K}\gamma^{b\,n}$$

where n, K, b, and A are material parameters depending on temperature.
These parameters were obtained from the dependence of τ and N_1 on γ.

To observe the dependence of τ and N_1 on γ, τ and N_1 of the toluene solution were measured according to the change of γ by the rheometer.

Figure 1 shows typically the logarithmic plot of shear stress vs. shear rate for toluene, the toluene solutions of PB of 30 wt%, and of PB of 30 wt% containing PIB of 1wt%. The best straight-line fit was determined by the least-squares method with the plots in Fig. 1.

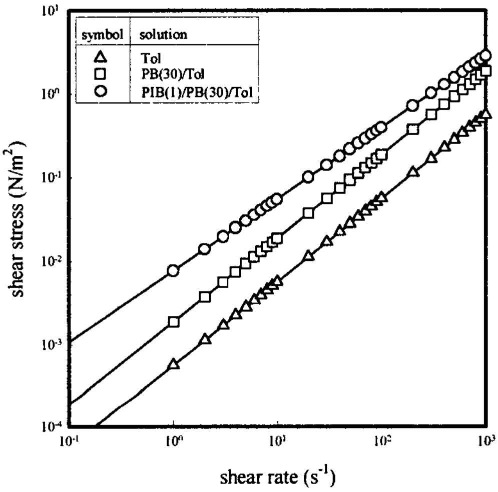

Figure 1. Shear stress of toluene solution as a function of shear rate.

From the intercept and slope of the line, the values of K and n were evaluated. Also, Fig. 2 shows the logarithmic plot of primary normal stress difference vs. shear rate for the same solution in Fig. 1.

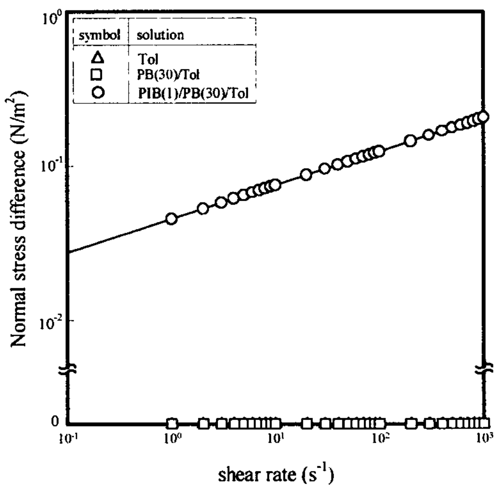

Figure 2. Normal stress difference of toluene solution as a function of shear rate.

As shown in Fig. 2, the plots are linear, but the values of the primary normal stress difference of toluene and toluene solution of 30 wt% PB are zero. From the intercept and slope of the straight line in the toluene solution of 30 wt% PB and 1 wt% PIB, the values of A and b were evaluated.

To correlate the membrane-side mass transfer coefficient with the viscosity of the toluene solution, k_m is plotted against μ in the toluene solution of PB of 0~1 wt%. Figure 3 shows logarithmic plots of k_m against μ, in which the black circles and the empty circles represent the plots of toluene solution of PB, (PB/Tol) and toluene solution of PIB and PB(PIB/PB/Tol), respectively.

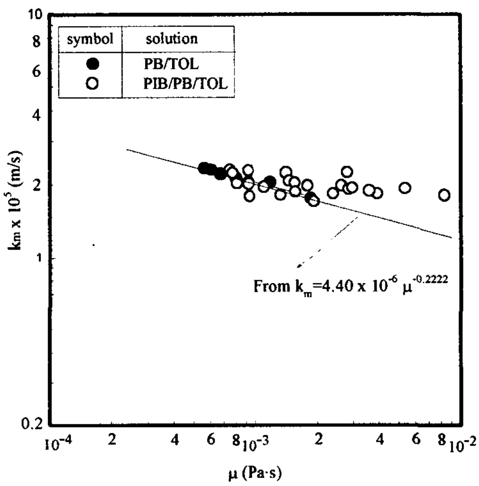

Figure 3. Plot of k_m of Cr(VI) in liquid membrane vs. viscosity of PIB/PB/Tol solution. (MD=13.66%, SD=3.31%)

As shown in Fig. 3, the plots of PB/Tol are linear but the plots of PIB/PB/Tol deviate from the plots of the PB/Tol solution. The slope and intercept from the straight line of plots of black circles are obtained by the least-square method with correlation coefficient of 0.965, mean deviation of 1.25%, and standard deviation of 0.03%, and their values are −0.222 and 4.40×10^{-6}, respectively. Also, the plots of open circles (PIB/PB/Tol) deviate from the straight line of PB/Tol with mean deviation of 13.66% and standard deviation of 3.31%.

To lessen the deviation of the plots in PIB/PB/Tol from those in PB/Tol as shown in Fig. 3, a new term of k_m combined with the elasticity such as $(1+a_1 Wi^{a_2})$ against μ was used to apply the behavior of non-Newtonian viscoelastic liquid to the empirical form such as $k_m = 4.40\times 10^{-6}\mu^{-0.2222}$. A simple multiple regression exercise gave the values of a_1 and a_2, and their values are 1.1533 and 0.8173, respectively, with correlation coefficient of 0.98, mean standard of 7.0% and standard deviation of 0.98%, and correlation is plotted in Fig.4.

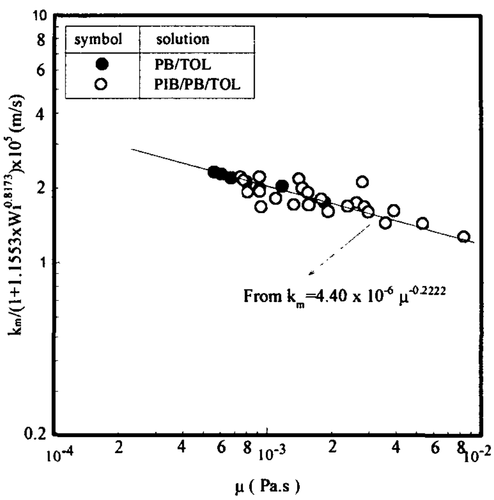

Figure 4. Correlation of k_m of Cr(VI) in liquid membrane with viscosity of PIB/PB/Tol solution by Weissenberg number. (MD=7%, SD=0.98%)

The empirical correlation between k_m and μ of toluene solution of PB and PIB is given such as $k_m = 4.40 \times 10^{-6} \mu^{-0.2222} (1 + 1.1553 Wi^{0.8173})$.

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Reference

Park, S. W. G. W. Kim, S. S Kim, I. J. Sohn, 2001, Facilitated transport of Cr(VI) through a supported liquid membrane with trioctylmethylammonium chloride as a carrier. Sep. Sci. Technol., *36* (10), 2309-2326.