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QUARTERLY REPORT

ROLES OF ADDITIVES AND SURFACE CONTROL IN SLURRY ATOMIZATION

by

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ABSTRACT

This quartery report describes a quantitative correlation between the flow behavior index of a micronized coal slurry and the interparticular van der Waals attraction force as measured by the Hamaker constant. Preliminary results on the effects of interparticular electrostatic repulsion and the liquid viscosity on both the flow behavior and the relative viscosity are also presented.

DISCUSSION

In earlier publications,[1,2] we have shown that the pseudoplastic behavior of a concentrated suspension of noncolloidal particles can be attributed to the interparticular van der Waals attraction. As the interparticular attraction increases, the number of aggregated particles increases. In turn, the number of aggregated particles decreases as the shear rate increases. As a result, unless the interparticular attraction is negligible, the concentrated suspension is pseudoplastic (shear thinning with the flow behavior index $n < 1$) at low and moderate shear rates, but becomes Newtonian ($n = 1$) at high shear rates when the hydrodynamic force predominates.

The Hamaker constant A/kT, for convencience scaled to the thermal energy at room temperature, is a measure of the interparticular van der Waals attraction force, where k is the Boltzman constant. Table I lists the Hamaker constants (A/kT) of coal particles suspended in various liquids as calculated by the Lifshitz equation[3]:

$$A = 3/4\ kT \left(\frac{\varepsilon_1 - \varepsilon_3}{\varepsilon_1 + \varepsilon_3}\right)^2 + \frac{3h\nu_e (n_1^2 - n_3^2)^2}{16\sqrt{2}(n_1^2 + n_3^2)^{3/2}} \qquad (1)$$

where k is the Boltzman constant; ε_1 and ε_3 are, respectively, the dielectric constants of particle and the suspending liquid; n_1 and n_3 are the corresponding refractive indices; ν_e is the absorption frequency. The experimental values for the dielectric constant and the refractive index reported in the literature are used in this calculation. These values for coal are 2.89 and 1.701, respectively. The absorption frequency of graphite, $1.15 \times 10^{15}\ s^{-1}$, is used for coal. The Hamaker constant of coal suspended in a liquid mixture is assumed to be the sum of those for coal in pure liquids multiplied by the liquid volume fractions, and is given in Table I. Also given in this table are the Hamaker constants for graphite, polystyrene, and glass in silicone oil, ethylene glycol, and glycerol for comparison.

Fig. 1 shows that the flow behavior index n of a suspension containing 0.46 volume fraction of Upper Freeport coal (with volume mean diameter of 4.4 μm and zeta potential of 24 mv in deionized water) in a glycerol-water mixture or an ethylene-glycol-water mixture is proportional to A/kT (open triangles). The flow behavior index n for the suspension of polystyrene in silicone oils at 0.45 volume fraction reported by Gadala-Maria and Acrivos[4] also falls on this line (solid circle). Similar behavior is also seen in this figure for suspensions containing 0.40 volume fraction of slightly oxidized Upper Freeport coal (with volume mean diameter of 4.4 μm and zeta potential of -2 mv in deionized water) and surface oxidized Illinois #6 coal (with volume mean diameter of 3.7 μm and zeta potential of -30 mv in deionized water) in aqueous glycerol solution (inverted triangles and squares, respectively).

Figure 1 also shows that the flow behavior indices of the suspensions of polystyrene spheres (with volume mean diameters of 6 μm and 78 μm and zeta potential of -4 mv in deionized water) at 0.55 volume fraction in silicone oil, ethylene glycol, and glycerol obtained in this study (open circles) are in good agreement with that reported by Gadala-Maria and Acrivos[4] for polystyrene spheres (45 μm) in silicone oil (solid circle). Note that the zeta potential is measured by Mavern Zeta Sizer IIc. From this figure we see that the suspension becomes more pseudoplastic (n decreases) as the particle volume fraction increases[4] because of decreased interparticle distance. In addition, the interparticular electrostatic repulsion, which is negligible in the nonaqueous polystyrene suspensions (circles in Fig. 1)[1,2], may be significant in the aqueous coal suspensions.

As shown in Fig. 2, the relative viscosity of a coal suspension in a less viscous liquid (viscosity of 3.7 cP) is considerably greater than that in a more viscous liquid (viscosity of 60 cP). This observation is also seen in the pseudoplastic polystyrene sphere suspensions[2]. It should be noted that the effect of particle size on the relative viscosity of a suspension[2] is taken into account in the Peclet number, $\eta_o \bar{a}^3 \dot{\gamma}/kT$ in Fig. 2, where $6\pi \eta_o \bar{a}^3/kT$ is the diffusional relaxation time, $\bar{a}$ is the volume mean radius of particles, and η_o is the viscosity of the suspending liquid. This figure shows that nondiffusion-controlled mechanisms, such as internal turbulence, may occur in the concentrated pseudoplastic suspensions. The liquid viscosity appears to have a significant on the flow behavior index as well. Further experimentation is needed to determine the underlying mechanisms of this liquid viscosity effect.

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TABLE I

Dimensionless Hamaker Constant A/kT for van der Waals Interaction Across Various Suspending Liquid

Solid/liquid	Polystyrene	Glass	Coal
Silicone oil	1.1	0.2	2.0
Glycol	1.3	0.6	2.1
Glycerol	0.9	0.6	1.7
Water	--	--	3.7
80/20 w/w glycerol/water			2.2
40/60 w/w glycerol/water			3.0
20/80 w/w glycerol/water			3.3
50/50 w/w isopropanol/water			3.1

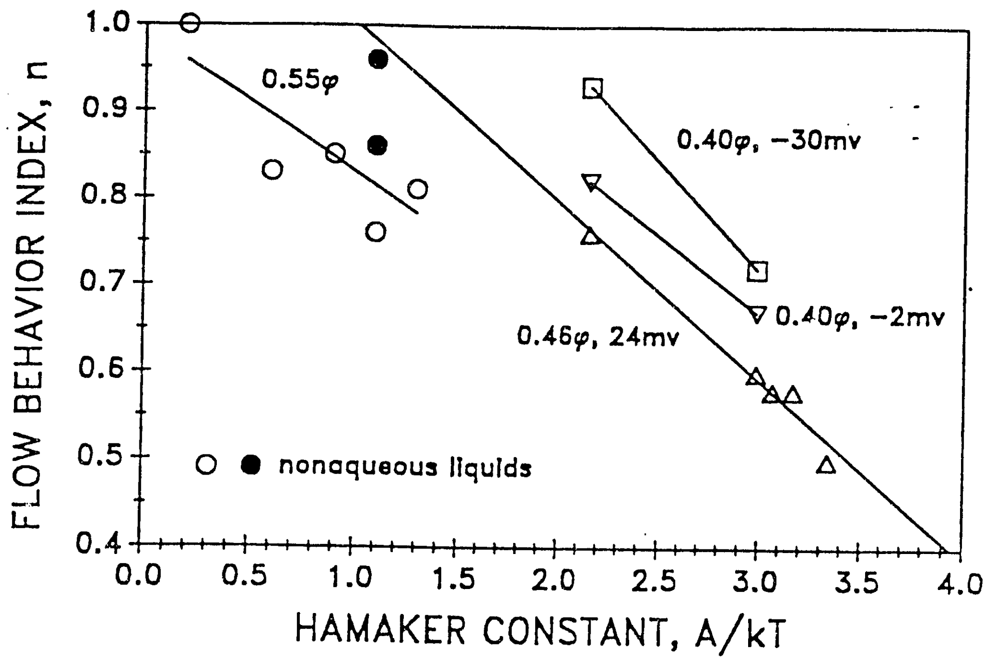

Fig. 1. Correlation between flow behavior index n of a concentrated suspension in aqueous solutions (except circles) and its Hamaker constant (solid circles are data for 0.55 and 0.45 volume fractions from Gadala-Maria and Acrivos[4]. φ: particle volume fraction.)

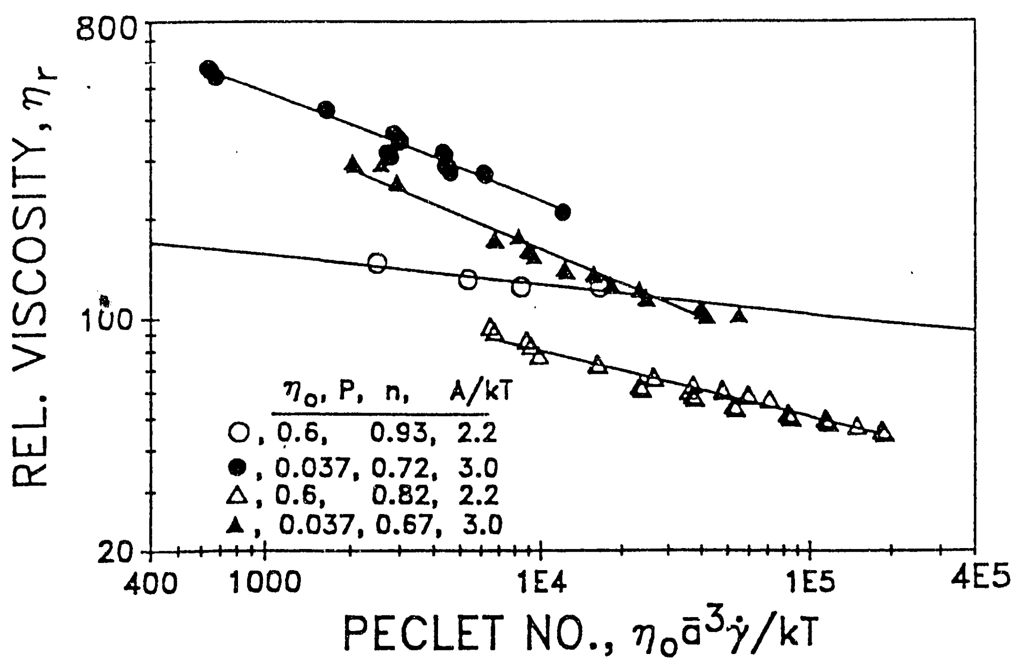

Fig. 2. Effects of liquid viscosity on the relative viscosity of a concentrated pseudoplastic suspension of coal in aqueous glycerol solutions (circles and triangles are for surface oxidized Illinois #6 coal and Upper Freeport coal, respectively).

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