VISCOSITY OF CONCENTRATED SUSPENSIONS OF SPHERE/ROD MIXTURES

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INTRODUCTION

Most investigations on the rheology of concentrated suspensions have focused on monodisperse suspensions of either spherical or rodlike particles. In practice, suspensions contain particles that are polydisperse both in size and in shape. Only a limited number of studies have been devoted to the problem of size polydispersity and even less is known about the behavior of suspensions composed of particles of different shapes. In this paper we provide experimental data for the low shear rate viscosity of concentrated suspensions of neutrally buoyant, rod-sphere mixtures and develop a simple phenomenological model for the viscosity of such systems.

Farris [1] developed a model for the viscosity of multimodal suspensions of spheres. In his model, for each fraction of a given particle size, the smaller particles in the suspension do not interact with the larger particles and are 'sensed' by the large particles as part of a continuous Newtonian suspending fluid. In what follows, we use Farris's concepts to develop an equation for the viscosity of a suspension of a mixture of rodlike and spherical particles. If the rods are large enough relative to the spheres, we may consider the spherical particles as part of the homogeneous suspending continuum. Let us define an apparent sphere volume fraction $\phi^*_s = V_s/(V_0+V_s) = \phi_s/(1-\phi_r)$ where V is volume, ϕ is the volume fraction, and the subscripts 0, r, s, T stand for the fluid, rods, spheres, and total solids respectively. If we assume the viscosity of a suspension composed of spheres and rods is the same as the viscosity of a suspension of rods suspended in a Newtonian homogeneous fluid of viscosity identical to the viscosity of an equivalent suspension of spheres with a volume fraction ϕ^*_s we may write:

$$\mu_{suspension}(\phi_T) = \mu_{rel,rods}(\phi_r)\ \mu_{spheres}(\phi^*_s) \quad (1)$$

$$\mu_{spheres}(\phi^*_s) = \mu_{rel,spheres}(\phi^*_s)\ \mu_0 \quad (2)$$

$$\mu_{rel}(\phi_T) = \mu_{rel,spheres}(\phi^*_s)\ \mu_{rel,rods}(\phi_r) \quad (3)$$

Here we adopt the Thomas relations for spheres [2] and Milliken's for randomly oriented rods with aspect ratio of 20 [3]. The relative viscosity of a mixed suspension may now be calculated for any combination of rods (of aspect ratio 20) and spheres.

EXPERIMENTAL

The experimental apparatus, materials, and methods have been described in great detail elsewhere [3-5]. Suspensions composed of mixtures of poly(methyl methacrylate) spheres with diameter of 3.175 mm and rods with length of 31.65 mm and diameter of 1.587 mm were used. The rod-sphere mixtures were suspended in a three-main-components Newtonian fluid with 50%wt alkylaryl polyether alcohol 35%wt polyalkylene glycol, and 15%wt tetrabromoethane. The quantity of tetrabromoethane in the mixture was adjusted so that the density and the refractive index of the fluid would match those of the PMMA particles. The falling balls with diameters between 6.35 mm and 15.88 mm were either chrome-plated steel ball bearings, monel, or tungsten carbide. The trajectories of the falling balls were recorded on a high-speed digitizing video system. An average velocity was determined by measuring the elapsed time for the ball to settle a known distance on the screen. Up to 40 individual drops were required for each data point.

RESULTS AND DISCUSSION

The relative viscosity is obtained from the dimensionless ratio of the measured Stokes viscosity of the suspension, incorporating the Faxen boundary correction [3-5], to the viscosity of the suspending fluid. The average relative viscosity for each suspension is obtained by averaging up to 120 separate ball drops for any given suspension. In Fig. 1 the measured average viscosities (symbols) are compared to the theory described in the first section (lines). The agreement between the limited number of available experimental points and the calculated lines is very good. This agreement seems to validate the assumption that, in a suspension in which two populations of solid particles with large size difference coexist, the larger particles 'sense' the smaller particles only as part of an effective suspending continuum.

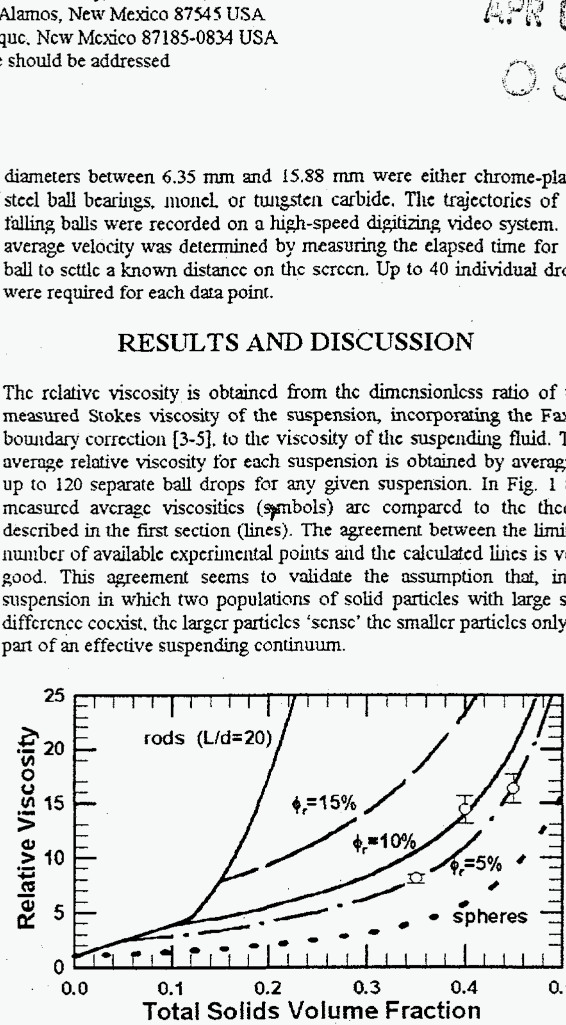

Fig 1. The relative viscosity of the mixed suspension as function of the total solids volume fraction. The lines represent the calculated theoretical values and the points represent the average experimental values for any given composition.

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