Particle motion during shear

The influence of particle shape and roughness on rheology

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SUMMARY: The influence of a particle's roughness and shape on suspensions rheology is studied with a modified Stokesian dynamics calculation. Particle-particle contact or electrostatic interactions order the particles in shear layers to give shear thinning and/or thixotropic rheology. Large scale structure form at high solid concentrations to increase viscosity: these structures are stronger and last longer for rough particles.

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The rheological properties of paper coating suspensions have long been recognized to be important in determining the runnability of a particular suspension. However, a single rheological property, or even a series of rheological tests, have not been correlated with runnability. In the last few years, the high shear rate viscosities were thought to reveal runnability, but results at shear rates of order 10^6 sec-' show either a steady viscosity or a shear thinning behavior, not a drastic shear thickening region for poor running suspension (Tsuji, Sasagawa 1990; Kurath, Larson 1990; Laun, Hirsch 1989; Sandas, Salminen 1991; Triantafillopoulos, Grankvist 1992). One exception is the finding that narrow particle size distributions contribute to shear thickening at shear rates of order 10^4 sec-' (Eriksson et al. 1990). However, high shear rate rheology has not been correlated to a coating runnability at present.

The current mill practice is to ramp up and down in shear rate on a concentric cylinder type rheometer. Two typical results of this type of test are depicted in *fig.* I. The shape of the curve is qualitatively examined by an experienced operator to judge the runnability of the coating. The hysteresis in curve B is a demonstration of thixotropy, a decrease in viscosity at a constant shear rate. Shear thickening or dilatant rheology (an increase in viscosity with shear rate) is thought to cause poor runnability, though a few examples are present in the literature which show good runnability with shear thickening coatings (Windle, Beazley 1967; Bohmer 1968). Runnability problems are only apparent with shear thickening coatings with solids greater than 65% (Huang 1986; Canard 1970). The hysteresis of curve B is thought to be caused by break down of flocs by shear in time, but a new mechanism will be discussed in this paper.

Coating rheology, in conjunction with the appropriate conservation equations, has the potential to predict runnability, to aid in coater control, and in the design and evaluation of new coater heads. The polymer industry has used polymer melt rheology to understand a number of processes. For example, elongational and viscoelastic behavior of polymer melts determines the maximum operation speed or draw ratio in the production of synthetic fibers (Denn 1980). In a similar manner, coating rheology, once fully understood, should be able to predict a number of operational limitations. Coating rheology is also an indication of the coating structure which is related to the final product quality. The important rheological properties to the coating operation need to be identified and these properties need to be described by mathematical expressions.

The goal of modeling the motion of particles during drying or shear is to understand the "microscopic" mechanisms (structure) which cause the "macroscopic" properties (e.g. rheology). In particular, the influence of particle surface roughness and shape on rheology is of interest in this paper. A new mechanism is proposed to explain shear thinning and short time thixotropic behavior of suspensions. The high viscosities of disk shaped particles is explained by the formation of small scale structures in shear. These structures are more stable for rough particles.

Background

The rheology of suspensions is reviewed by a number of researchers (Metzner 1985; Mewis, Spaull 1976; Ganani, Powell 1985). Particle concentration, shape, and size distribution influence the high shear rate viscosity. Electrostatic interactions and polymer addition also control suspension rheology.

Understanding the correct microscopic structure (the spatial arrangement of particles) is important in order to predict and understand suspensions rheology. We can learn this from recent history about the viscosity of spherical particles in a suspension. Frankel and Acrivos (1967) proposed an equation to describe the viscosity increase with volume fraction of solids for spheres using a cell model approach. (This cell model approach studies the flow near a sphere in a hypothetical cell around the sphere.) However, their result did not predict a strong

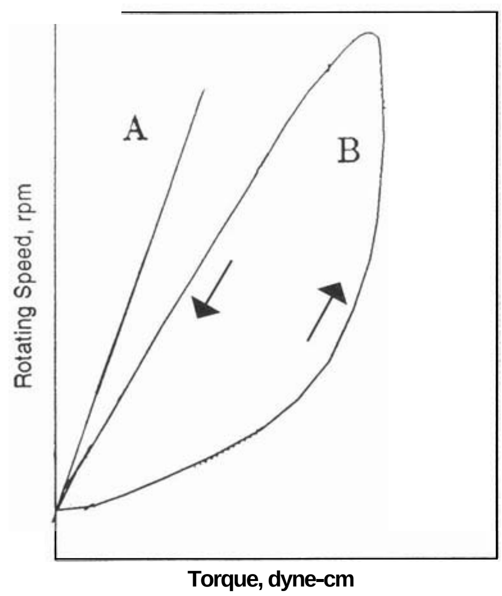

Fig. I. Typical rheological test in the mill. Shear rate is increased in time and then decreased. Curve A represents a Newtonian fluid. Curve B is a thixotropic fluid