Effect of Surfactants on the Rheology of Hematite Slurries

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Abstract

The rheological behavior of aqueous hematite slurries has been studied by laboratory viscosity and flow measurements. Data are presented for slurries with volume concentrations of hematite up to 40%. Solids concentration and particle size distribution were found to be important variables in the rheological behavior of hematite slurries as contrasted to temperature which was found to have only a small effect. Chemical dispersant additives and viscosity control additives used in relatively small concentrations improved the flow characteristics of the hematite slurries. Specifically, a lignosulfonate dispersant markedly increased the flow of slurries containing finely divided hematite, −325 mesh, and a viscosity control additive increased the carrying capacity of other slurries for coarse particles.

Introduction

The world's first long distance iron ore slurry pipeline (1) was put into service by Savage River Mines, Tasmania, Australia on October 26, 1967. Operation of the pipeline to date has been successful, moving 2.2 million tons per year of ore a distance of 53 miles. The technical success of pipelining high density slurries with the attendant low capital investment and operating costs points the way to increased application and the need to gain a better understanding of the rheological behavior of these slurries.

The data presented in this paper are part of a comprehensive laboratory study of the properties of hematite slurries. Data were selected for presentation that show the marked influence of surfactants on the viscosity and flow behavior of slurries of the iron ore, hematite.

Experimental Procedures

Materials

The hematite used in this study was a naturally occurring hematite ore averaging 85% to 93% ferric oxide with an average iron content of 62.5% and a density of 4.76 gm/ml. In order to achieve specific particle size distributions the ore was processed in a Bivco Pulverizer, type VA, which operates on a rotating plate principle. The pulverized material was then screened with a Sweco 18 in. Vibro Energy Separator and recombined in the desired proportions. The particle sizes in the fractions were based on the Tyler Standard Screen Scale. Hematite or ferric oxide, Fe_2O_3, as evidenced by its abundance as a naturally occurring ore, is a very stable compound practically insoluble in water. Our experiments for the most part were carried out with tap water. Aging tests show no tendency for chemical action as a result of intimate contact with water for several months at 25 C. The slurries in the aging tests easily redispersed with light agitation.

A number of commercially available dispersants were tested. The one selected for presentation in this paper is a lignosulfonate. The lignosulfonates are by-products of the wood sulfite pulping industry. They are water soluble, anionic, surface active derivatives of lignin with molecular weights varying between 1,000 and 20,000. The organic structure has not been completely determined but it is known that the basic monomer unit is a phenylpropane which is substituted with hydrophilic groups, mainly hydroxyls. The material we used was a brown powder completely soluble in water but insoluble in oils and most organic solvents. Aqueous solutions of 40 wt % can be prepared. Higher concentrations form extremely viscous solutions. A 3% aqueous solution has a pH of 8.5 to 9.0. The total sulfur content of the dry solid was 1.70% as sulfur.

We tested the behavior of a number of chemical additives to water which are described as friction reducing agents. One such additive was a white, water soluble powder described by the manufacturer as a synthetic organic polymer for application primarily as a friction reducing agent for fresh water or as a *thickening agent* for fresh water. Data are presented for this viscosity control additive.

Fann Viscosity Measurements

Viscosity measurements were made using a calibrated Fann rotational V-G viscometer to obtain values of apparent viscosity as a function of shear rate. Our experimental procedures followed closely those reported by Govier et al. (2). The Fann data were used to screen chemical additives as well as to study the effect of the other variables on the rheological properties of the slurries.

Flow Behavior

A flow trough was placed in operation which would permit us to observe the behavior of slurries under actual flowing conditions. The stainless steel trough had straight sides and a rounded bottom equivalent to one half of a pipe with a 2 in. inner diameter. The trough was 12 ft long, and its inclination could be varied. The Jabsco pump which fed the trough had a volumetric capacity sufficient to generate flow velocities in the trough in excess of 40 gal/min or 8 ft/sec. The experimental procedure was to set the trough inclination to give the desired pressure gradient. The flow rate was then adjusted through the infinitely variable drive and pump combination so that the liquid level in the trough was exactly 1 in.

Results and Discussion

Fann viscosity data were obtained for slurries of increasing concentration of hematite ground so that 100% would pass through a Tyler 325 mesh screen. The viscosity of the slurry could not be measured with concentrations of solid in excess of 28% by volume. These data are shown in Figure 1. The curves for the slurries are typical of non-Newtonian fluid, that is, they do not have a constant viscosity at a given temperature and concentration, but instead exhibit a variable viscosity dependent upon the rate of shear. Information on the classification of non-Newtonian fluids and a theoretical discussion of shear diagrams is given by Alves et al. (3).

Fann viscometer measurements were made on hematite slurries at four temperatures: 5, 15, 25 and 40 C. These data showed that increasing the temperature decreased the apparent viscosity but the effect was small compared to the effect of changing the hematite concentration.

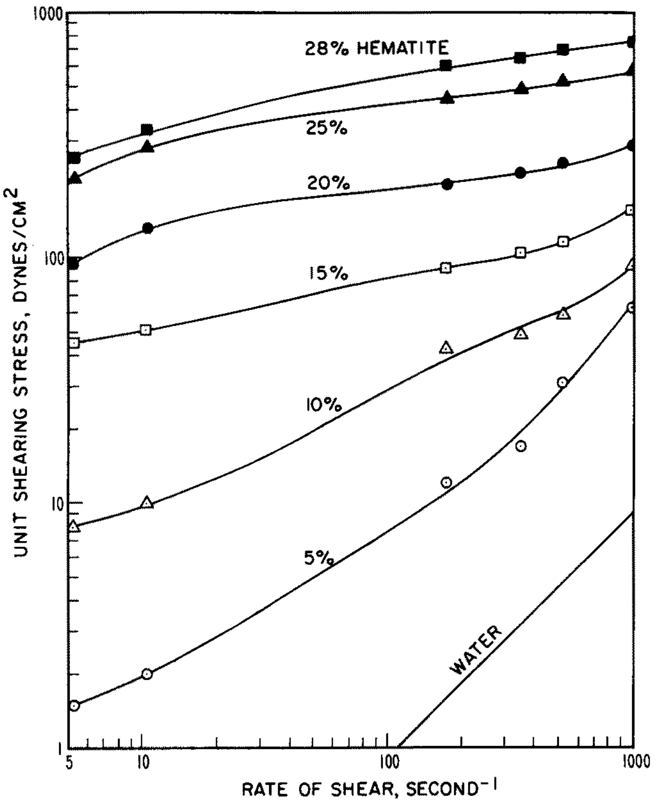

FIG. 1. Effect of hematite concentration (volume per cent −325 mesh) on unit shearing stress of slurry.

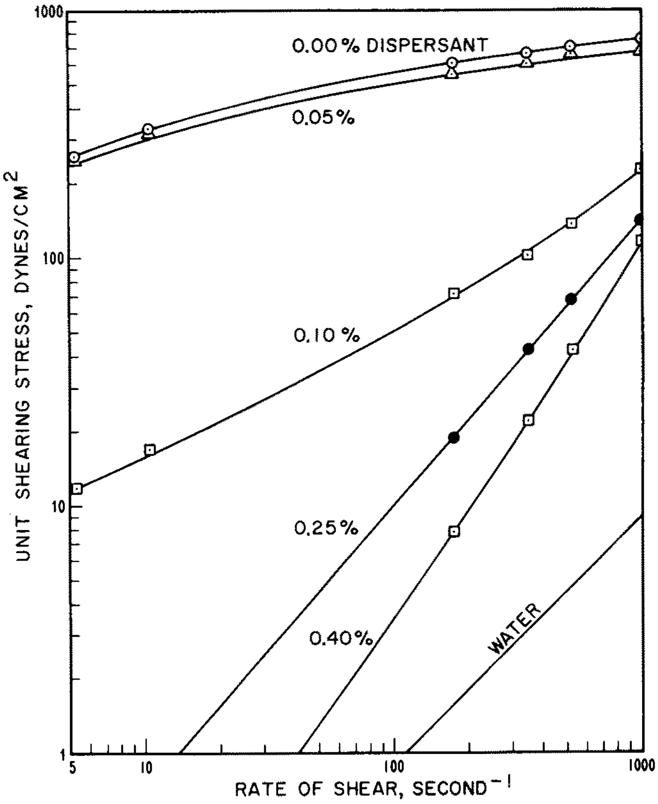

FIG. 2. Effect of dispersant (weight per cent) on unit shearing stress of 28% hematite slurry (−325 mesh).

The marked influence of a dispersant on the apparent viscosity of the 28% hematite slurry is shown in Figure 2. Adding higher concentrations of dispersant caused a systematic reduction in the viscosity of the slurry up to concentrations of 0.40%. The concentrations of dispersant are based on the weight of solid in the slurry. There was no further reduction in viscosity at higher concentrations of dispersant. In fact, at concentrations above 0.40% the viscosity began to increase.

The viscosity control additive produced Fann viscosities greater than that of water at all concentrations tested. As the concentration was increased the solutions exhibited non-Newtonian behavior. However, in the flow trough experiments shown in Figure 3 one concentration of additive, 0.03% by weight of water, caused the flow rate of water to increase 25% from 31.5 to 39.5 gal/min at a trough inclination of 0.10 ft/ft. At higher concentrations the flow rate was slower than that of water.

The lower viscosity caused by adding dispersant to the 28% hematite slurry shown in Figure 2 produced the expected increase in flow rate shown in Figure 4. The magnitude of the effect is shown by comparing the flow rates at a trough inclination of 0.15 ft/ft. The slurry without dispersant had a flow rate of 3.5 gal/min compared with a rate of 31 gal/min when only 0.05% dispersant was added.

The maximum flow rate in the trough tests was set by the pump capacity and the minimum flow rate by the point at which solids would "drop-out" of the slurry and pile up on the bottom of the trough. In flow tests, using varying concentrations of −325 mesh hematite without chemical additive, we observed solids building up on the bottom of the trough. We refer to this condition as "drop-out." The drop-out was observed for the 10% slurry at rates below 20 gal/min. When the dispersant was added to the 28% slurry drop-out was again observed at dispersant concentrations of 0.25% at rates below 8 gal/min. The advantage of increased flow achieved by adding dispersant is thus offset to some extent by the increased tendency for solids to drop-out of the slurry.

Fann viscosity data showed that for a given concentration of hematite a size distribution made up of larger particles produced lower viscosities. This was also borne out in the flow trough tests. Figure 5 shows the results for a 40% hematite slurry composed of 9% +200 mesh, 20% +325 mesh. This slurry had a flow rate of 14 gal/min at an inclination of 0.145 ft/ft whereas the 40% hematite slurry composed of

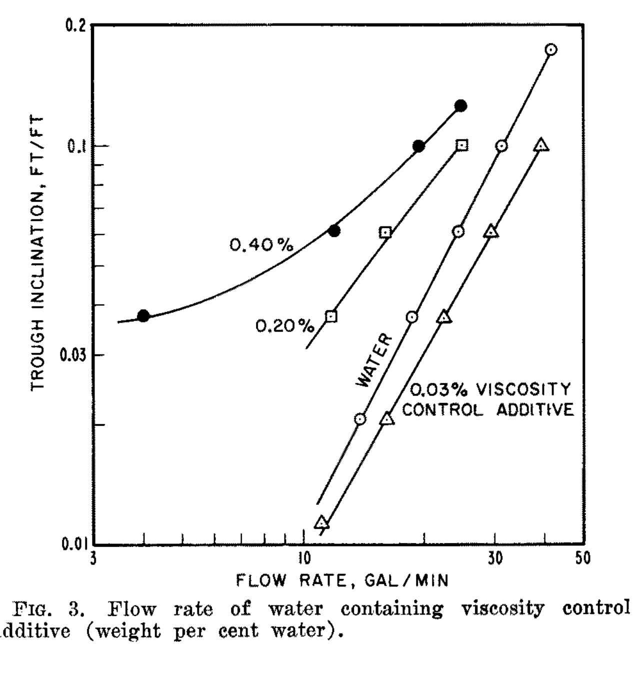

FIG. 3. Flow rate of water containing viscosity control additive (weight per cent water).

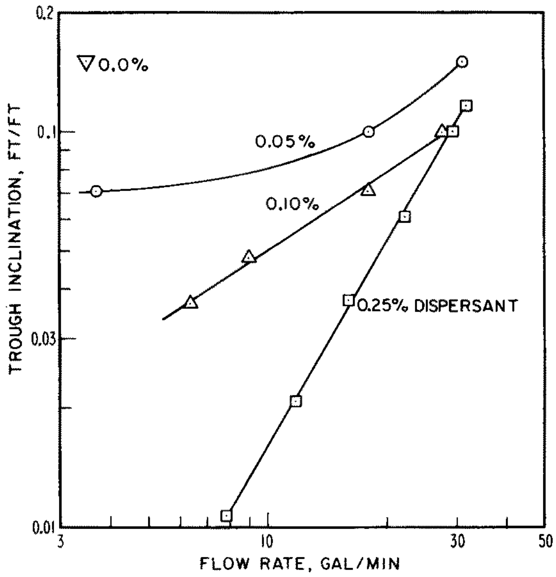

FIG. 4. Flow rate of 28% hematite slurry (−325 mesh) containing dispersant (weight per cent solid).

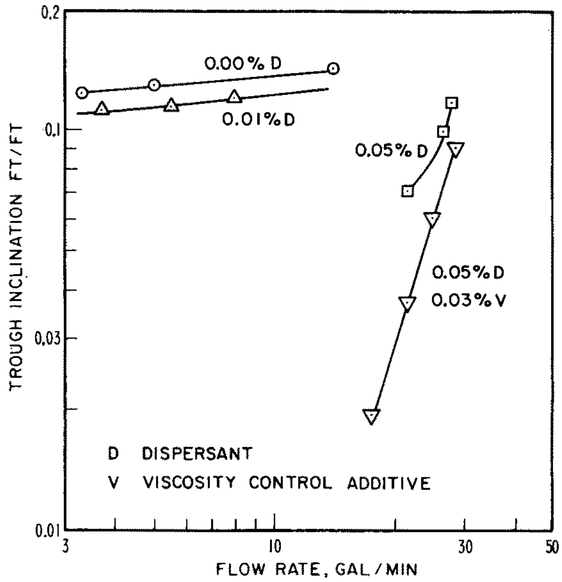

FIG. 5. Flow rate 40% hematite slurry (20% +325 mesh) containing dispersant and viscosity control additive.

100% −325 mesh slurry would not flow. Figure 5 also shows the effect on the flow of a coarse slurry caused by adding dispersants. At 0.05% dispersant the flow rate was significantly increased but drop-out occurred at flow rates lower than 22 gal/min. By adding viscosity control chemical to this slurry the coarse particles were kept in suspension at much lower trough inclinations and drop-out did not occur until the flow rate dropped below 18 gal/min.

The fundamental problem of evaluation of the forces exerted on the individual slurry particles by the fluid, the relation of these forces to the actual particle behavior and the resultant energy losses have been considered in detail by Newitt et al. (4). Superimposed on these interactions is the influence of the dispersant. Our data show that particle interaction is significantly decreased by dispersant so that viscosities are reduced and flow rates are greatly increased.

Some polymers in low concentration appear to suppress turbulence in water flowing at high rates and as a result reduce the pressure required to produce a given flow rate. One author (5) attributes this property to the viscoelasticity of the polymer. Visualize long chain molecules orienting themselves preferentially in the direction of flow and impeding lateral velocity fluctuations. Our data show that the effective concentration of polymer, based on weight per cent water, was identical in water and slurry, suggesting that its function is related to pipe water interaction in both systems. The effect of the viscosity control additives was to increase the carrying capacity of the slurries for coarse particles.

ACKNOWLEDGMENT

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