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Rheology of Coal-Water Slurries Prepared by the HP Roll Mill Grinding of Coal

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INTRODUCTION

The objective of this research is the development of improved technology for the preparation of coal-water slurries that have potential for replacing fuel oil in direct combustion. This should be of major importance to the United States in its efforts to reduce dependence on imported oil and to rely more on its enormous low-cost coal resources.

In Quarterly Report No. 1, we summarized preliminary results on the rheological behavior of coal-water slurries prepared from Pittsburgh No. 8 coal that had been ground in a ball mill under various conditions. Quarterly Report No. 2 presented the results of studies of the effect of solids content and the immobilization of water on the rheological behavior of coal-water slurries. We also compared the rheological behavior of coal-water slurries measured with the Haake viscometer and a Brookfield viscometer and found that the Haake Rotovisco RV12 viscometer with an MV II sensor is superior to the Brookfield Synchro-Lectric LVT viscometer with a spindle No. 4 for coal-water slurries. In Quarterly Report No. 3, we compared the rheological behavior of Pittsburgh No. 8 coal-water slurries obtained using the Haake RV-12 viscometer with both the MV-II and MV-DIN sensor systems and found that the MV-DIN sensor system performs better than the MV-II sensor system for slurries with high solids content. Quarterly Report No. 3 also presented the results of studies of the effect of chemical additives (the Triton X series of nonionic surfactants) on the rheological behavior of coal-water slurries. The results showed that the addition of these nonionic surfactants significantly reduces the viscosity of the slurries, especially at higher reagent additions (1 wt%), and those nonionic surfactants having a larger number of ethoxy groups in the molecules are more effective for reducing the viscosity of a slurry than the surfactants with a smaller number of ethoxy groups.

because of the hydrophilic nature of ethoxy groups.

During the Fourth Quarter, we studied the effect of the initial mixing procedure in the preparation of coal-water slurries, the storage time of ground coal samples, and the addition of anionic surfactants such as 2-TEPA on the rheology of coal-water slurries. The details of these studies are presented in the following paragraphs.

EFFECT OF THE INITIAL MIXING PROCEDURE IN THE PREPARATION OF COAL-WATER SLURRIES ON THEIR RHEOLOGICAL BEHAVIOR

In the earlier experimental investigation, the coal-water slurries used to evaluate their rheological behavior were prepared by manually mixing coal with water in a plastic bottle, and then conditioning the slurries in a mechanical shaker for 16 hours at 20°C. However, this procedure presents some difficulties in obtaining homogeneous slurries when the solids content is over 60 wt%. In this quarter, the effect of the mechanical mixing in the preparation of coal-water slurries on their rheological behavior was studied. In these experiments, Pittsburgh No. 8 coal was used in preparing the slurries. This coal sample was dry ground in a ball mill for 30 minutes to produce a product with particles 90% finer than 75 μm and a mean size of 27 μm . Coal-water slurries were prepared by mixing the coal sample with water in a plastic bottle, and then stirring the slurry for 5 minutes at 1000 rpm. The slurries were then conditioned for 16 hours at 20°C. The rheological behavior of the coal-water slurries was determined using the Haake RV-12 Viscometer with the MV-DIN sensor system. Coal-water slurries of 60 wt% solids content without chemical additives and 60 to 67 wt% solids content with the addition of 1 wt% Triton X-405 were prepared. Triton X-405 was chosen because it significantly reduces the viscosity of coal-water slurries, as discussed in Quarterly Report No. 3.

Figure 1 compares the flow curves obtained for slurries having 60 wt% solids content prepared by manual and mechanical stirring in the absence of chemical additives. This figure

Figure 1. Flow curves (rheograms) for Pittsburgh No. 8 coal-water slurries having 60 wt% solids content in the absence of chemical additives.

Figure 2. Viscosity curves for Pittsburgh No. 8 coal-water slurries having 60 wt% solids content in the absence of chemical additives.

shows that the slurry prepared with mechanical-initial mixing has lower shear stress than that prepared by manual mixing in the shear rate range of 50 s^{-1} to 500 s^{-1} . Furthermore, no slipping of the rotor was observed when mechanical-initial mixing was applied to the slurries. Figure 2 presents the viscosity as a function of shear rate for coal-water slurries (60 wt%) in the absence of chemical additives. Clearly, the slurry prepared with the mechanical initial mixing has lower viscosity than that with manual mixing. It appears that this mechanical-initial mixing step contributes to the dispersion of particles more efficiently than does manual mixing. Possibly edges, corners and rough surfaces of the particles are also abraded to smoother their surface. Moreover, mechanical-initial mixing improves the initial wetting of the coal particles, reducing the presence of agglomerates of small hydrophobic coal particles.

Figure 3 presents the flow curves for Pittsburgh No. 8 coal-water slurries at different solids content in the presence of 1 wt% Triton X-405 with both manual and mechanical-initial mixing. These plots show that up to 66 wt% solids content no slipping of the rotor was observed at shear rates over 165 s^{-1} in the case of mechanical-initial mixing, in contrast to the behavior of manually mixed systems. Furthermore, mechanical initial mixing also significantly reduces the yield stress of coal-water slurries with higher solids content (66 and 67 wt.%).

The effect of solids content on the viscosity of coal-water slurries prepared by manual and mechanical-initial mixing is shown in Figure 4. As expected, for both slurry preparation procedures, the viscosity of Pittsburgh No. 8 coal-water slurries increases sharply as the solids content increases at the shear rate of both 83 s^{-1} and 165 s^{-1} , which agrees with the findings of other researchers [1]. This is mainly due to less water available for the particles to flow as the solids concentration increases. Furthermore, the results given in Figure 4 show that at the shear rates of both 83 s^{-1} and 165 s^{-1} , the viscosity of the slurries prepared with mechanical-initial mixing is lower than that prepared without mechanical-initial mixing at a given solids content. This may be due not only to the improved dispersion of the particles but also to the smoothing of and smoothes sharp edges, corners and rough surface of coal particles, which reduces the resistance of particles to flow.

Figure 3. Flow curves (rheograms) for Pittsburgh No. 8 coal-water slurries of different solids content in the presence of 1 wt% Triton X-405: (a) manual-initial mixing and (b) mechanical-initial mixing.

Figure 4. Viscosity of Pittsburgh No. 8 coal-water slurries as a function of solids content in the presence of 1 wt% Triton X-405 for both manual and mechanical-initial mixing at the shear rates: (a) 83 s^{-1} and (b) 165 s^{-1} .

Figure 5. Viscosity of Pittsburgh No. 8 coal-water slurries having 60 wt% solids content as a function of storage time for four different shear rates.

EFFECT OF STORAGE TIME OF THE GROUND COAL SAMPLE

In this research project, the coal samples used to prepare coal-water slurries for rheological measurements were obtained by dry grinding 500 grams of coal in a ball mill for 30 minutes to produce a product with 90% of the particles finer than 75 μm and a mean particle size of 27 μm . After grinding, the coal sample was then stored in a glove box under an argon atmosphere to minimize coal oxidation. Normally, one batch of the ground sample was consumed in a week. To delineate the effect of storage time of the ground samples on their slurry rheology, Pittsburgh No. 8 coal-water slurries having 60 wt.% of solids content were prepared following the mechanical mixing procedure using the ground sample stored for 0 to 30 days. No chemical additives were used in the slurry preparation.

Figure 5, which presents the viscosity of the slurries as a function of storage time at four

different shear rates, shows that the measured viscosity decreases slightly as the storage time of the coal sample increases from 0 to 30 days. For example, the decrease in the viscosity due to storage up to 30 days is 15% and 12% at shear rates of 83 s^{-1} and 165 s^{-1} , respectively. This indicates that little oxidation of the coal surfaces has taken place during this period since oxidation of coal would result in the formation of oxygenated functional groups on its surface which make the coal more hydrophilic and reduce the viscosity of a coal-water slurry. However, the reduction in the viscosity due to storage time is not significant comparing with that due to the addition of chemical additives. With our normal storage time of 6 days, the decrease in the viscosity of the slurries due to the storage is less than 3% at the shear rates of 83 s^{-1} and 165 s^{-1} .

EFFECT OF CHEMICAL ADDITIVES

2-TEPA, an anionic hydrophilic reagent of short hydrocarbon chain, belongs to a family of reagents that contains sulfur and Nitrogen its molecule. Even though this reagent has a short hydrocarbon chain in comparison with the Triton X series of reagents, the hydrophilic 2-TEPA was selected to evaluate the effect of reagents functional groups of high electronegativity, which could disperse the system better. In this series of experiments, coal-water slurries of 60 wt% solids content were prepared with the mechanical-initial mixing procedure in the presence of 2-TEPA reagent. Figure 6, which presents the effect of 2-TEPA concentration on the shear stress of Pittsburgh No. 8 coal-water slurries as a function of the shear rate, shows that the shear stress decreases as the reagent addition increases and that the coal-water slurries maintain a pseudoplastic fluid with a yield stress for all reagent additions. The effect of 2-TEPA on the viscosity is shown in Figure 7. As was expected, this figure shows that the viscosity is decreased with the increase in the reagent dosage and the shear rate. Figure 8 presents the measured viscosity as a function of the 2-TEPA addition for four different shear rates. Similar to the case of the nonionic surfactants discussed in Quarterly Report No. 3, the viscosity decreases as the concentration increases. This reagent seems to decrease the viscosity of the slurries by

Figure 6. Flow curves (rheograms) of Pittsburgh No. 8 coal-water slurries having 60 wt% solids content at different 2-TEPA additions.

Figure 7. Viscosity of Pittsburgh No. 8 coal-water slurries having 60 wt% solids content as a function of shear rate at different 2-TEPA additions.

Figure 8. Viscosity of Pittsburgh No. 8 coal-water slurries having 60 wt% solids content as a function of 2-TEPA addition at four different shear rates.

adsorbing on the surface of coal particles, which increases the electrical repulsive forces and hydrophilicity of the coal particles. At 0.5 wt% of 2-TEPA addition, a small increase in the viscosity is observed. This could be related to the increase in the effective radii of the particles due to the adsorption of this hydrophilic compound on the coal surface, as discussed in Quarterly Report No. 3.

SUMMARY

The effect of the initial mixing procedure in the preparation of coal-water slurries on their rheological behavior was investigated. It appears that a better dispersion of the particles in the water can be obtained by mechanically stirring the slurries at 1000 rpm for 5 minutes instead of mixing manually before conditioning the slurries in a shaker for 16 hours at 20°C. As a consequence, the slurries prepared using mechanical-initial mixing had a lower yield stress and

viscosity than those obtained by manual-initial mixing, probably due to the elimination of partially wetted agglomerates of coal particles, and possibly to the smoother surface of coal particles in the slurries. However, for both modes of initial mixing, the yield stress and the viscosity increase sharply as the solids content increases, which seems to be related to the decrease in the water available for the particles to flow as the solids content increases.

In studying the effect of storage time of ground samples on the rheological behavior of their slurries, we found that the viscosity of the slurries decreases slightly as the storage time is increased up to 30 days, indicating little oxidation of the surface of coal particles has taken place during this period. However, for our normal storage time of less than six days, the drop in the viscosity is within 3% at shear rates of 83 s^{-1} and 165 s^{-1} .

The effect of 2-TEPA, an anionic and hydrophilic reagent, on the rheology of coal-water slurries was also studied. Despite of the short hydrocarbon chain of this reagent, the addition of this reagent does reduce the viscosity of a coal-water slurry. This may be due to the adsorption of the reagent onto the surface of coal particles which renders their surfaces both negatively charged and more hydrophilic.

RESEARCH WORK PLAN FOR NEXT QUARTER

During the fifth quarter, investigation of chemical additives on the viscosity, sedimentation rate, and sedimentation volume of coal-water slurries will be continued. The effect of high pressure roll grinding on the rheological behavior of coal-water slurries will be initiated.

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