

DOE/PC/92526--T11

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

DOE Grant No. DE-FG22-92PC92526

Quarterly Technical Progress Report No. 11
March 1, 1995 - May 31, 1995

Prepared By

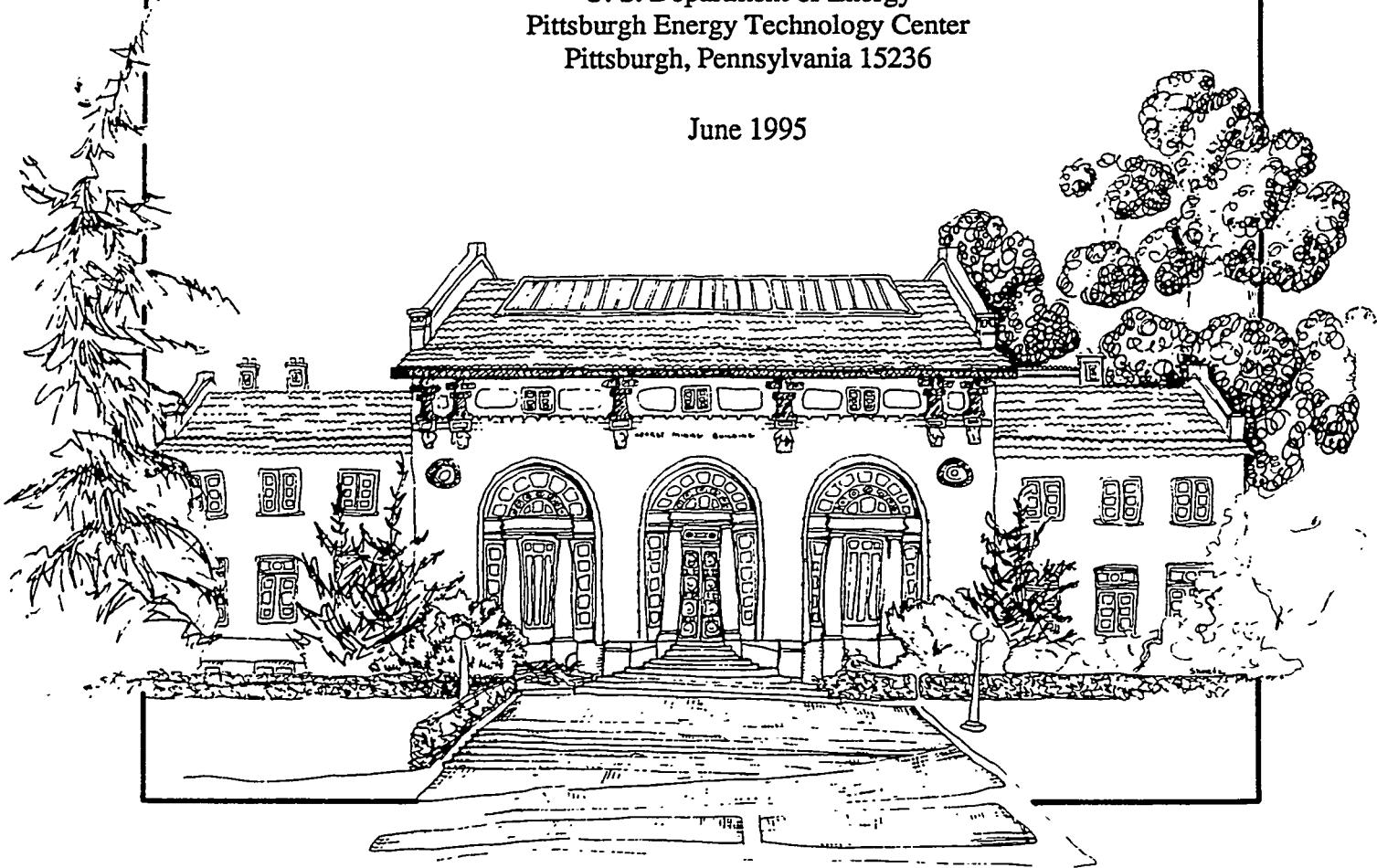
D. W. Fuerstenau
Principal Investigator
University of California
Berkeley, California 94720

Prepared For

U. S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania 15236

June 1995

RECEIVED
USDOE/PETC
95 AUG 11 AM 10:36
REGISTRATION & ASSISTANCE DIV.



Hearst Mining Building
University of California, Berkeley

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

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

DOE Grant No. DE-FG22-92PC92526

Quarterly Technical Progress Report No. 11

March 1, 1995 - May 31, 1995

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 accordance with this objective, in the first stage of this project, considerable work was conducted to standardize experimental procedures for sample preparation, coal grinding, and rheological measurements to assure reproducibility of the experimental results. Since a Haake RV-12 viscometer with an MV-DIN sensor system was found to give the most reproducible results for measurement of slurry viscosities, it has subsequently been used for all of our rheological measurements. Methods were developed for applying the acoustophoresis technique for studying the electrokinetic behavior of concentrated coal-water suspensions. These measurements were carried out using this technique to identify the potential of chemical additives for functioning as reagents for effective dispersion. Detailed investigations of the effect of solids content and chemical additives on the rheology of coal-water slurries, prepared with fines produced by the ball milling of Pittsburgh No. 8 coal, were conducted during the first phase of our research program. These experiments were to provide a baseline against which the rheological behavior of slurries prepared with fines produced by high-pressure roll milling or hybrid high-pressure roll mill/ball mill grinding could be compared.

Detailed investigation of the effect of high-pressure roll milling on the energetics of fine grinding and the rheology of coal-water slurries prepared with such fines was carried out in the

second stage of the project. Preliminary investigations showed that although the high-pressure roll mill grinding of Pittsburgh No. 8 coal resulted in a briquetted product, due to the plastic nature of bituminous coals, deagglomeration of the briquettes and further reduction in particle size could be achieved by grinding the roll mill product in a ball mill with modest additional energy expenditure. Our experimental results indicated that a given degree of size reduction could be achieved by hybrid high-pressure roll mill / ball mill grinding with significantly lower energy expenditure as compared to that required for grinding in a ball mill alone. Viscosity measurements showed that the rheological properties of the slurries prepared with fines produced by the hybrid grinding of coal are similar to or better than slurries prepared with fines produced by grinding coal in a ball mill only. A commercially available popular reagent used to prepare the slurries, Coal Master A-23-M from Henkel Corporation, proved to be a very efficient dispersant.

Study of the aging behavior of slurries showed a non-linear increase in their apparent viscosity over time. This increase was found to be partly due to iron released through the oxidation of pyrite contained in the coal. This was confirmed through spectroscopic studies and chemical analysis. Removal of iron by washing coal with iron-complexing reagents significantly lowered the apparent viscosity of freshly prepared coal-water slurries and slowed down the degradation of the rheological properties of the slurries, but only temporarily. Physical cleaning of coal, prior to the preparation of slurries, further improved the long-term rheological behavior of the slurries.

The viscosity of slurries with high solids content is strongly influenced by the packing density of the feed material. The packing density can be significantly altered by mixing distributions of different median sizes, and to an extent by modifying the grinding environment. The research during this quarter was, therefore, directed towards: 1) establishing the relationship between the packing characteristic of fines and the viscosity of slurries prepared with the fines 2) investigation of the effect of mixing distributions on the rheology, and 3) study of the effect of grinding environment in the ball mill on the rheology of coal-water slurries.

RELATIONSHIP BETWEEN THE PACKING DENSITY OF FEED AND THE VISCOSITY OF SLURRY

The viscosity of coal-water slurries at high solids content is strongly influenced by the surface and packing characteristics of the particles. Improvement in the rheology of dense slurries can be achieved either by addition of chemical modifiers or by modifying the packing density of the solids. In this section, we will attempt to correlate the rheological behavior of slurries with the packing density of the feed material.

First, a minus 8-mesh coal sample was ground in the high-pressure roll mill and then reground in a 10-inch ball mill with respective energy expenditures of 2.0 kWh/t and 1.0 kWh/t. The ball mill discharge was screened at 150 mesh and the undersize (median size being 28 μm) was further ground in a 5-inch ball mill to median sizes of 22 and 10 microns. The packing densities of the fine products were measured using a tap density machine. The fines were used to prepare coal-water slurries containing 61, 63, 65, 66 and 67 weight percent solids. Apparent viscosities of the slurries as a function of solids content (by volume) are shown in Figure 1. It can

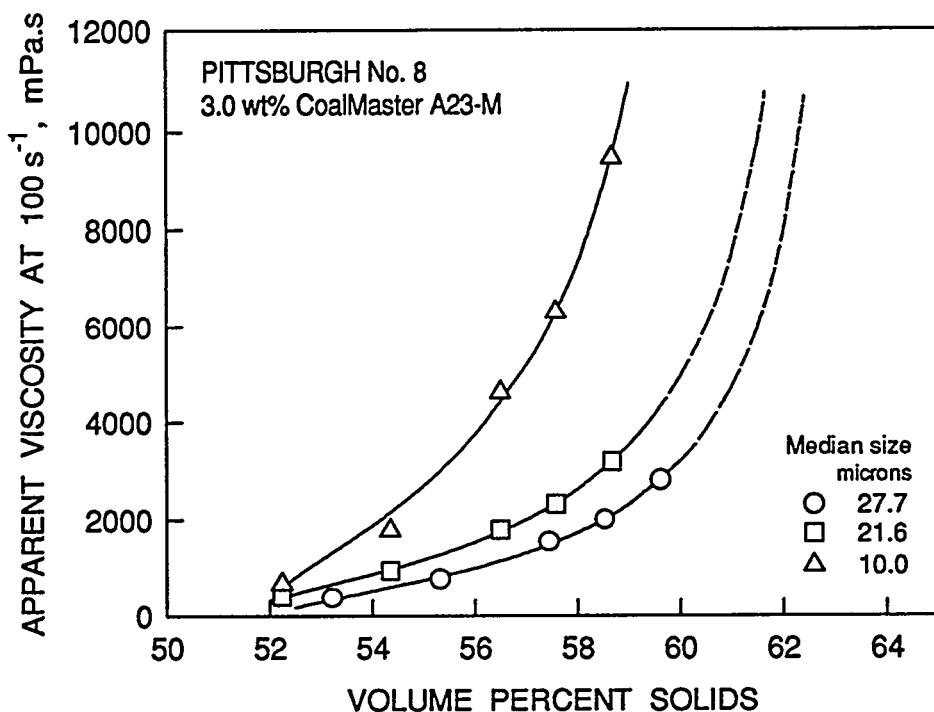


Figure 1. Apparent viscosity of coal-water slurries, prepared with fine feed of various median sizes, as a function of volume percent solids in the slurry.

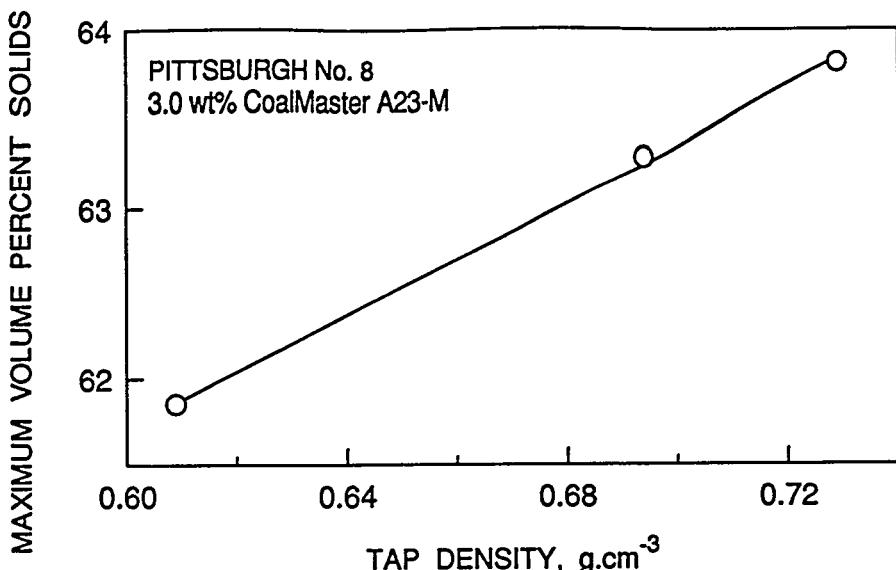


Figure 2. Relationship between the tap-density of the feed and the maximum volume percent solids in the slurry.

be seen from Figure 1 that there is a non-linear increase in the apparent viscosity, at any given solids content with increased fineness of the feed. Estimated maximum volume percent solids are plotted in Figure 2 against the tap densities of the feeds. Figure 2 shows that there is a linear dependence between the tap density and the maximum volume percent solids. It turns out that for unimodal, self-similar distributions, the tap density increases exponentially with the increase in the median size of the distribution, as shown in Figure 3.

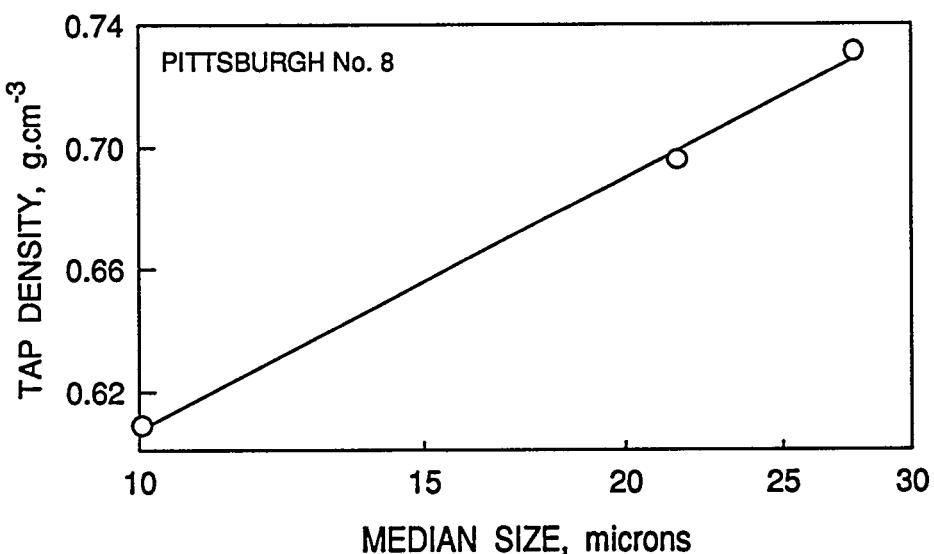


Figure 3. Relationship between the median size and the tap-density of fine coal products.

EFFECT OF MIXING FEED DISTRIBUTIONS ON THE PACKING DENSITY OF COAL FEED AND THE RHEOLOGY OF COAL-WATER SLURRIES

In the previous section, we established the relationship between the packing density of the ground coal and the maximum possible solids content of coal-water slurries prepared with those ground products. We observed that an increase in the packing density of the feed results in a linear increase in the maximum possible solids content of the slurry. This implies that any improvement in the packing density of the feed material should result in a corresponding decrease in the viscosity of the slurry, with a given solids content, prepared with such feed.

It is well-known that mixing different particle sizes increases the packing density, especially when the particles are very different in size. The improved packing density is a consequence of the smaller particles filling the interstices between the packed coarse particles. For every ratio of particle sizes, there is a composition that will optimize the packing density. Continuous particle size distributions can also be mixed to improve the packing density. A density benefit from such a mixture requires a large difference in the mean sizes of the two distributions. As in the case of mixing different particle sizes, the packing density of the mixed distributions increases as the ratio of the mean particle sizes increases. The results of our studies on the effect of mixing distributions on the packing density of fine coal feed and the viscosity of coal-water slurries prepared with such ground products are presented in this section.

The three distributed ground coals, mentioned in the previous section, were used for these studies and are designated as coarse (C), medium (M), and fine (F) distributions, their median sizes being 28, 22 and 10 μm , respectively. Four binary mixtures were investigated — three of these were mixtures of medium and fine distributions with M/F ratios of 4:1, 2:1, and 1:1, and the fourth was a coarse-fine mixture with C/F ratio of 7:3. Coal-water slurries, with 61, 63, 65, 66 and 67 weight percent solids content, were prepared using each of the feed mixtures.

The tap densities of the mixtures as well as the original distributions are plotted in Figure 4 against the logarithm of median size of the feeds. As is apparent from the figure, mixed

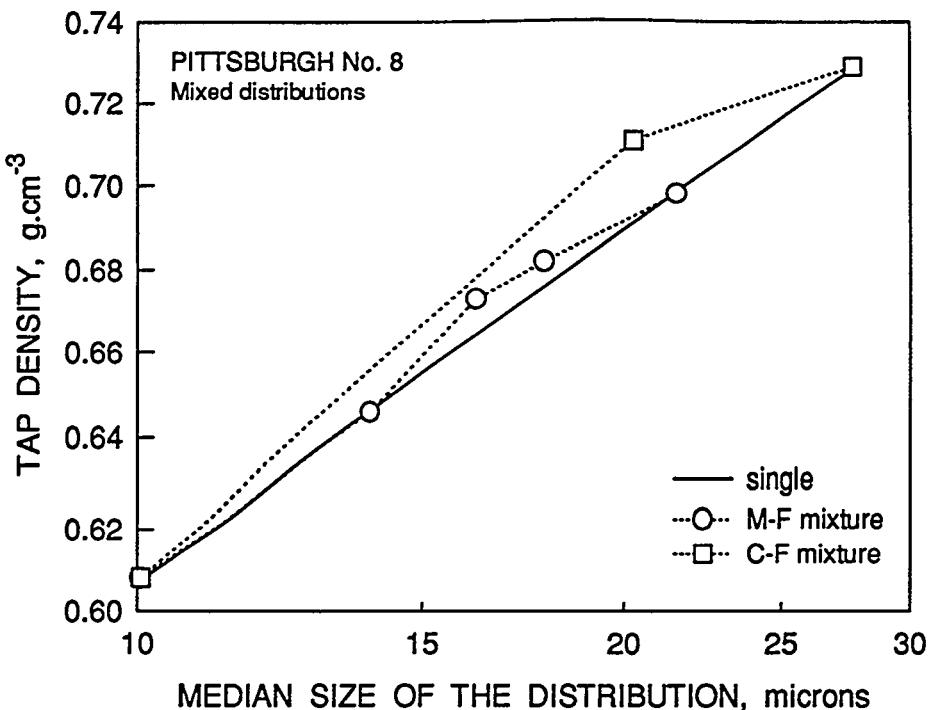


Figure 4. The effect of mixing distributions on the median size and the packing density.

distributions have a higher packing density than that of single distribution with the same median size. The improvement is more pronounced in the case of coarse-fine mixture.

Figure 5 shows the apparent viscosities of the coal-water slurries of various solids contents as a function of the fraction of the medium distribution in the M-F mixtures. As seen from the figure, except at the highest solids content where the viscosity increases almost exponentially with increasing fraction of fines, the addition of the fine-component up to about 30 percent either lowers the viscosity or leaves it unchanged. The apparent viscosity of slurries prepared with the mixed distributions are plotted as a function of the median size of the distributions in Figure 6. The apparent viscosities of single distributions are also shown in the figure for the sake of comparison. The benefit of mixing distributions is even more clear from this figure when one compares the plots for the single distributions with those for the mixed distributions. The results presented in the figure also show the superiority of the C-F mixture over M-F mixtures. This is consistent with the observation made earlier regarding the effect of the ratio of the median sizes of the distributions on the packing density.

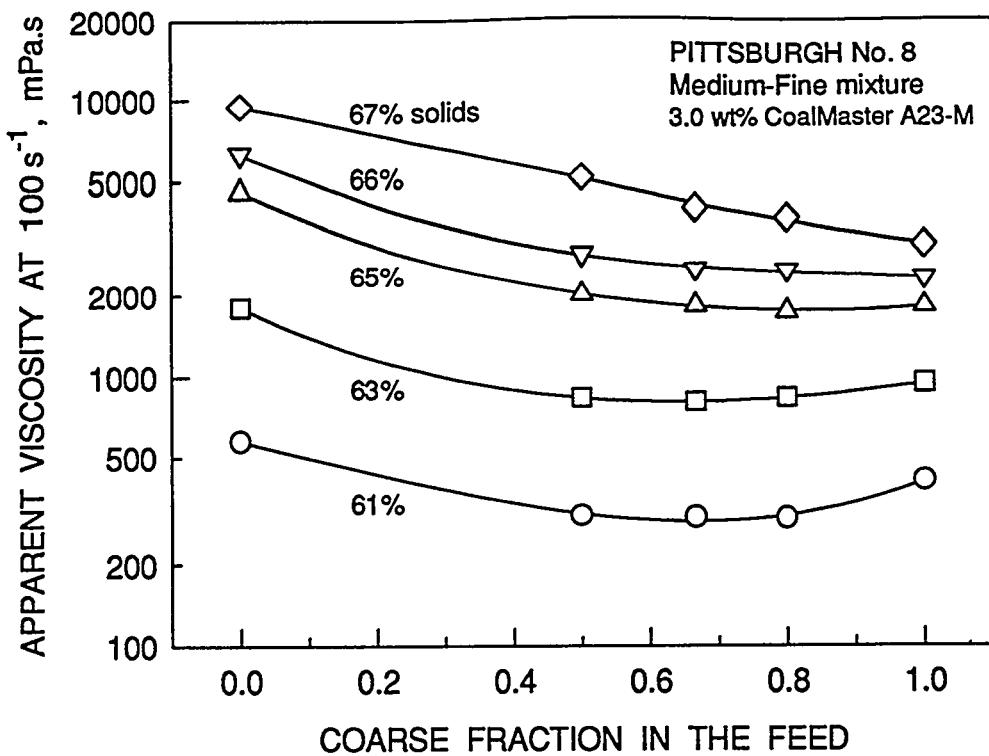


Figure 5. The effect of the fraction of coarse component(M) in medium-fine mixed distributions on the apparent viscosity of slurries prepared with such mixed feeds.

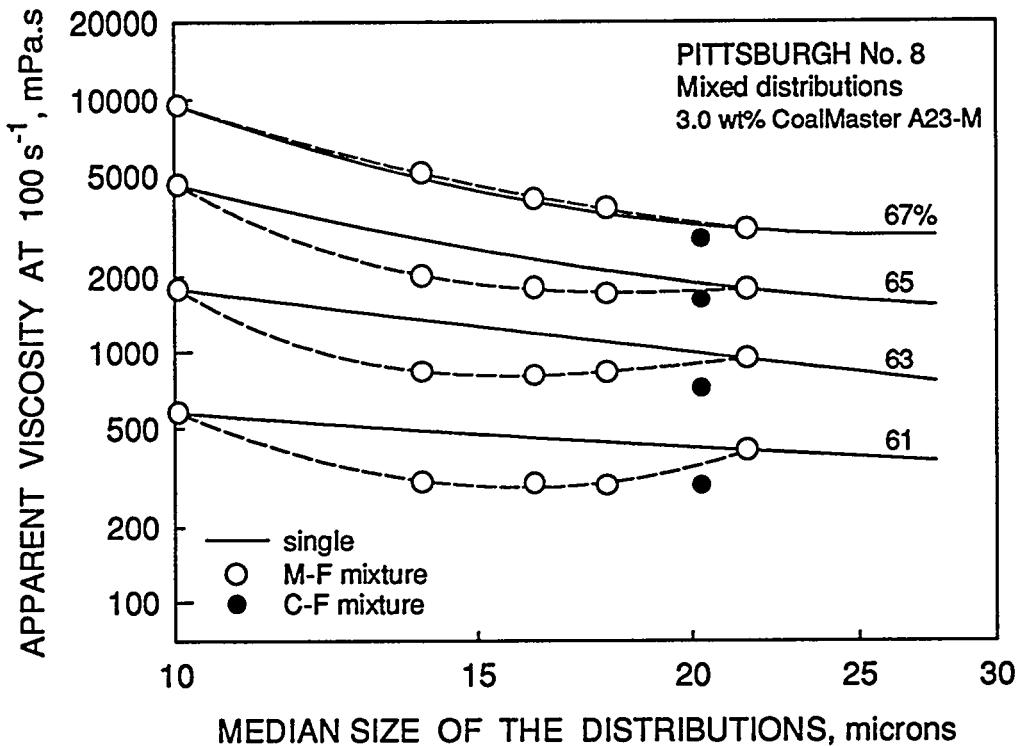


Figure 6. Comparison of the apparent viscosity of slurries prepared with single-component feeds with that of slurries prepared with mixed feeds.

INFLUENCE OF GRINDING ENVIRONMENT IN THE BALL MILL ON THE ENERGY UTILIZATION AND THE RHEOLOGY OF SLURRIES

Fine grinding of coal for our research has been carried out mostly under dry conditions primarily because of the difficulty of experimentation using wet grinding conditions. Preparation of coal-water slurries with dry fines involves addition of water and mixing at high shear. It is known that energy utilization in wet grinding is slightly higher than that in dry grinding. Optimal energy utilization in wet grinding, however, depends on the solids content of the slurry in the mill. Beyond a certain solids content, there is a significant decrease in the energy utilization with increasing fineness of grind. The addition of grinding aids which lower the viscosity of the slurry helps prevent this loss in efficiency. In the mineral processing industry, reagents are often added to the wet-grinding stage to facilitate uniform adsorption of reagents on the mineral surfaces.

Research work has been initiated in this quarter to study the effect of wet grinding with and without dispersant on the energy utilization and rheology of slurries prepared with fines produced by wet grinding.

A minus 8-mesh coal sample was ground in the 5-inch torque ball mill for 30 minutes under dry, wet, and wet with an addition of 0.5 wt% CoalMaster. Wet grinding was carried out at 60 wt% solids content. The torque and the mill speed were continuously measured during the grinding experiments. Figure 7 shows the variation of net torque with time for each of these experiments. While the torque during dry grinding remains more or less constant with time, there is a steady decrease in the grinding torque with time beyond the first few minutes. As can be seen from the figure, the addition of CoalMaster prevents such a lowering of torque.

Similar experiments were carried out with high-pressure roll mill ground product. The torque-time profiles for these experiments are given in Figure 8. Unlike the results for wet grinding of primary feed without CoalMaster, there is no decrease in torque over time for wet grinding of the high-pressure roll mill product. This is perhaps due to improved packing density of the feed during high-pressure roll mill grinding.

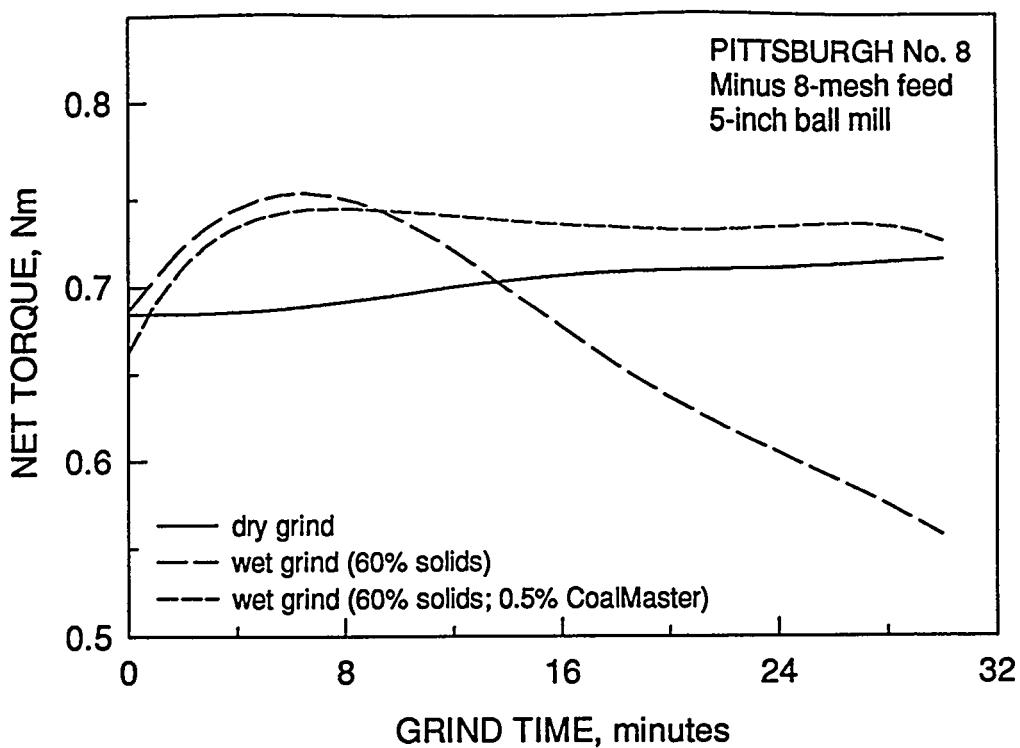


Figure 7. Effect of grinding conditions on the efficiency of ball mill grinding of primary feed.

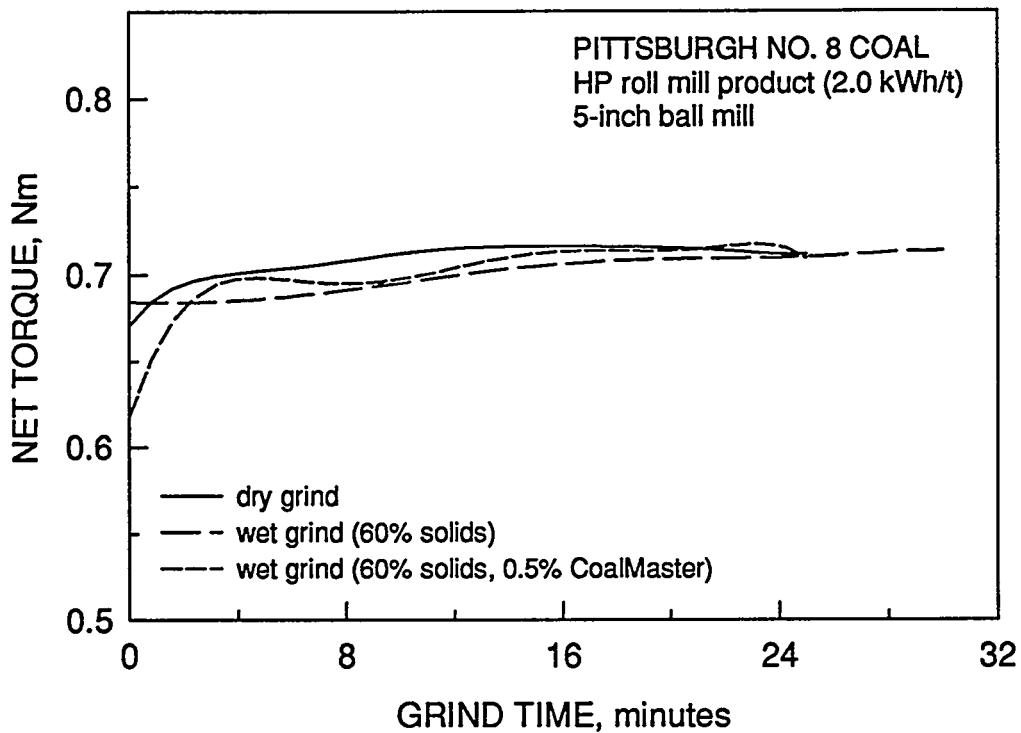


Figure 8. Effect of grinding conditions on the efficiency of ball mill grinding of high-pressure roll mill product.

Table 1. Effect of grinding conditions on the efficiency of ball mill grinding of primary feed and high-pressure roll mill product.

Grinding condition	Specific grinding energy, kWh/t	Percent minus 200-mesh	Median size, μm	
			Mill discharge	Minus 200-mesh
Primary feed				
Dry	15.0	85.2	33.9	27.3
Wet (60% solids)	14.5	87.0	32.3	26.0
Wet (60% solids) with 0.5 wt% CoalMaster	15.9	92.1	28.4	24.6
HPRM product				
Dry	14.7	90.9	29.2	26.0
Wet (60% solids)	15.6	94.2	24.8	22.3
Wet (60% solids) with 0.5 wt% CoalMaster	14.6	92.3	26.2	22.5

Table 1 gives a summary of the grinding condition for each of these experiments as well as the total specific grinding energy and median sizes of the ball mill discharge and the minus 200-mesh fraction in the discharge. Although there are differences in the specific grinding energy and the product median size, the particle size distributions are essentially self-similar as shown in Figure 9.

Besides improving the efficiency of grinding, wet grinding probably results in better rheological properties, as suggested by the viscosity measurements on slurries prepared with minus 200-mesh fines produced by wet grinding. Figure 10 shows the apparent viscosity plots as a function of shear rate for the slurries prepared with fines produced by ball mill grinding of primary feed under different conditions as well as by wet grinding of the high-pressure roll mill product without any dispersant. If the effect of median size of the distribution is taken into account, the results presented in the figure indicate that wet grinding results in a lowering of viscosity. The beneficial effect of high-pressure roll milling is also observable.

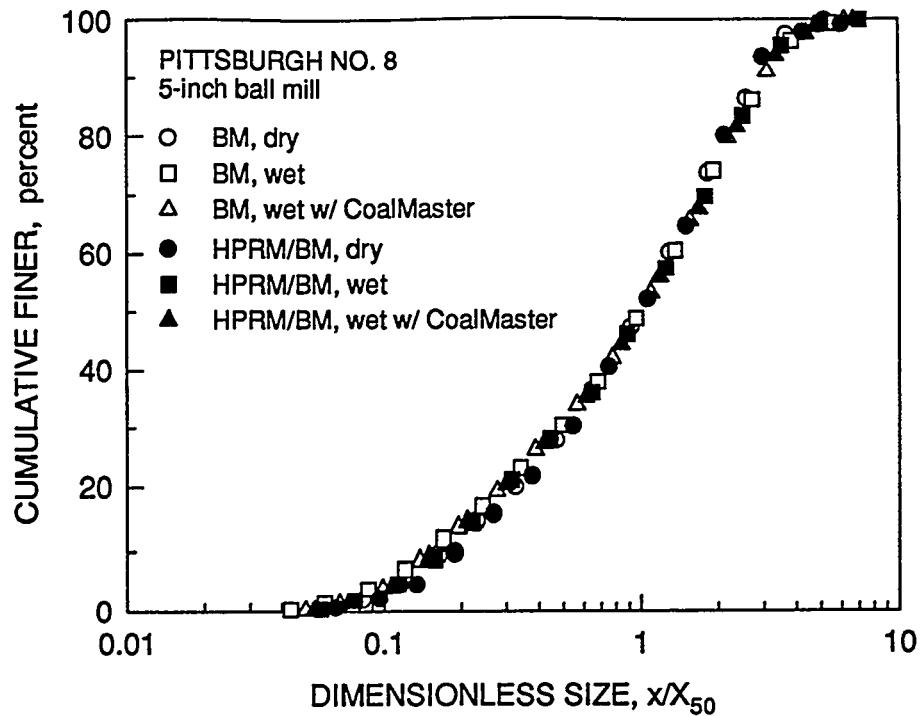


Figure 9. Self-similarity of size distributions produced by ball milling of primary feed as well as high-pressure roll mill product under different grinding conditions.

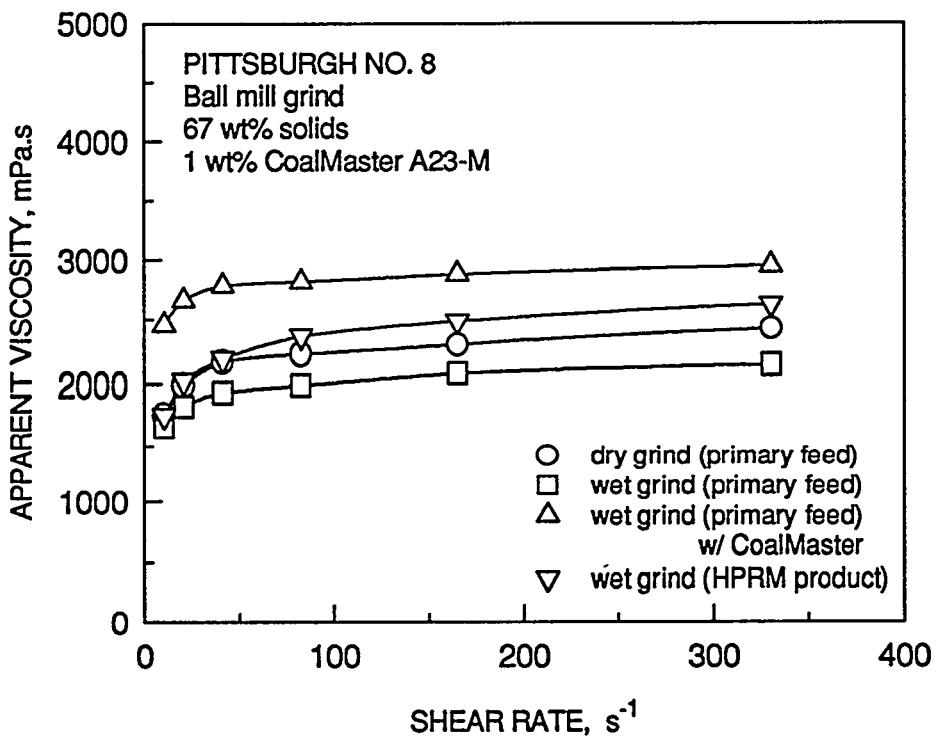


Figure 10. Apparent viscosity as a function of shear rate for slurries prepared with fines produced by ball mill grinding of primary feed under different conditions as well as by wet grinding of high-pressure roll mill product without any dispersant.

RESEARCH WORK PLAN FOR THE NEXT QUARTER

Detailed investigation of the effect of mixing distributions on the rheology will be carried out in the next quarter. In particular, research will be conducted to optimize the ratio of the median sizes of the coarse and fine distributions and the mixing ratio of the distributions. Experiments will be carried out to quantify the specific energy consumption for the preparation of such mixed distributions and compare it against that for a single distribution.

The effect of supplementary modifying reagents on slurry rheology will be investigated in greater detail. The effect of co-addition of various dispersants as well as dispersants and stabilizers on the viscosity of coal-water slurries will be studied. The influence of added iron cations on the viscosity of very clean coal will be studied in order to finally prove that iron removal is the solution of our problem. More work will be done on studying long term viscosity and stability of beneficiated / cleaned coal-water slurries.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.