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RHEOLOGICAL PROPERTIES ESSENTIAL FOR THE ATOMIZATION OF
COAL WATER SLURRIES (CWS).

Quarterly Progress Report
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FRANK OHENE
Department of Chemistry
Grambling State University
Grambling, LA 71245

Technical Project Officer
U. S. Department of Energy
Pittsburgh Technology Energy Center
P. O. Box 10940
Pittsburgh, PA 15236

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OVERALL OBJECTIVE:

The overall objective of this project is to perform experiments to understand the effect of high shear and extensional properties on the atomization of coal-water slurries (CWS). In the atomization studies, the mean drop size of the CWS sprays will be determined at various air-to CWS. A correlation between the extensional and high shear properties, particle size distributions and the atomization will be made in order to determine the influence of these parameters on the atomization of CWS.

Work Done

A CV20 attachment to a Haake RV20 viscometer and a PQ45 sensor were received during this past quarter. This was followed by several hours of calibration of the sensors using a non-elastic fluid. Also, a literature review was made in order to further understand dynamic oscillatory shear flow.

Dynamic Oscillatory Shear measurements or dynamic mechanical measurements a sinusoidally varying shear field is imposed on a fluid and the amplitude of the resulting shear stress and the phase angle between the imposed shear and the stress is measured. The test is said to be in the "linear viscoelastic" regime if the stress is linearly proportional to the imposed strain and the stress response is sinusoidal [1].

The oscillating velocity field can be written as:

$$V_x = [\gamma_{\max} \cos(\omega t)]y \quad (1)$$

where ω is the frequency, $\gamma_{\max}$ is the maximum velocity gradient and the maximum velocity of the strain is given by $\dot{\gamma}_{\max} = \gamma_{\max} \omega$.

The stress will also oscillate and will also have a maximum value $\tau_{\max}$, and a phase shift Φ , from the imposed shear.

$$\tau_{\max} = \tau_{\max} \cos(\omega t - \Phi) \quad (2)$$

The stress can be decomposed into two terms, one in-phase with the velocity and one 90° out of phase. These can be written in terms of the maximum velocity gradient

$$\tau_{\max} = -\eta' \dot{\gamma}_{\max} \cos(\omega t) - \eta'' \dot{\gamma}_{\max} \sin(\omega t) \quad (3)$$

where $\tau_{\max} \cos(\Phi) = \eta' \dot{\gamma}_{\max}$, and $\tau_{\max} \sin(\Phi) = \eta'' \dot{\gamma}_{\max}$

This defines the two dynamic viscosity coefficients η' and η'' . At low frequencies, η' approaches the zero shear viscosity measured in steady shear. Alternatively, coefficients can be defined in terms of the maximum strain instead of the strain rate.

$$\tau_{xy} = -G' \gamma_{\max} \cos(\omega t) - G'' \gamma_{\max} \sin(\omega t) \quad (4)$$

where

$$\tau_{\max} \cos(\Phi) = G' \gamma_{\max}, \quad \text{and} \quad \tau_{\max} \sin(\Phi) = G'' \gamma_{\max}$$

This defines the two functions G' and G'' which are the storage and loss moduli, respectively. G' , proportional to the stress in-phase with strain, provides information about the elasticity of a material. For example, an ideal elastic rubber band would have all of its stress in-phase with strain or displacement. G'' , the loss modulus, is proportional to stress out-of-phase with displacement and, therefore, in-phase with rate-of-displacement or shear-rate. For a purely viscous liquid, all of the stress is linearly proportional to strain and that the stress response involves only the first harmonic and not higher harmonics in frequency (i.e., the stress is a sinusoidal).

The linear viscoelastic dynamic moduli are functions of frequency. They have proven to be sensitive probes of materials that have structures. Figures 1-4 illustrate the variation of G' and G'' as a function of frequency based on the structure of some materials analyzed [2]. The material begins as a solution in Figure 1, and ends as a solid gel in Figure 2. For materials with yield point, there is a network of physical nature, such as in dispersions, due to dipole forces, hydrogen bridges, electrostatic and/or Van der Waals forces. The strain behavior corresponds to the partly cross-linked substance with $G'=0$ Pa as $\omega \rightarrow 0$.

The variation of G' , G'' and $\tan(\delta)$ as a function of frequency are as shown in Figures 5-7. Comparison of the curves labeled in Figures 5-7 are as follows [3]:

- (1) Unlinked molecules, low molecular weight
- (2) Unlinked molecules, high molecular weight
- (3) Partly cross-linked molecules or substance with yield point
- (4) Fully cross-linked substance

Figures 8-11 show oscillatory shear measurements of 1% xanthan gum solution, 57% , 63% and 65% PSOC-1475 coal slurries. The oscillatory data for the xanthan gum has some characteristics similar to that of Figure 3. This is an indication of a partly cross-linked substance. The oscillatory data for the CWS examined show characteristics which fall between Figures 1 and 3. This is an indication that the dispersion forces become more important as the coal content increases.

Further work in oscillatory measurements is continuing.

References

1. Prud'homme, R. K., "Rheological Measurements", Polymers as Rheology Modifiers, ACS Symposium Series, Vol 462, (1991).
2. Clark, D., Miller, W., Polym. Preprints (1983), 24, 87.
3. Parr Physica Rheology Lectures, March 1993, Houston.

Figure 1.

Figure 3.

Figure 2.

Figure 4.

Dynamic moduli versus frequency during the process of gelation.

Figure 5: Storage modulus curves

Figure 6: Loss modulus curves

Figure 7: Loss factor curves

FIGURE 8. Oscillatory Data For 1% Xanthan Gum Solution.

Date: 05.07.94, 22:10 Operator: Sample:
Sensor system : Q45 System : CV20

Oscillatory Data For 57%

Figure 9. Oscillatory Data For 57% CWS (PSOC 1475)

Date: 08.07.94, 22:30 Operator: Sample:
Sensor system : Q45 System : CU20

Oscillatory Data For 63% CWS

Figure 10. Oscillatory Data For 63% CWS (PSOC-1475).
 Date: 09.07.94, 20:40 Operator: Sample:
 Sensor system : Q45 System : CU20

Figure 11. Oscillatory Data For 65% CWS (PSOC-1475)

Date: 05.07.94, 22:41	Operator:	Sample:
Sensor system : Q45	System : CV20	

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