EFFECT OF COAL BENEFICIATION PROCESS ON
RHEOLOGY/ATOMIZATION OF COAL WATER SLURRIES.

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Quarterly Progress Report
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OVERALL OBJECTIVE:

The overall objective of this project is to perform experiments to understand the effect of coal beneficiation processes and high shear rheological 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 high shear rheological properties, particle size distributions and the atomization will be made in order to determine the influence of these parameters on the atomization of CWS.

PROJECT STATUS:

Rheological properties of freshly prepared samples were made and the results compared to previous obtained data in order to determine the effect of time of storage and stability on the rheological properties.

Rheological evaluations made include:

- (A) Flow characteristics under low shear rates
- (B) Flow Characteristics under high shear rates
- (C) Viscoelastic behavior under low frequency of oscillation

The flow characteristics of the CWS under high shear rates were conducted in a series of horizontal capillary tubes of diameters 0.8, 1.5 and 3.0 mm tubes in order to investigate the effect of particle size and concentration on pressure drop and, the transitional Reynolds number from laminar to turbulent flow in the CWS slurry .

RESULTS

Conventional rheological evaluation of Coal-Water Slurries by steady shear flow measurements and specifications of plastic viscosity and yield stress, have provided a

strong technical base for preparing and controlling the stability of CWS [1,2,3]. These specifications fail to provide complete insight into the CWS properties that control the flow properties and those necessary for their subsequent atomization [4,5]. This is because steady flow measurements reveal only the viscous, energy dissipative effects in the CWS flow for very long shearing time and with constantly increasing deformation.

Shear deformation of CWS suspensions produces a very significant elastic energy storage in addition to the viscous energy dissipation. Consequently, both the viscous and elastic properties of the CWS must be evaluated in order to gain a complete understanding of their interactive behavior.

Viscoelastic Behavior

Viscoelastic properties can be exhibited in systems which have internal structure. These properties could affect the stability and fuel breakup of ligaments upon exiting a nozzle or orifice [6]. The linear viscoelasticity can be measured by subjecting the sample through a small amplitude oscillatory test. For a system where the strain varies sinusoidally with time, t , The strain amplitude can be given by:

$$\gamma(t) = \gamma_{\max} \sin \omega t \quad (1)$$

where $\gamma_{\max}$ is the maximum strain amplitude and ω is the angular frequency of oscillation [7]. The corresponding stress is given by

$$\tau(t) = \tau_{\max} \sin(\omega t + \delta) \quad (2)$$

where δ is the phase shift between stress and strain.

The above equation, (2), can be re-written as:

$$\tau(t) = \gamma_{\max}(G' \sin \omega t + G'' \cos \omega t) \quad (3)$$

The storage modulus, G' and the loss modulus, G'' are defined in terms of the phase angles as:

$$G' = (\tau_{\max} \cos \delta) / \gamma_{\max} \quad (4)$$

$$G'' = (\tau_{\max} \sin \delta) / \gamma_{\max} \quad (5)$$

The storage modulus G' represents the "stored" or elastic component of the stress and is in phase with the strain. The loss modulus, G'' , represents the viscous component and it is the out of phase component.

For a fluid that is purely viscous, G' is zero and the phase is 90° and for a purely elastic material where energy is stored but not dissipated, G'' is zero and the phase is 0° [8].

The use of complex numbers greatly facilitates the manipulation of the viscoelastic function. The advantage is that no reference need be made as to the mechanism of damping, or to a particular experimental method.

Thus, equations (1) and (2) can be re-written as

$$\dot{\gamma} = \gamma_{\max} e^{i\omega t} \quad (6)$$

$$\dot{\tau} = \tau_{\max} e^{i(\omega t + \delta)} \quad (7)$$

The viscoelastic properties were measured using Haake RV20-CV20 and a Q45 sensor system. This system is integrated with an IBM/PS2 which allows for data acquisition and evaluation.

Figures 1-2 show the oscillatory data for freshly prepared 59% and 61 % "run-off" CWS samples. The G' shows a lower value in the 59% slurry compared to the 61% slurry. This observation is consistent with increased interaction among the coal particles as the coal content increases.

High Shear Rheology

In a capillary flow, CWS rheology can be adequately described by a power law model:

$$\tau = K \dot{\gamma}^n \quad (8)$$

where τ = shear stress

$\dot{\gamma}$ = shear rate

K = consistency index

n = power law index

$n = 1$ for Newtonian

$n > 1$ dilatant fluids

$n < 1$ for pseudoplastic fluids

HVA-6 Capillary Viscometer was used to determine the high shear rheological properties. The HVA 6 automated high shear capillary viscometer permits measurements from medium up to high shear rates ($D=10^2$ to 10^6 S^{-1}). A capillary of diameter 0.8 and 1.5 mm and length 100 mm were used in these measurements. The

sample to be measured is forced through a capillary at definite pre-adjusted pressure and pressed into a burette where volume measurement takes place. Figures 3-6 show the volumetric flow as a function of applied pressure. Each of these slurries contained xantham gum as a stabilizer. Rheological analysis shows that there were no significant differences in the rheological behaviors when compared to the stored CWS samples. However, the stored sample formed a hard pack sediment and had to be re-suspended before usage.

Figures 3-7 show the volumetric flow rate of the CWS as a function of the pressure drop. In these experiments, the slurry exiting from the capillary tubes were collected and the solids content determined at each applied pressure. It was found out that the solid content in the exit slurry was not uniform and that it varied with the applied pressure and the concentration of the initial slurry. The analyses of the flow characteristics suggests that the slurries may be going through different grades of complexity depending on the concentration profile of the solid content. Also, for initial slurry concentration of 59%, the maximum pressure drop across a capillary size of 1.5 mm diameter and 100 mm length at which the slurry flow rate could be determined accurately was 20 bar.

Tables 1-3 show the flow rate and the fraction of solids obtained in the exit slurry at each applied pressure for the slurries analysed. The flow of the 62% slurry through the 1.5 mm capillary tube, (Table 3), can be characterized as homogeneous since there was no significant variation in the amount of solids obtained in the exit slurry as a function of applied pressure. For CWS of initial solids concentration of

59%, there was a maximum pressure at which the flow rate could be measured, and for the CWS of initial solids concentration beyond 63%, flow could only be measured using a capillary size of 3.00 mm diameter.

Further flow measurements are being made to determine the type of flow and characterize the flow as either homogenous or heterogeneous. Also, the concentration of the polymer is being varied in order to determine possible transition from laminar to turbulent flow.

Table 1

Flow Rate of 62 % CWS through 1.5 mm Capillary Tube.

Pressure (bar)	Flow Rate (ml/s)	% CWS Content (Exit).	Reynolds #
5.6	2.16	59	7
9.6	3.3	59	9
13.8	4.8	59	13
19.4	6.7	59.5	19
22.3	8.75	60	28
25.3	8.4	61	23

Table 2

Flow Rate of 59 % CWS through 1.5 mm Capillary Tube.

1.5	0.27	54	0
4.7	3.0	57	16
6.0	3.95	56.5	21
7.4	4.9	56.8	27
9.7	6.28	57.7	33
11.6	7.73	57.6	43
13.5	8.4	58	43
15.3	9.6	57.6	58

Table 3

Flow Rate of 63 % CWS through 1.5 mm Capillary Tube.

4.7	0.92	58.4	1
8.8	1.7	60.5	3
9.0	1.9	59.3	3
14.3	3.2	59.3	6
18.4	4.2	58	8
24.4	6.09	57.4	12
28.5	7.2	57.5	15

REFERENCES

1. Kikkawa, H., Okiura, K., Arikawa, Y., Hitachi, K., and Kure, K., "Development of Highly Loaded CWM Preparation System". Proc. Sixth Int'l. Symp. on Coal Slurry Fuels Preparation and Utilization, 1984, 949.
2. Dinger, D. R., Funk, J. E., Jr., and Funk, J. E., Sr., " Rheology of High Solids Coal-Water Mixture." Proc. 4th Intl. Symp. on Coal Slurry Combustion, Orlando, FL., (1982)
3. Casassa, E. Z., G. D. Parfitt, A. S. Rao and E. W. Toor, "The Effects of Surface Active Agents On Coal-Water Slurry Stability". Proc. 6th Intl. Symp. on Coal Slurry Combustion and Technology, Orlando, FL., 1984, 251.
4. LaFlesh, R.C., Y.V. Lachowicz and J.G. McGowan, "Combustion Characteristics of Coal-Water Fuels", Proc. Eighth Int. Symp. on Coal Slurry Prep. and Util., U.S. Dept. of Energy, P.E.T.C., Pittsburgh, PA, pp.438-452, 1986
5. Winters, P.J., R. T. Bailey and K. R. Olen, "The Effect of Fuel Formulation on the Atomization Characteristics of Coal-Water Mixtures", Proc. Seventh Int. Symp. on Coal Slurry Fuels Prep. and Util., U.S. Dept. of Energy, P.E.T.C., Pittsburgh, PA, pp. 430-439 (1985).
6. Wildman, D.J., Ekmann, J.M., and Dooher, J. "A Comparison of Rheological Data for Coal-Water Mixtures and Liquid Mixtures with Implications for Atomization," Proceedings of the Thirteenth International Conference on Slurry Technology, April 1989.
7. Goldstein, R.J. "Fluid Mechanics Measurements" Hemisphere Publishing Corporation, New York (1983).
8. Philippoff, W. "Vibrational Measurements with Large Amplitudes, Trans. Soc. Rheol., 10 (1966) 317-334.

Figure 1. Oscillatory Data For 59% CWS.

Date: 21.05.95, 16:30 Operator: Sample:
Sensor system : Q45 System : CU20

Figure 2. Oscillatory Data For 61% CWS.

Date: 20.05.95, 21:36 Operator: Sample:
 Sensor system : System : CU20

Figure 3. Flow of 63Z CWS (Uncleaned) Through 3.00 mm Capillary Tube.

*** A P P A R

H V A - 6

1g FLOW (ml/s) 43PA700, 50C; 43PA750, 50C; 43PA7700, 50C; LB1g P (bar)

RESULTS from 23/05/198

File : 7515.HVA

Number : 5

Operator : yolanda

Sample : 1475 uncleaned w/31

Solvent : 1000

Density (kg/m3) : 1190

Temperature (°C) : 25

Capillary-length (mm) : 100.00

Capillary-diameter (mm) : 3.000

Figure 4. Flow of 59Z CWS (Uncleaned) Through 1.5 mm Capillary Tube.

*** A P P A R

H V A - 6

10 FLOW (ml/s) + 3PA700, 500; PPA7500, 500; FPA7700, 500; LBIG P (bar)

RESULTS from 20/05/19

File : 75Y1B.HVA

Number : 1

Operator : yolanda

Sample : 1475 uncleaned

Solvent : 1000

Density (kg/m³) : 1180

Temperature (°C) : 25

Capillary-length (mm) : 100.00

Capillary-diameter (mm) : 1.500

Figure 5. Flow of 60 Z CWS (Uncleaned) Through a Capillary Tube of 1.5mm Diameter Tube.

AP P A A R

H V A - 6

lg FLOW (ml/g) + 3PA700, 500; PUPA7500, 500; PUPA7700, 500; LB1g P (bar)

R E S U L T S from 20/05/198

File : 7512.HVA

Number : 1

Operator : yolanda

Sample : 1475 uncleaned
W/30ml H₂O

Solvent : 1000

Density (kg/m³) : 1180

Temperature (°C) : 25

Capillary-length (mm) : 100.00

Capillary-diameter (mm) : 1.500

Figure 6. Flow of 61 Z CWS (Uncleaned) Through a 1.5 mm Diameter Capillary Tube.

*** A P P A R

H V A - 6

lg FLOW (ml/g) + 439A700, 500; PUPA7500, 500; PUPA7700, 500; LB1g P (bar)

RESULTS from 19/05/19

File : 75Y1.HVA

Number : 1

Operator : KATH

Sample : 1475 uncleaned

Solvent : 1000

Density (kg/m³) : 1180

Temperature (°C) : 25

Capillary-length (mm) : 100.00

Capillary-diameter (mm) : 1.500

Figure 7. Flow of 62% CWS (Uncleaned) Through a 1.5 mm Capillary Tube of Diameter 1.5mm Tube.

*** A P P A R

H V A - 6

lg FLOW (ml/s) + 43PA700, 500; PIPA7500, 500; PIPA7700, 500; LB1g P (bar)

RESULTS from 21/05/199

File : 75Y3.HVA

Number : 1

Operator : yolanda

Sample : 1475 uncleaned w/45%
H₂O

Solvent : 1000

Density (kg/m³) : 1190

Temperature (°C) : 25

Capillary-length (mm) : 100.00

Capillary-diameter (mm) : 1.500