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

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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.

Work Done

In suspensions, there are interactions between the particles, and between the particles and the continuous phase. These interactions may give rise to agglomerates, which can trap some of the continuous phase. At low shear rates, there is random orientation of these agglomerates and the shear force is not sufficient to affect either the size or the alignment of the agglomerates. As the shear is increased, the structure of the agglomerates is broken down, the trapped fluid is released, and the particles and smaller agglomerates are oriented in the direction of the flow. These effects give rise to a decrease in viscosity. When the maximum degree of de-agglomeration and orientation has occurred, the viscosity of the fluid again become constant, but at a much lower value than the original apparent viscosity.

Also, the rheological properties of suspensions are predictable from basic principles in only a few cases for extremely dilute suspensions. One can, however, investigate the degree of structural formation in a suspension by studying the variables which affect the system through rheological measurements, thus obtaining a qualitative picture of the behavior of the system. Rheological analysis is also the best quantitative method to obtain information on the properties of a concentrated suspension as it settles. Besides examining the viscosity of the suspension at low shear rates for information on the structure of the system, the high shear rate behavior is important for practical use considerations.

The viscoelastic behavior of several concentrations of the slurries under study: Heavy Cleaned , Flotation Cleaned and Uncleaned samples were measured. The results obtained will be correlated with the atomization data.

Viscoelastic Behavior

Dense suspensions will exhibit viscoelastic behavior depending on the type of strain or stress applied to the material. Viscoelastic properties of material relate directly to its internal structure. If a dense suspension is subjected to a varying external force of frequency, ω, then the dense suspension will behave as an ordinary viscous liquid if $\omega T < 1$ where T is the time during which the stresses are damped, and if $\omega T > 1$, the internal stresses will not be damped and the suspension will behave as an amorphous solid. When dense suspensions are elastically deformed during short intervals of time, shear stresses remain, which are damped after sufficiently long time, T.

The response of viscoelastic material which has been subjected to a small-amplitude oscillatory shear is given by [1]:

$$\gamma(t) = \gamma_o \exp(i\omega t) \qquad 1$$

where ω, is the frequency and γ_o is the strain amplitude.

In oscillatory shear, a complex modulus, G*, can be defined as:

$$\sigma(t) = G^*(\omega)\gamma(t) \qquad 2$$

G* can also be expressed as:

$$G^* = G' + iG'' \qquad 3$$

where G' and G" are the storage modulus and loss modulus respectively.

Dense suspensions such as coal-water slurries, can be treated as a continuum model where their response to applied stresses and strains can be examined.

For ideally elastic substances based on a model following Hooke's Law, the following relationship applies:

$\tau(t) = G.\gamma(t)$ with controlled strain. 4

$\gamma(t) = \frac{1}{G}.\tau(t)$ with controlled stress. 5

For ideally viscous substances, the relationship

$\tau(t) = \eta.\gamma^{\cdot}(t)$ with controlled strain or shear rate 6

$\gamma(t) = \frac{1}{\eta}.\tau(t)$ with controlled stress 7

The angular frequency ω, is related to both the strain and the stress sinusoidally thus:

$\gamma(t) = \gamma_o.Sin\omega t$ (controlled strain) 8

$\tau(t) = \tau_o.Sin\omega t$ 9

The delay of $\tau(t)$ curve against $\gamma(t)$ curve has the phase displacement angle $0^o > \delta > 90^o$.

The storage modulus, G', which is the strain energy reversibly stored in the sample and recoverable is defined as:

$G' = \frac{\tau_o}{\gamma_o}.Cos\delta$ 10

alternatively,

$G'(\omega) = G_1 \frac{\omega^2 t_R^2}{(1+\omega^2 t_R^2)}$ (Maxwell's Model) 11

This chracterizes the elastic behavior of the sample. The G' value represents the quantity of the strain energy reversibly stored in the substance and recoverable.

The loss modulus is given by:

$G'' = \frac{\tau_o}{\gamma_o}.Sin\delta$ 12

alternatively

$G''(\omega) = G_1 \frac{\omega t_R}{(1+\omega^2 t_R^2)}$ (Maxwell's Model) 13

This quantity represents the energy which is irreversibly given off by the substance to its environment and thus lost. It characterizes the viscous behavior of the substance. The loss factor, $\tan\delta$, which is a ratio of the dissipated and the stored energy is given by:

$\tan\delta = \frac{G''}{G'}$ 14

The study of the oscillatory behavior allows the systematic characterization of the CWS suspensions so that their flow properties could be described by mechanical parameters which represent the system in the region of interest. The oscillation test provide more detailed information about the elasticity of the sample. The creep and relaxation test are made with a given constant load (shear stress,τ or shear rate,γ) and permit the determination of the ratio between the viscous and the elastic portions, the retardation time, and the shear modulus. These values depend on the constant presetting and results are obtained only under these constant conditions. Oscillation test can be made under varying loads with controlled shear stress, τ or controlled shear strain, γ. especially, the characterization of the relative importance of elastic to viscous effects. Stress and strain relaxation as well as viscometric measurements are essential in relating elastic to viscous effects. Other parameters such as: yield points, shear moduli, storage moduli, and moduli of rigidity can be related to interparticle forces. These parameters form good basis for characterizing the flow properties.

Figures 1-3 show plots of the viscoelastic behavior 61-63% solids content of the Uncleaned coal slurry. The data show an increasing value of the storage modulus, G' as the solids content increase. The increasing G' value as the solids content increase was noted for the two other slurries; the Heavy media and the Flotation cleaned samples. A Comparison of the G' values for 63% solids content of the three different samples show that the Uncleaned sample exhibits a much higher storage modulus compared to the Heavy Media and the Flotation Cleaned samples (Figure 4), even though, the high shear flow behavior of these samples are almost identical, and in the shear rate regime of 100,000/s, they have almost identical shear viscosity (Figure 5).

Studies on the atomization of these slurries indicate that the uncleaned slurries did not atomize very well compared to the cleaned samples (Tables 1 and 2). This observation can be attributed to the high storage modulus present in the Uncleaned sample. Oliver and Young-Hoon [2] have previously observed that fluids of increasing pseudoplasticity have lessened interaction between the phases and that viscoelasticity damps waves that occur in air-Newtonian fluid flow. Thus, the variation in the sauter mean diameter (SMD)as a function of the viscoelastic property of the CWS is due to the fact that the restoring force must be overcome before a drop can break up since more energy would be required to overcome the forces associated with viscoelasticity. This property is still dominant even at high AFR for fluids that have high storage modulus. The energy associated with the large mass of air is not completely able to dominate and overcome the fluid viscoelastic properties. As a result, the SMD values at high AFR showed significant differences for the different CWS atomized.

The effect of the viscoelastic property on the atomization is being investigated further, and the results will be reported in the final report.

TABLE 1

ATOMIZATION DATA

COAL-WATER SLURRY MIXTURE (FLOATATION CLEANED COAL)

VISCOSITY (mPas.s)**	A/F	SURFACE TENSION dynes/cm	DENSITY g/ml	SMD M
.0875	.427	67	1.14	24.5
.0875	.401	67	1.14	52.6
.0875	.336	67	1.14	71
.0875	.271	67	1.14	85
.0875	.207	67	1.14	193
.0875	.14	67	1.14	256

TABLE 2

ATOMIZATION DATA

COAL-WATER SLURRY MIXTURE (UNCLEANED COAL)

VISCOSITY (mPas.s)**	A/F	SURFACE TENSION dynes/cm	DENSITY g/ml	SMD M
.094	.441	67	1.16	38.5
.094	.414	67	1.16	69.6
.094	.347	67	1.16	95
.094	.281	67	1.16	129
.094	.186	67	1.16	195
.094	.145	67	1.16	354

References

1. Macdonalds, I.F., B.D Marsh, and E. Ashare, "Rheological behavior for Large Amplitude Oscillatory Motion", Chem. Eng. Sci., 24 (1969) 1615-1625.

2. Oliver, R.D., and Young-Hoon, " Two phase and non-Newtonian Flow: Pressure Drop and Hol-up.: Transactions Institute of Chemical Engineers, 46 T106-T115, 1968

Fig. 1. Viscoelastic Behavior:Uncleaned Slurry (62.5%).

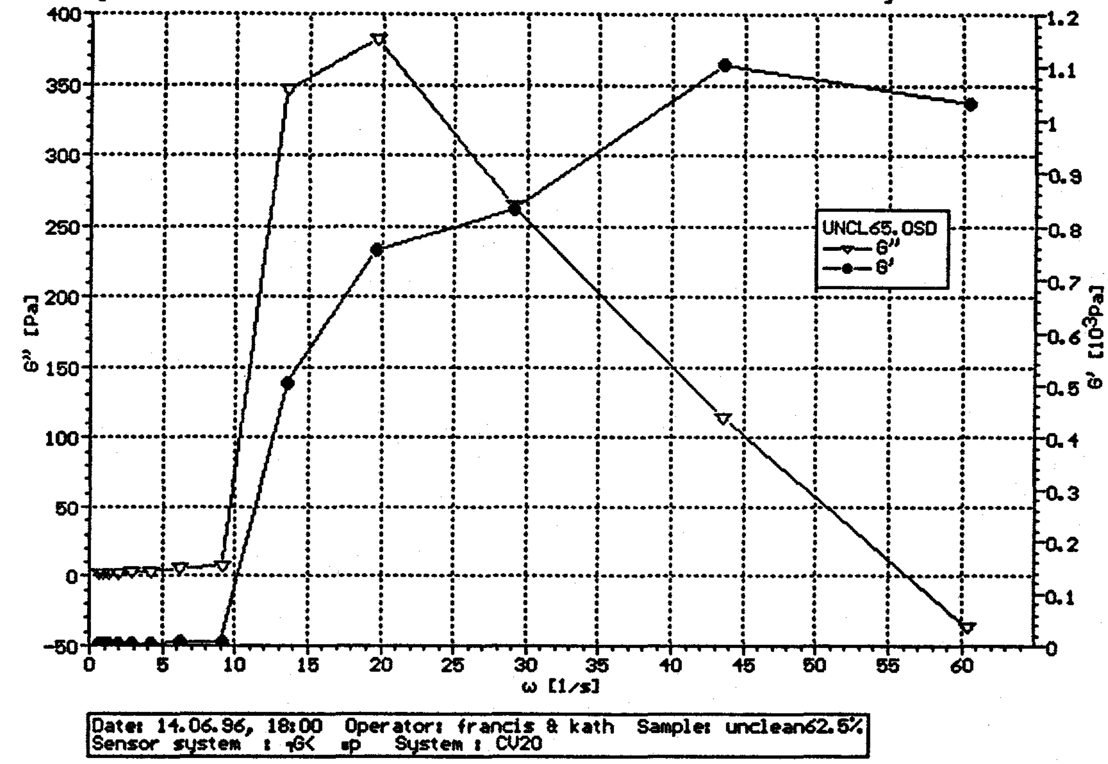

Fig. 2. Viscoelastic Behavior:Uncleaned Slurry (63%).

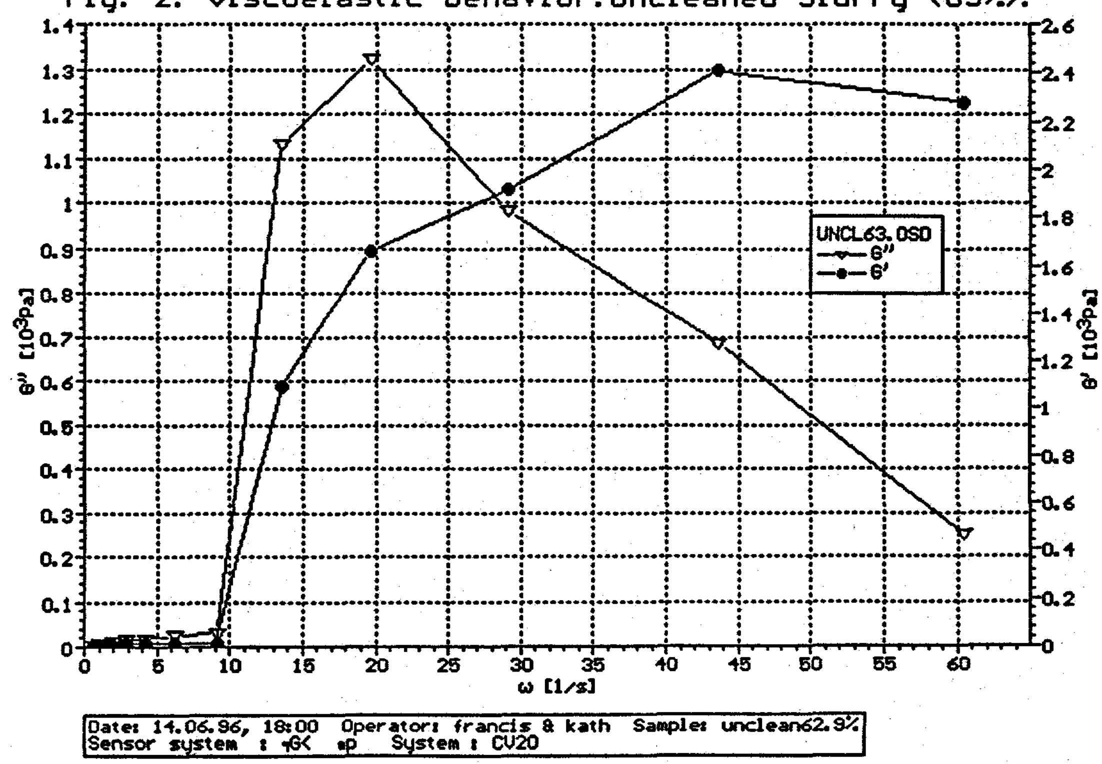

Fig. 3. Viscoelastic Behavior:Uncleaned Slurry (61%).

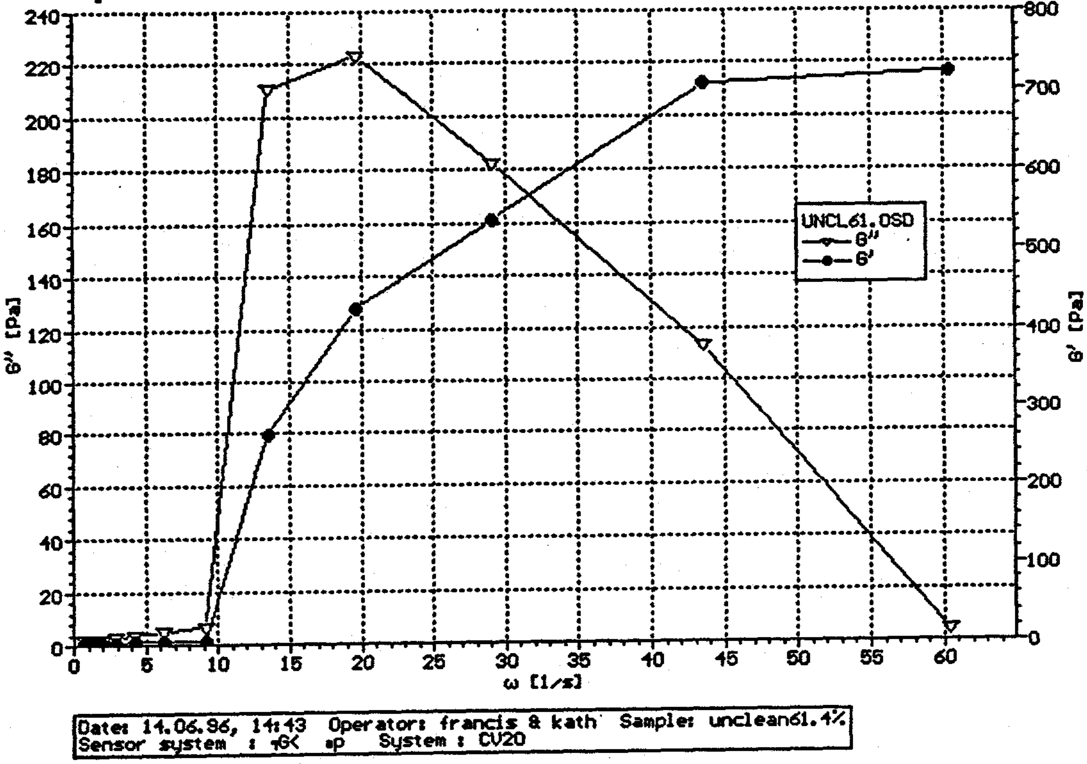

Fig. 4. Comparison of G' and G'' of 63% of Slurries.

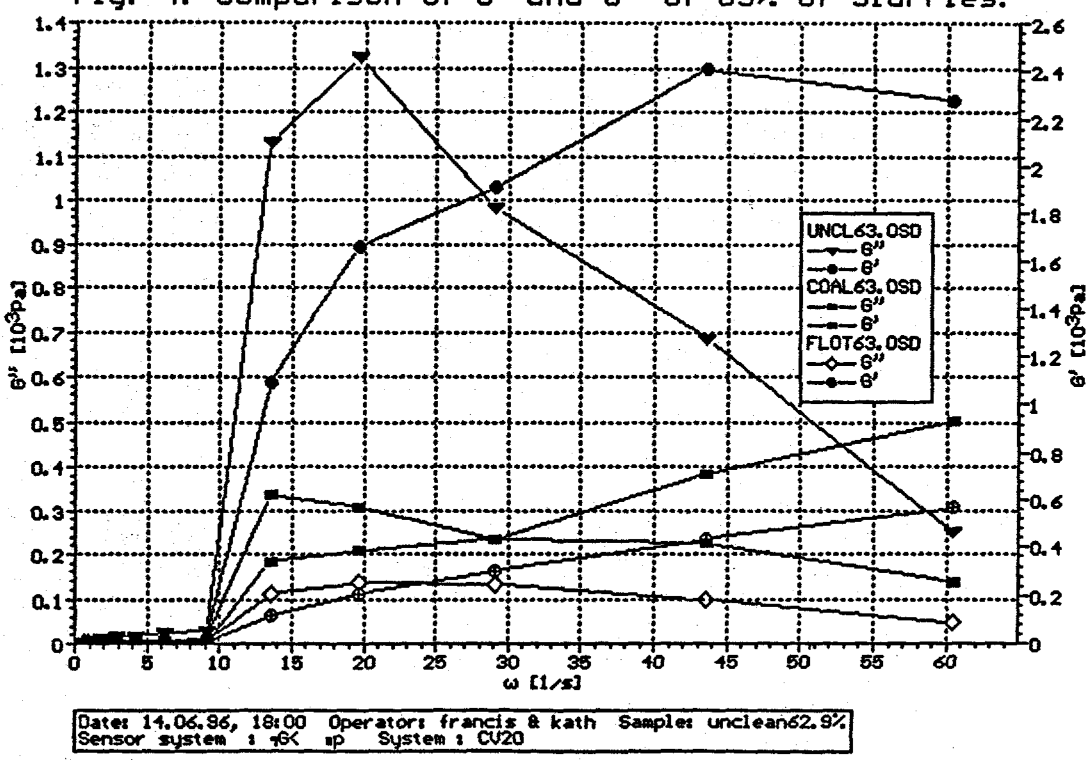

FIGURE 5. RESULT COMPARISON