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

Quarterly Progress Report
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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

During this past quarter, an attempt was made to establish a theoretical relationship between the sauter mean diameter, (SMD), the Air/Fuel ratio and the viscosity. Also the effect of polymeric additives on the rheology of glycerol was studied.

Results

Effect of Fuel/Air Ratio on Atomization

Atomization is a process whereby a volume of liquid is converted into waves, ligaments, and ultimately into a multiplicity of small drops [1]. This process can be considered as a collision process between the atomizing air and fuel.

The air with mass (M_A) and velocity (V_A) after transferring part of the kinetic energy to the slurry with mass (M_F) and velocity (V_F), the resulting atomized droplets, travel at the same velocity, V . The momentum balance requires that:

$$M_F V_F + M_A V_A = (M_F + M_A) V. \quad (1)$$

where ($M_F + M_A$) is the center of mass entraining droplets with

diameter $\{d_i\}_{i=1, \dots, N}$.

The velocity of the entrainment droplets is given by:

$$V = \{1 / (M_A + M_F)\} (M_F V_F + M_A V_A) \quad (2)$$

The Initial kinetic Energy, T of the fuel and the air is given by:

$$T = 1/2 [M_F V_F^2 + M_A V_A^2] \quad (3)$$

The kinetic Energy of the final state of air and droplets, T' is given by:

$$T' = 1/2 [(M_F + M_A) V^2] \quad (4)$$

assuming that the air and droplets move with a common velocity, V and that the relative motion between drops and air is negligible. Using the conservation of energy equation, the surface energy of the atomized drops with diameter, $\{d_i\}_{i=1, \dots, N}$ is proportional to the loss of kinetic Energy of the air and the fuel.

$$T - T' = \Delta E = 1/2 [M_F V_F^2 + M_A V_A^2] - 1/2 (M_A + M_F) V^2 \quad (5)$$

$$\Delta E = 1/2 [M_A V_A^2 + 1/2 M_F V_F^2 - 1/2 [M_A V_A^2 / (M_A + M_F)] - 1/2 [M_F V_F^2 / (M_A + M_F)]$$

$$- [(M_A M_F V_A V_F) / (M_A + M_F)] \quad (6)$$

$$= V_A^2 / 2 [M_A - M_A^2 / (M_A + M_F)] + V_F^2 / 2 [M_F - M_F^2 / (M_A + M_F)]$$

$$- V_A V_F [(M_A M_F) / (M_A + M_F)] \quad (7)$$

$$= 1/2 [(M_A M_F) / (M_A + M_F)] \{V_A - V_F\}^2 \quad (8)$$

The surface energy of the N droplets can be represented by;

$$\Delta E_\sigma = \sigma \sum n_i d_i^2 \pi / 2 \quad (9)$$

where σ is the surface tension and there are n_i drops with diameter d_i such that $\sum n_i = N$

Letting $M_F = \rho_F \sum n_i d_i^3 \pi / 6$ and sauter mean diameter (SMD) $= \sum n_i d_i^3 / \sum n_i d_i^2$

Equation (9) can be written as

$$\Delta E_\sigma = (3\sigma / \rho_F) M_F / \text{SMD} \quad (10)$$

combining equations (8) and (10) yields:

$$SMD = [3\sigma/\rho_F (V_A - V_F)^2] (1 + m_F/M_A) \quad (11)$$

Assuming that $V_A/V_F = \rho_F/\rho_A = 10^3$, equation (11) can be written as

$$SMD = [3\sigma/\rho_F (V_A)^2] (1 + m_F/M_A) \quad (12)$$

This equation demonstrates that for a given fuel flow for a fixed air flow, the SMD is directly proportional to m_F/m_A .

According to Lefebvre [2], the average droplet size is governed by air velocity, the air-liquid ratio, viscosity and the surface tension of the liquid. The properties of the air are less significant and thus, the average drop size becomes more dependent on the liquid properties.

The above correlation equation can thus be modified by assuming that the kinetic energy transfer goes into breaking the fluid into ligaments which requires work against viscous, elastic and possible extensional forces and break up of ligaments into drops which requires an increase in surface energy.

Thus the change in energy ΔE , can be represented by

$$\Delta E = \Delta E_\sigma + \Delta E_\mu + \Delta E_e + \Delta E_i \quad (13)$$

where ΔE_σ is the increased energy of the spray and ΔE_μ is the dissipative viscous energy loss, ΔE_e is the elastic energy loss and ΔE_i is the extensional component.

The effect of each of these factors on the SMD is as follows:

Considering the surface and viscous energy loss, equation (13) can be re-written as:

$$\Delta E = \Delta E_\sigma + \Delta E_\mu \quad (14)$$

Equation (14) can be written as:

$$\Delta E = \Delta E_\sigma (\Delta E_\sigma + \Delta E_\mu / \Delta E_\sigma) \quad (15)$$

$$\text{setting } \Delta E_\mu / \Delta E_\sigma = K (Re/We)^{-1}$$

where

$$Re = \text{Reynolds number} = \rho_F V D_F / \mu$$

$$We = \text{Weber number} = \rho_A V_A^2 L$$

$$K = \text{characteristic constant.}$$

$$\Delta E = \Delta E_\sigma (We^{-1} + K Re^{-1}) / We^{-1} \quad (16)$$

Thus, using equations (10) and (16) yields:

$$[We^{-1} / (We^{-1} + K Re^{-1})] \Delta E = (3\sigma / \rho_F) M_F / SMD \quad (17)$$

which results in

$$SMD/L = 1/3 \rho_A / \rho_F (We^{-1} + K Re^{-1}) (1 + M_F / M_A) \quad (18)$$

Based on these model equations (12,18), rheological measurements of different concentrations of glycerol have been made. Also, the effect of different concentrations of xantham gum on the rheology of glycerol has also being examined. The data obtained, together with subsequent atomization data on these solutions, will be used to fit the model equations (12,18) established.

Further work is being done to incorporate both the elastic and extensional forces in this model equation.

Figures 1-4 show the effect of varying concentrations of xantham gum on glycerol. Data analysis show that the solutions become more dilatant as the concentration of xantham gum concentration increase.

References

1. Tsai, S.C., and E.W. Knell, "Rheology and its Effects on Atomization of Coal Water Slurry", Proc. First Annual Pittsburgh Coal Conf., U. of Pittsburgh and U.S. Dept. of Energy, P.E.T.C., Pittsburgh, PA, pp. 190-200 (1984).
2. Wang, X.F., and A.H. Lefebvre, "Atomization Performance of Pressure-Swirl Nozzles," presented at AIAA/SAE/ASME 22nd Joint Propulsion Conference, June 1986.

Figure 1. . Flow Curve of Glycerol

Figure 2. Flow Curve of 90% Glycerol in 0.5% Xanthan Gum

Figure 3. Flow Curve of 80% Glycerol in 0.5% Xanthan Gum

Figure 4. Flow Curve of 60% Glycerol in 0.5% Xanthan Gum

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