

QUARTERLY REPORT NO. 2 (FY96)

Investigation of the Effect of Coal Particle Sizes on the Interfacial and Rheological Properties of Coal-Water Slurry Fuels

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1. SUMMARY

Experiments have been performed to simulate the effects of high viscosity and surface tension of CWS fuel on its atomization. Aqueous solutions of glycerol simulated the high viscosity condition of CWS fuels and ethanol solutions allowed to separately investigate the effect of surface tension. A Fraunhofer diffraction particle sizing technique measured the spatial distribution of Sauter mean diameters (*SMDs*) for the cross injecting sprays which were previously described in the Quarterly Report No. 1. Experimentally determined parametric correlation reveals the dependence of the spray *SMDs* on the liquid viscosity, surface tension, the air flow rate, the liquid flow rate, the orifice nozzle diameter, and the measurement locations. This simulated correlation will provide important guidelines for the actual CWS spray experiment to be performed in the successive quarter.

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2. ACCOMPLISHMENT

2.1 Experimental Apparatus Figure 1 schematically illustrates the cross-injecting atomizer system. The test channel has a 25 mm \times 33 mm cross-section and the cross injector nozzle installed at the channel ceiling produces liquid jet into a crossflow. Two sides of the test channel are made of glass 3.175 mm thickness and 914.40 mm length glass, as viewing windows to allow spray visualization and optical access of the droplet sizing system. The channel establishes the fully developed flow near the liquid injector location.

Injectors are made of aluminum rod material. The nozzle diameters of different injectors range from 0.2 to 0.6 mm for the present experiment. Test liquid is transferred to the injector nozzle from a liquid reservoir and the pressurized nitrogen gas is used to inject the liquid in a well controllable manner.

The Malvern 2600c Laser diffraction particle sizer measures the spray *SMDs* for a spatial resolution equivalent to the cylindrical measurement probe of 4.5 mm beam diameter. The instrument works on Fraunhofer Diffraction principle in that smaller particles scatter light to a wider angle and larger particles scatter light with a relatively narrow angle.

2.2 Tested Liquids Four different types of liquid have been used as the atomized liquids with different surface and rheological properties: water, ethanol, and two aqueous solutions of glycerin. Figure 2 shows the surface tension and dynamic viscosity properties of aqueous solutions of ethanol and glycerin (CRC table, 1985). The properties are presented versus the weight ratios of ethanol (C_2H_5OH) and glycerin ($C_3H_8O_3$) mixed

in deionized water. Pure ethanol has significantly lower surface tension coefficient of 22.75×10^{-3} N/m at 20 °C whereas its dynamic viscosity remains nearly identical to the dynamic viscosity of water. Therefore, comparison of pure ethanol spray with water spray allows a separate examination of the effect of surface tension. Two different glycerin mixtures with deionized water are prepared to exclusively examine the effect of viscosity: (1) 46.3 % glycerin in weight that has 5 cP (5×10^{-3} kg/m·s) dynamic viscosity, 1115.4 kg/m³ density, and 70.37×10^{-3} N/m surface tension, and (2) 58.8 % weight glycerin that provides 10 cP dynamic viscosity, 1150 kg/m³ density, and 68.99×10^{-3} N/m surface tension. It is noted that the surface tension remains nearly unchanged from that of water (72.75×10^{-3} N/m) while the dynamic viscosity doubles from 5 cP to 10 cP. This also allows to exclusively examine the effect of viscosity on atomization decoupled from other effects.

2.3 Effects of Viscosity and Surface Tension on Atomization Table 1 summarizes the experimental matrix for the tested four different liquids with different injection conditions. Selected results of spray *SMD* profiles are presented in Fig. 3. The coordinates *x* and *y* denote the air flow direction and the liquid injection direction, respectively. Figure 3-a shows a comparison of the spray *SMD* distribution of water (dynamic viscosity = 1 cP) with 58.8% glycerin solution (dynamic viscosity = 10 cP) at a fixed liquid flow rate of 1.05 ml/s injected from 0.4 mm diameter nozzle. Higher liquid viscosity develops a longer potential core and a larger facing area with the cross wind than its counterpart of lower

liquid viscosity. This can increase the efficiency or effectiveness of atomization of and *SMDs* at the same y location show slight decreases for the glycerin solution. However, the present cross-injection system turns out that it is not properly atomizing the injected liquid with high viscosity. This was confirmed by the fact that the spray drop concentration quickly decreased for the glycerin solution compared with the water injection. To properly atomize CWS fuels whose viscosity ranges from one hundred to one thousand times higher than water, the airblasting shear energy must be significantly enhanced. A sonic airblast atomizing system is under construction for the future CWS atomization studies.

Figure 3-b shows the *SMD* distribution versus y for water and ethanol for two different liquid flow rates injected from the 0.4 mm orifice at the air Reynolds number of 70,000. The surface tension of water, 72.75×10^{-3} N/m, is approximately 3.5 times higher than the surface tension of ethanol, 22.75×10^{-3} N/m, while the dynamic viscosity is almost identical for both liquids. This allows a separate investigation of the surface tension effect on atomization keeping other properties and conditions fixed. Increasing surface tension of injected liquid shows increasing *SMD* distributions. The lower surface tension of the ethanol jet results in a shorter potential core length and the jet breaks up into smaller ligaments and drops. Ethanol generates far higher spray drop concentration with a noticeably lower maximum drop diameter than water. Lower surface tension contributes to generate finer sprays.

2.4 Sauter Mean Diameter (SMD) Correlation A linear regression applied to all the present *SMD* data (Table 1) results in two experimental correlations of local and averaged *SMDs* with fluid properties and injection conditions:

$$\frac{SMD}{D_0} = 1.867 \times 10^{-5} \left(Re_f\right)^{0.3216} \left(We\right)^{-0.225} \left(\frac{V_s}{V_f}\right)^{2.1513} \left(\frac{x}{D_0}\right)^{-0.6757} \left(\frac{y}{D_0}\right)^{1.8975} \quad (1)$$

$$\frac{SMD}{D_0} = 0.2898 \left(Re_f\right)^{-0.00497} \left(We\right)^{-0.6436} \left(\frac{V_s}{V_f}\right)^{1.0202} \quad (2)$$

The local and average correlations, Eqs. (1) and (2), are compared with measurements in Figs. 4-a and b, respectively. The local spray *SMD* shows a decreasing correlation with increasing viscosity while average *SMD* increases with increasing viscosity. This ambiguity of the viscosity effect on atomization will be resolved by continuing the investigation using a more effective means of atomization, such as a sonic airblasting. Both local and average *SMDs* show increase with increasing surface tension. Effect of surface tension on the spray *SMD* is more clearly understood for the cross-injecting atomization.

FUTURE PLAN

CWS mixtures will be used as the atomized fluid and the spray *SMD* measurement will be made to examine the effect of the CWS physical properties on its atomization. Sonic air jet from a converging nozzle will be used to properly and effectively atomize the CWS fuels of much higher viscosity.

BIBLIOGRAPHY

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2. *CRC Handbook of Chemistry and Physics*, 65th Edition, 1985, CRC Press, Boca Raton, Florida, pp. D-231, D-235, F-31, and F-32.

TABLE 1. Experimental matrix of tested liquids and injection conditions.

CASE	Liquid Viscosity (cP)	Surface Tension (N/m)	Orifice Diameter (mm)	Gas Reynolds Number	Liquid Volume Flow Rate (ml/s)	x (mm)
Water	1	0.0728	0.2 - 0.6	50,000-70,000	0.79 - 2.63	10, 20
46.3 % Glycerin	5	0.0704	0.6	70,000	1.05 - 1.84	10
58.8 % Glycerin	10	0.0690	0.4	70,000	0.53 - 1.05	10
58.8 % Glycerin	10	0.0690	0.4	91,000	0.79 - 2.10	10
Ethanol	1.2	0.0228	0.4	70,000	0.79 - 2.10	10

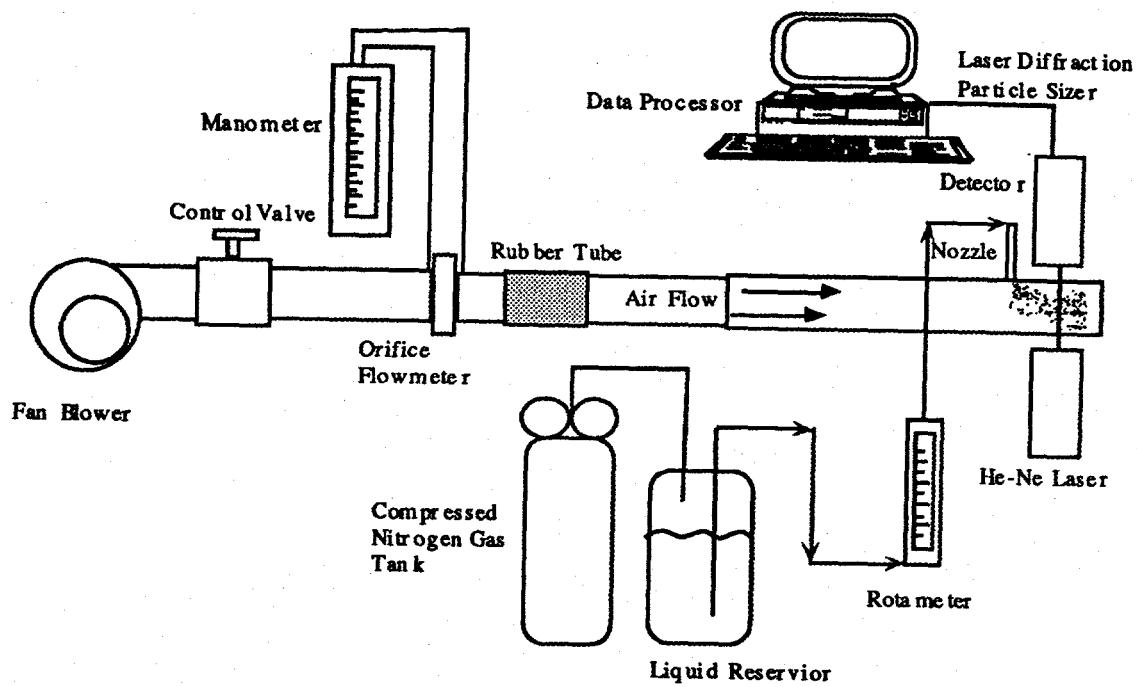
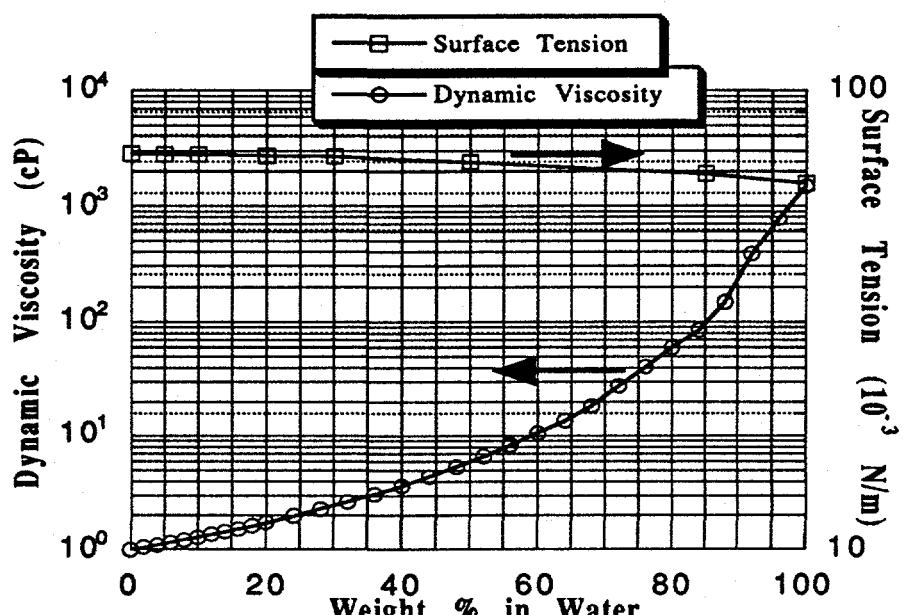


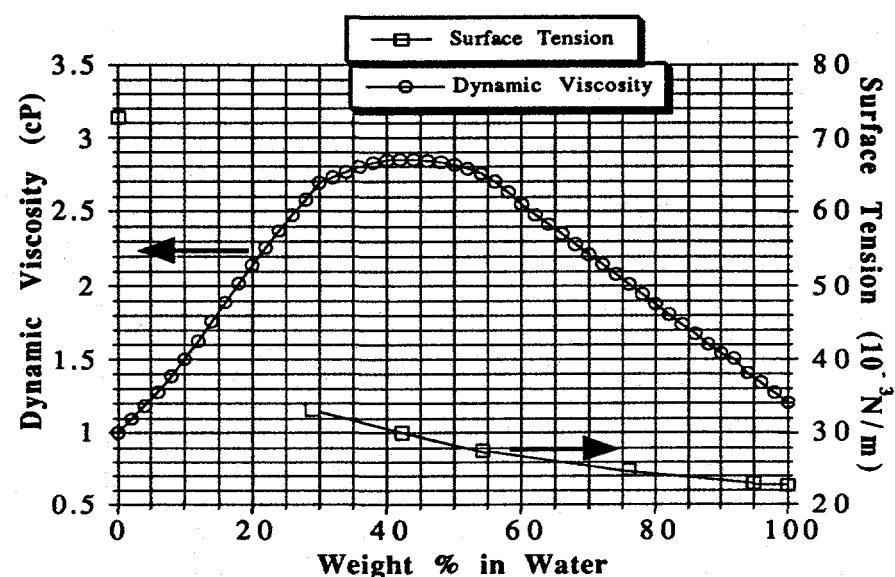
Fig. 1 Schematic illustration of cross-injecting atomization system.

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(a)



(b)

Fig. 2 Dynamic viscosity and surface tension of aqueous solutions of (a) glycerin, and (b) ethanol.

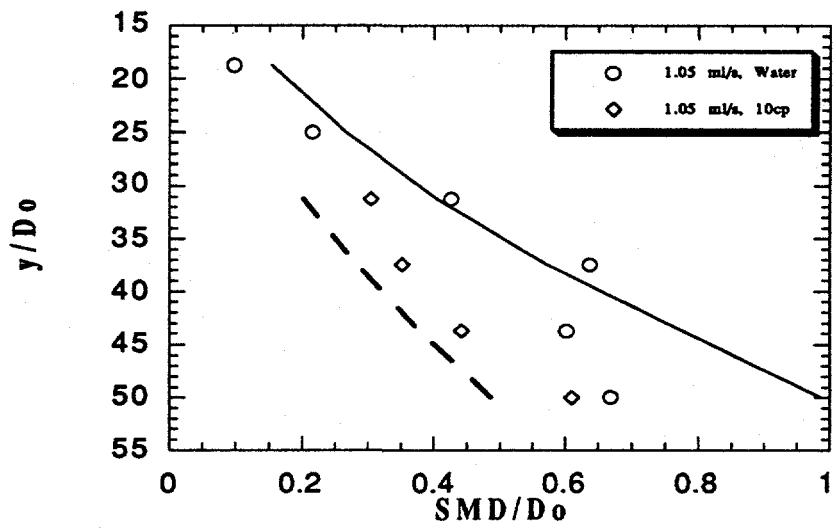


Fig. 3-a Spray SMD versus y for water and 10 cP glycerin solution: injector orifice $D_0 = 0.4$ mm; $Re_g = 70,000$; liquid injection rate of 1.05 ml/s; and $x = 10$ mm.

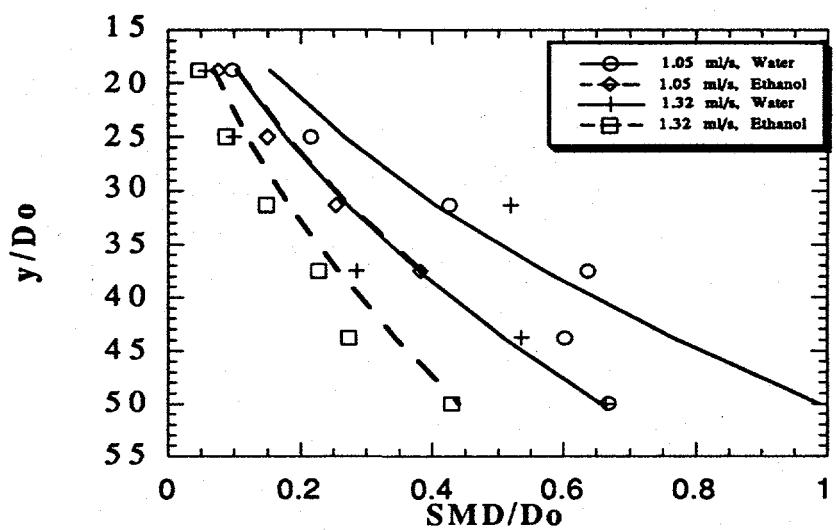


Fig. 3-b Spatial SMD versus y for water (0.07275 N/m) and ethanol (0.02275 N/m): $D_0 = 0.4$ mm; $Re_g = 70,000$; liquid injection rate of 1.05 and 1.32 ml/s; and $x = 10$ mm.

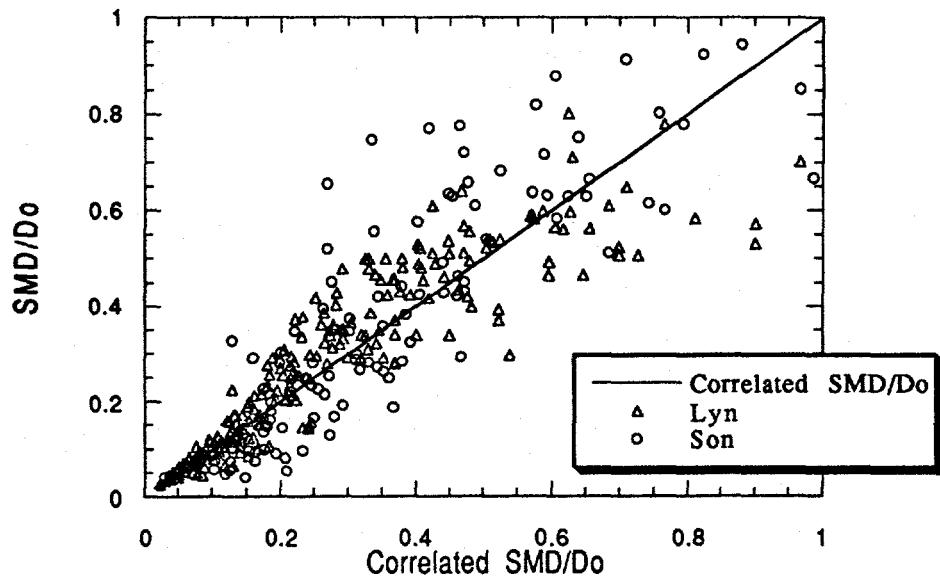


Fig. 4-a Comparison of measured spatial $SMDs$ with correlation.

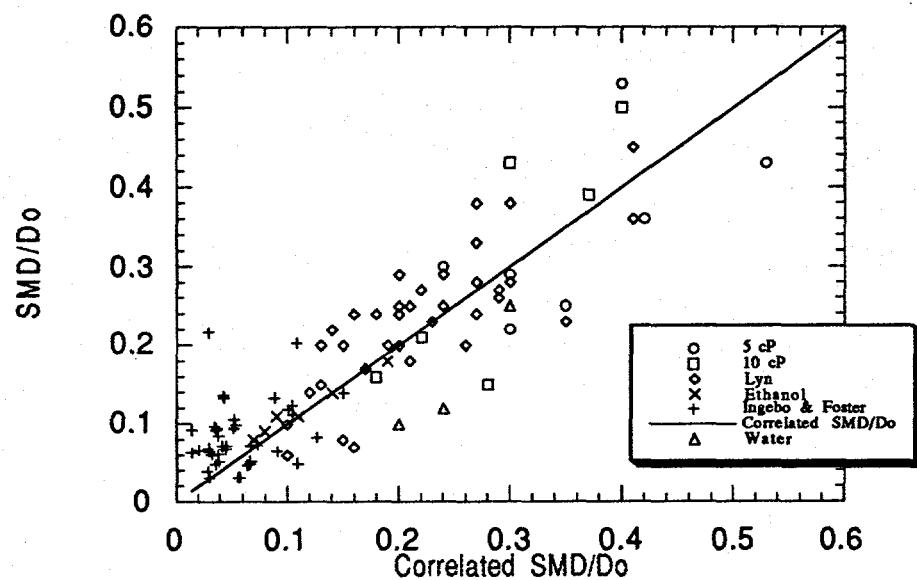


Fig. 4-b Comparison of number weighted average $SMDs$ with correlation.