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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

Preliminary experiment has been made for cross injecting water sprays into a convective air stream to test the air-blast atomization system which has been constructed for CWS atomization in the future. A laser diffraction particle analyzing technique (the Malvern system) nonintrusively measured the drop size SMDs for various injection parameters including the convective air flow rate, flow rate of the injected liquid (distilled water), orifice diameter, and measurement locations along the two-dimensional spray plane. Buckingham-PI analysis finds the correlation of dimensionless parameters. A correlation of drop Sauter mean diameter (SMD) normalized to the orifice diameter is obtained from all the experimental data for the case of distilled water sprays.

2. ACCOMPLISHMENT

2.1 Test Channel Figure 1 schematically illustrates the cross-injecting atomizer system. The test channel is fabricated from Plexiglas. Two glass viewing windows conform to the side walls and allow spray visualization and optical access of the drop sizing system. The channel has a 25 by 33 mm cross-section and is approximately 914 mm long, which ensures fully developed flow near the end of the channel where the injection nozzle is found. The entire channel is laid on a two-dimensional positioning system, which allows precise spatial location of measurement. A bypass control plate placed on the blower outlet adjusts the air flow rate. An orifice flow meter installed five feet upstream of the channel inlet measures the air flow rate. A Kiel probe (a type of Pitot tube) measures the mean velocity profiles across the y coordinate and shows excellent agreement with the one-seventh law velocity profile for fully-developed turbulent flows. The 1.5 HP fan blower provides the air Reynolds number ranging from 20,000 to 75,000 based on the 28.4 mm length scale of the channel hydraulic diameter. Distilled water is the atomized liquid and the flow rate is measured with a calibrated rotameter.

2.2 Injector Nozzle Regulated nitrogen gas pressurizes the liquid reservoir and drives the liquid at constant injection pressure. Five different injectors (0.2, 0.3, 0.4, 0.5, and 0.6 mm orifice diameter) are tested in the experiment. The injectors are made of aluminum rod material (Fig. 2) with external dimensions of 9.5 mm outside diameter by 64.8 mm long. The orifice length-to-hole diameter ratio, l/D_0, is 10.0 for all the injectors so that the inside geometrical effect on the atomization between injectors can be small [1]. The orifice exit was protruded from the duct wall by approximately 2 mm. The air velocity calculated with the one-seventh law at the orifice exit location approached nearly 80% of the maximum centerline velocity and the effect of the decelerated flow near the duct wall was considered negligible.

2.3 Diagnostic Equipment A high-speed photographic recording provides instantaneous visualization of the sprays to examine the characteristics of the jet entering the cross flow and the subsequent atomization downstream of the initial breakup. One-half microsecond pulsed lighting of the Microflash system illuminates the spray and a standard 35 mm camera with a macro extension lens magnifies the view. The photographic recording of the sprays has successfully guided the drop diameter measurement taken downstream of the breakup region to eradicate erroneous data that occur due to the presence of ligaments or non-spherical drops.

The Malvern 2600C Laser diffraction particle sizer measures the drop sizes. To enhance the spatial resolution of the measurement, the standard laser beam diameter of 9 mm has been reduced to 4.5 mm by replacing the transmitting lens with one with a shorter focal length [2]. Care has been taken to minimize the data biasing due to the multiple reflections of the beam passing the two side windows. This has been achieved by aligning the test channel windows slightly off the right angle with the laser beam. The modified Malvern instrument has been satisfactorily calibrated using a standard calibration reticle.

2.4 Preliminary Results for Distilled Water Sprays Table 1 shows the test conditions investigated with distilled water as an injected liquid. The measurement conditions include five different orifice diameters ranging from 0.2 to 0.6 mm, three different Reynolds number of 50,000, 60,000, and 70,000, and two different x-locations of 10 and 20 mm from the nozzle orifice center. The range in the y direction extends to the spray boundary that gives 1% or higher light obscuration and allows the Malvern measurement. Measurement further downstream than $x = 20$ mm is not possible because of window wetting of the deposition of spray drops. The high momentum of the injected liquid beyond a certain limit makes the stream penetrate to the opposite wall without developing a noticeable spray. On the other extreme, if air momentum is too strong compared with that of the liquid jet, the spray is quenched down to the upper channel surface and no measurement is possible.

Figure 3 shows spray drop size distributions measured for three different y-coordinates at x = 10 mm downstream of the 0.6 mm diameter nozzle injecting distilled water at a rate of 3.68 ml/s, and $Re_g = 60{,}000$. As the y location increases, the peak of the size distribution clearly shifts toward a larger median diameter. Such transition of the peak of the size curve is consistently observed for all results obtained for other experimental conditions. This indicates that larger drops with high inertia-to-drag ratios penetrate deeper in the y-direction than smaller drops.

2.5 Sauter Mean Diameter (SMD) Correlation Figure 4 compares the experimental results with the calculated values from the correlation. A functional relation between the injection parameters is established based on Buckingham-PI analysis. By employing a regression method for all the SMD data, an experimental correlation of the Buckingham-PI dimensionless parameters is:

$$\frac{SMD}{D_o} = 1.015x10^{19}\,\mathrm{Re}_g^{-3.5998}\,\mathrm{Re}_f^{-1.8094}\,We^{2.2474}\left(\frac{x}{D_o}\right)^{-0.6867}\left(\frac{y}{D_o}\right)^{1.9718} \qquad (3)$$

where D_o is the injector orifice diameter that constitutes the length scale of Re_f and of We. The air Reynolds number Re_g is defined based on the channel hydraulic diameter D_H. In examining the exponent of Weber number, which is defined as $\rho_g V_g^2 D_o / \sigma$, SMD decreases with increasing surface tension. This contradicts what is generally observed in conventional air-blast atomization where SMD increases with increasing surface tension. The way to change the Weber number in the current study, however, is to alter either the gas velocity or the orifice diameter. Increasing gas velocity or orifice diameter, which increases the Weber number, will reduce the spray penetration and decrease the shearing area and make atomization less effective resulting in larger drop SMDs.

A statistical analysis of the correlation equation shows a 97.5% confidence interval and a coefficient of multiple determination, R^2, of 0.94. The R^2 value is an indicator of the correlation accuracy ranging from 0 to 1.0, where 1.0 denotes a perfect correlation. An error analysis has also been carried out using the Kline-McKlintok Error Analysis Method [3] to show drop SMD uncertainties of approximately ± 6.7%. In addition, the Malvern calibration with the calibration reticles gives equipment accuracy at nearly ± 4.0%. The r.m.s. of these two uncertainties is ± 7.8% so that the maximum uncertainties of the experiment do not exceed a very conservative estimate of 10%.

FUTURE PLAN

CWS mixtures containing coal particles of different sizes and different loading will be used as the atomized fluid and the spray SMD measurement will be made to examine the effect of the CWS properties on its atomization performance. Since the CWS viscosity is higher than water by a factor ranging from one hundred to one thousand, a significant increase in the airblasting energy may be necessary for CWS atomization.

BIBLIOGRAPHY

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3. S. J. Kline, The Purposes of Uncertainty Analysis, *J. Fluids Engineering,* vol. 107, pp. 153-160, 1985.

Table 1 Test matrix of experimental conditions

	Orifice Diameter (mm)	Air-to-Liquid Ratio (ALR)	Liquid Flow Rate (ml/s)	x (mm)
Base Case	0.4	Re = 70,000	.79-2.63	10
Liquid Flow Rate (ml/s)	0.5 0.6	25 25	2.10, 2.52, 2.94 2.10, 2.52, 2.94	10 10
Orifice Diameter (mm)	0.2 0.3 0.5 0.6	Re = 70,000 Re = 70,000 Re = 70,000 Re = 70,000	.79 .79 - 1.58 1.58 - 4.21 1.58 - 5.26	10 10 10 10
ALR	0.5 0.6	25, 30, 35 25, 30, 35	2.10 2.10	10 10
x (mm)	0.3 0.4	Re = 70,000 Re = 70,000	.79 .79 - 1.58	20 20

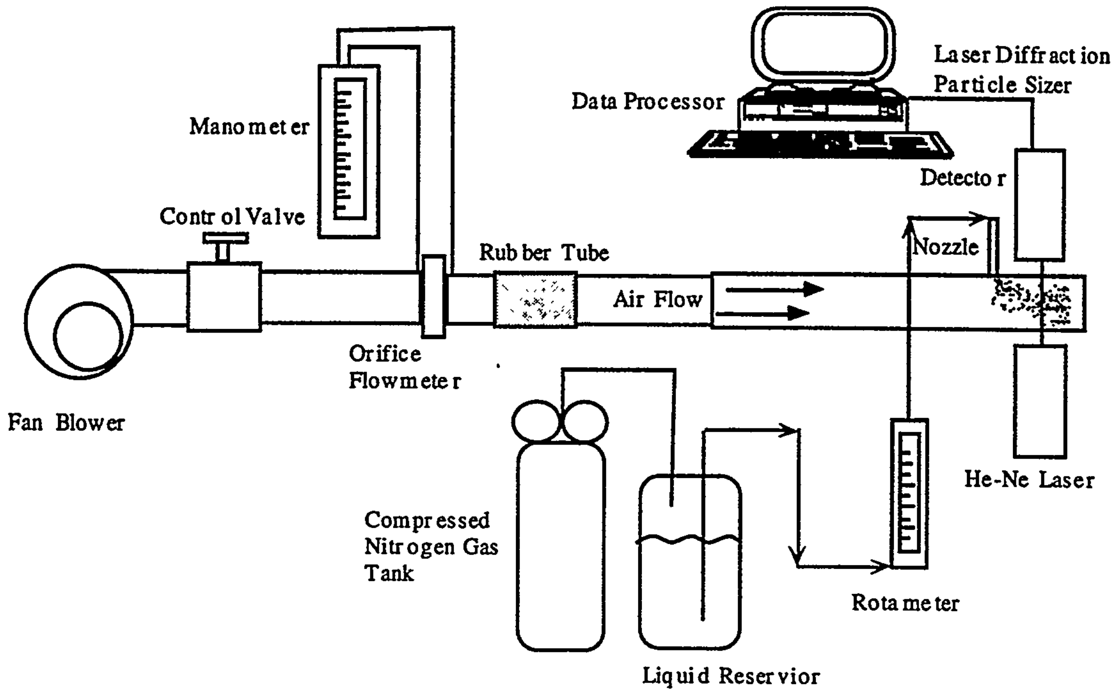

Figure 1. Schematic of experimental apparatus.

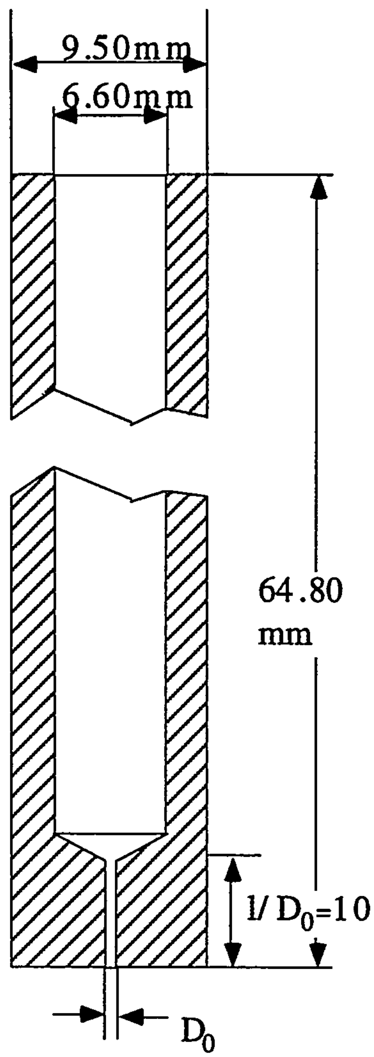

Figure 2. Cross sectional view of orifice injector.

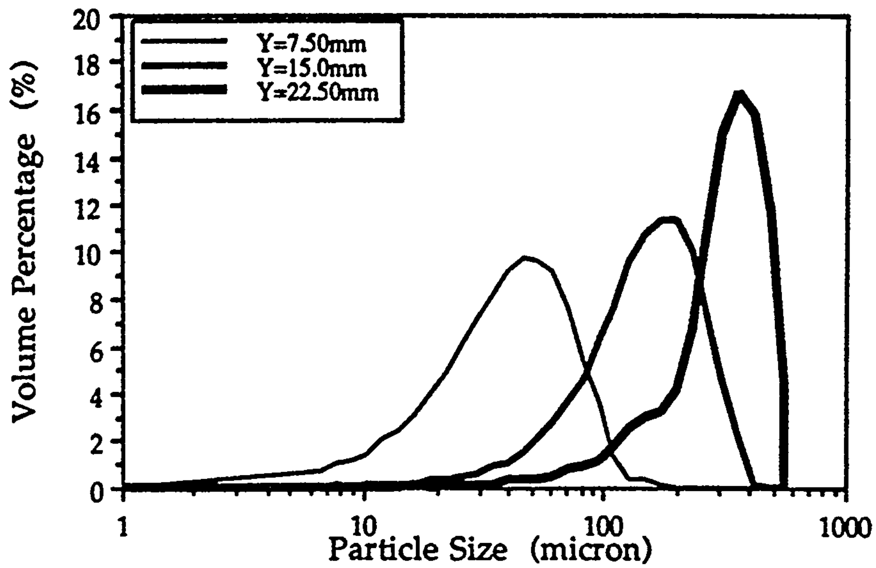

Fig. 3 Volume Percentage versus Particle Size for X=10 mm

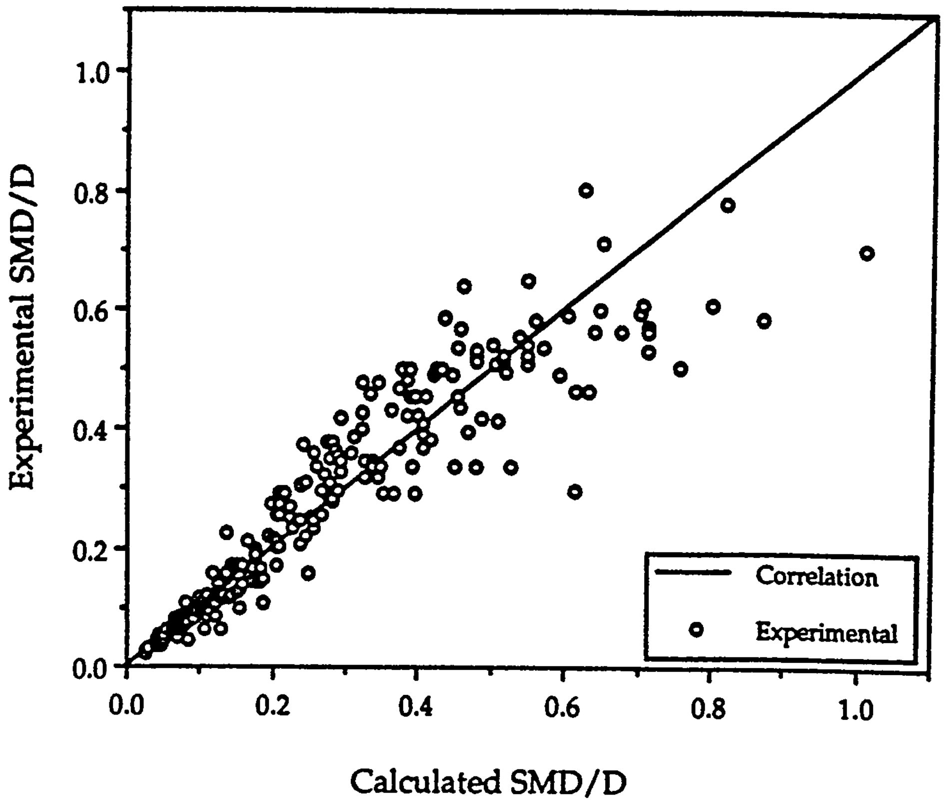

Fig. 4 Experimental SMD versus Calculated SMD