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QUARTERLY REPORT NO. 5

Development and Use of an Apparatus to Measure the Dynamic Surface Properties of Coal-Water Slurry Fuels for Applications to Atomization Characteristics

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ABSTRACT

A cross-injecting spray system was designed and constructed to investigate the spray development and atomization behaviors of CWS fuel samples containing different additives. Distilled water was used as an atomized fluid in this preliminary stage. A laser diffraction particle sizing technique (the Malvern 2600D system) was used to determine the spatial distributions of the spray droplet diameters versus other relevant injection parameters. The overall spray development was also visualized using a high-speed photographic recording technique. The cross-injecting atomization system is a very comprehensive means of inspecting sprays that depend to an uncertain degree on surface properties and rheology.

SUMMARY OF PROGRESS

Completion of the Cross-Injecting Atomization System

Figure 1 schematically illustrates the cross-injecting atomizer system. The test channel is fabricated from plexiglass. Two glass viewing windows conform to the side walls and allow spray visualization and optical access of the droplet sizing technique. The channel has a 25 by 33 mm cross section and approximately 914 mm long, which ensures fully developed flow near the

end of the channel where the liquid injecting nozzle is located. The entire channel is laid on a two-dimensional positioning system, which allows precise spatial resolution of measurement. Air flow rate is adjusted by means of a bypass control plate placed on the blower inlet and measured with an orifice flow meter installed five feet upstream of the channel inlet. The mean velocity profiles are measured using a Kiel probe (a type of Pitot tube) and shows excellent agreement with the one-seventh law velocity profile for fully-developed turbulent profiles.

Atomization occurs primarily as a result of the tearing action of the convective air flow. Since larger droplets travel farther into the air stream than smaller droplets due to their greater momentum (Ingebo and Foster, 1957), a monotonic increase in the droplet diameter distribution is expected with the y -distance from the orifice (schematically shown in Fig. 2). This unique feature of cross-injecting sprays makes it possible to carry out meaningful comparisons between data sets obtained for CWS sprays containing different size particles and different types of surfactants.

Preliminary Study with Water Sprays

Distilled water is used as an atomized liquid instead of CWS fuels in this preliminary stage. Table 1 shows the test conditions being investigated for water and to be repeated for CWS fuels. The measurement conditions include five different orifice diameters ranging from 0.2 to 0.6 mm, three different Reynolds number of 60, 70, and 80 thousands, and two different x -locations of 10 and 20 mm from the nozzle exit. Measurement is extended in the y direction to the maximum extent possible as long as the spray allows the minimum concentration required for the Malvern measurement. Measurement is not possible further downstream than $x = 20$ mm because of severe window wetting resulting from the deposition of spray droplets. The high momentum of the injected liquid beyond a certain limit in the liquid flow rate 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 channel surface near the nozzle exit and no measurement is possible.

Figure 3 shows spray droplet size distributions measured at different y -coordinates for $x = 10$ mm, 0.6 mm nozzle diameter, and $Re = 60,000$. As the measurement location moves away

from the nozzle exit, the peak of the size distribution clearly shifts toward a larger value in diameter. Such transition of the peak of the size curve is consistently observed for all results obtained for other experimental conditions, which confirms that larger droplets with high inertia-to-drag ratios will penetrate faster in the y -direction than smaller droplets.

Measurements are carried out at two different x locations, 10 and 20 mm downstream of the nozzle to inspect the spray development along the air flow direction. Figure 4 presents the results in terms of Sauter Mean Diameter (SMD) versus y -coordinate for the case of 0.75 GPH of water flow rate through a 0.3 mm injector, and $Re = 70,000$. For a conventional air-blast atomizer where the air is blown in parallel to the injected liquid, the spray SMD gradually increases along the spray axis primarily because of the enhanced coalescence of droplets as their travel distance increases (Kihm and Chigier, 1991). Preferential evaporation of smaller droplets also contributes to an increasing SMD along the spray axis. A decrease in SMD along with the air flow is observed in the present case of cross-injecting atomization. Distinctively different droplet paths in cross injection permit two-dimensional development of droplet size distribution in both the x and y directions. Larger droplets penetrate further away in the y -direction as x increases. Relatively smaller droplets will then be left downstream along the same y -distance from the nozzle exit. It is believed that the SMD decrease shown in Fig. 4 is attributed to the depletion of larger droplets as x increases on the same y .

SMDs were measured at $x = 10$ mm for different water flow rates for 0.4 mm nozzle at $Re = 70,000$ (Fig. 5). An interesting thing to note is that the spray droplets increase with decreasing liquid flow rate or equivalently increasing air-to-liquid ratio (ALR). It is generally known that increasing ALR reduces spray mean diameters for the case of conventional atomizers. Droplet size distribution of the present cross-injecting atomizer, however, shows more sophisticated and comprehensive spatial resolution. In other words, the SMD distribution is closely correlated with the physical development of the spray boundary and penetration characteristics. The spray for low liquid flow rate penetrates up to 15 mm from the nozzle exit, while the penetration for flow rates of 1.5 GPH or higher is fully extended to the opposite wall. The spray cross-section, where air-

blasting and shear exchange between air and liquid actively occur, has increased with increasing spray penetration or equivalently with increasing liquid flow rate. As a result, more effective atomization, i.e., smaller SMDs were observed with increasing liquid flow rate that in turn decreases ALR. All other nozzles show such a consistent behavior in their SMDs. The increased momentum or shear energy of the increased liquid flow rate also contribute to reduce the droplet SMDs.

FUTURE RESEARCH DIRECTION

Additional measurements of droplet SMDs of water sprays will be performed to complete the parametric investigation presented in Table 1. From these data, an experimental correlation of spray SMD will be determined in terms of all the related parameters, nozzle diameter, ALR, liquid flow rate, the distance away from the nozzle, y , and measurement location, x . CWS fuel samples will then be employed as the atomized fluid containing different additives, and the measurement of spray SMDs will be repeated for those conditions presented in Table 1. The effect of dynamic surface tension on CWS fuel atomization will be studied in addition to the other effects discussed above.

REFERENCES

1. Ingebo, R. D., and Foster, H. H., 1957, "Drop-Size Distribution for Crosscurrent Breakup of Liquid Jets in Air Streams," TN 4087, NACA.
2. Kihm, K. D., and Chigier, N., 1991, "Effect of Shock Waves on Liquid Atomization of a Two-Dimensional Airblast Atomizer," *Atomization and Sprays*, Vol. 1, No. 1, pp. 113-136.

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TABLE 1. Experimental Matrix

- SMD Measurement of Cross-Injecting Sprays-

	Orifice Diameter (mm)	Air/Liquid	Liquid Flow Rate (GPH)	x (mm)
Base Case	.4	Re=70K	.75-2.5	10
Orifice Diameter	.2	Re=70K	.75	10
	.3	"	.75-1.5	"
	.5	"	1.5-4	"
	.6	"	1.5-5	"
Air/Liquid	.5	25,30,35 (Re=50,60,70K)	Fixed=2.0	10
	.6	25,30,35 (Re=50,60,70K)	Fixed=2.0	10
Liquid Flowrate (GPH)	.5	Fixed=25 (Re=50,60,70K)	2.0, 2.4, 2.8	10
	.6	Fixed=25 (Re=50,60,70K)	2.0, 2.4, 2.8	10
x (mm)	.3	Re=70K	.75	20
	.4	Re=70K	.75-1.5	20

Fig. 1 Schematic illustration of the cross-injecting atomizer system

Fig. 2 Schematic illustration of the cross-injecting spray development

Fig. 3 Droplet size distributions measured at different y locations

Fig. 4 Sauter Mean Diameter (SMD) measured at different x locations

Fig. 5 Sauter Mean Diameter (SMD) measured for different water flow rates

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