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

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1. SUMMARY

A new sonic airblast atomization system has been designed and constructed to use in atomizing CWS fuels with two to three orders of magnitude higher viscosity values than water. Preliminary studies show that the new system successfully atomizes a glycerol/water solution that is one hundred times more viscous than pure water. This system, together with a constant displacement feed pump, will allow the study of CWS atomization under various surface tension properties, different coal loadings and particle sizes, and different surfactants.

2. ACCOMPLISHMENT

Viscosity properties of CWS fuels vary with coal loadings, coal particle sizes, and with the rate of shear strain that reveals a weak non-Newtonian behavior. Figure 1 shows the results of a variety of CWS viscosity measurements conducted in different laboratories. The apparent viscosity data covers a wide range of the rate of shear strain from 10 to 10^5 s^{-1} . CWS viscosity is several hundred times higher than that of pure water (viscosity of pure water at STP is one centi-poise (cP), which is equivalent to 10^{-3} Pa.s).

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The previous cross-injection atomization system, which used convective air flows up to Mach numbers of 0.25 (Figure 1 in Report No. 2 of FY 96), did not properly atomize CWS fuels because of its insufficient airblast energy. A new atomization system was necessary to significantly enhance airblast energy for CWS atomization. Figure 2 shows a schematic illustration of a new sonic atomization system where the sonic jet exhausts from a converging nozzle and the orifice perpendicular to the sonic jet injects the atomized liquid. A positive displacement syringe pumps the atomized liquid and the syringe operates by a stepper motor connected to a speed controller. The Malvern diffraction particle analyzer measures spray SMDs assuming Rosin-Rammler two-parameter distribution.

A converging nozzle establishes a sonic exit flow when the stagnation pressure reaches 191.7 kPa under one atmospheric back pressure of 101.3 kPa. This condition is called a perfect or isentropic expansion. When the stagnation pressure exceeds 191.7 kPa, the jet Mach number remains at unity, but the jet exit condition becomes an underexpanded state exhausting increased air mass flow rate. The underexpanded air must expand outside the nozzle by way of Prandtl-Meyer expansion fans. The air mass flow rate increases linearly proportional to the stagnation pressure. This increased mass flow rate of underexpanded sonic jet provides higher airblast shear energy and finer atomization with smaller SMDs.

Figure 3 shows the preliminary results of SMD variations for water sprays under two different underexpanded air jets at 239.2 kPa and 377.09 kPa. The measurements were conducted along the spray center ($y = 0$) at different axial locations. Spray SMDs first decrease because of the breakup of ligaments and larger drops into smaller drops, and reach a minimum SMD at a certain x -location. The spray SMDs then gradually increase, mainly because of the coalescence between drops as they travel downstream. Preferential evaporation of smaller drops also contributes to increasing the spray SMDs with increasing x . Note that the location of

minimum SMDs, $x_{\min}$, remains nearly unchanged for different stagnation pressure conditions.

Figure 4 shows the dependence of spray SMDs on the stagnation pressure for two fluids with different viscosity values. The measurements were conducted at $x = x_{\min}$ and $y = 0$. The stagnation pressure ranged from 135.8 kPa (Mach number = 0.65) through 191.7 kPa (perfect sonic) to 377.09 kPa (underexpanded sonic). For both pure water (1 cP) and an 85% glycerol solution (100 cP), spray SMDs consistently decrease with an increasing stagnation pressure that enhances the airblast shear energy per unit amount of liquid and improves the atomization. The system successfully atomizes liquids with high viscosity values and shows that SMDs for the same stagnation pressure increase by a factor of two to three when the liquid viscosity is increased by a factor of 100.

3. FUTURE PLAN

A series of measurements is planned to study the effect of surface tension properties of CWS fuels on their atomization characteristics. Representative SMD data will be obtained at $x = x_{\min}$ and $y = 0$. Table 1 shows the ranges of experimental parameters to be examined.

Table 1 Experimental matrix for CWS atomization study

Experimental parameter	Range
coal loading	0, 20, 40, 60%
coal particle sizes	$d < 63 \mu\text{m}$, $180 \mu\text{m} < d < 250 \mu\text{m}$
CWS mass flow rate	1.0 - 3.0 g/s
Stagnation pressure	135.8 - 377.09 kPa
Type of surfactants	DDBS-soft, 1840-x
Surfactant concentration	0 - 5%

Fig. 1 Apparent viscosity of various CWS fuels of different coal weight loadings.

Fig. 3 Water spray SMD variations along the jet axis for two different underexpanded air jets.

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Fig. 2 A schematic of sonic airblast atomization system.