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QUARTERLY REPORT

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INTRODUCTION

In order to observe the effects of rheology on the atomization of highly viscous non-Newtonian liquids, glycerin-water solutions and cellulose-glycerin-water solutions have been atomized. In this series of tests, nozzle pressure, air-liquid ratio and liquid viscosity were altered, and the effects were observed.

ATOMIZATION

Several solutions of glycerin and water were atomized in order to observe the effects of rheology on the atomization process. During these experiments, the nozzle pressure, air/liquid ratio and liquid viscosity were altered. The minimum air/liquid ratio reported in each figure was established by determining the minimum air/liquid ratio consistent with annular flow. This was accomplished by reducing the air flow until slugs of liquid were seen exiting the nozzle and then increasing the air flow until the liquid slugs disappeared. Therefore, the minimum air liquid ratio in each figure represents the smallest ratio that provides good atomization. The maximum air liquid ratio in each figure is near 0.4.

Figures 1-6 show Sauter mean diameter (SMD) versus air/liquid ratio for six mixtures of glycerin and water, ranging from 100% water to 100% glycerin. Spray data for at least two liquid delivery pressures are presented in each figure. Observation of the data shows that SMD does not vary significantly with delivery pressure for liquids with shear viscosity characteristic of CWS fuels ($167 \leq \mu \leq 968$ cP). Furthermore, SMD changes very little for fluids with shear viscosities between 167 and 968 cP. This is particularly advantageous since it suggests that wide

changes in CWS rheology will have little effect on sprays produced by this nozzle design.

Figure 7 shows Sauter Mean Diameter versus air/liquid ratio for a cellulose-glycerin-water mixture. The consistency index of this fluid is similar to that of figure 3, but the flow behavior index has been reduced to 0.90. Again, we note that SMD varies only slightly with changes in pressure and viscosity. More importantly, we note upon comparison of figures 3 and 7 that small changes in flow behavior index also have little effect on SMD. This is particularly advantageous since it suggests varying CWS additive packages will have little effect on CWS SMD produced using this nozzle.

Experimentation has shown that aerated atomization is difficult to obtain when atomizing highly viscous fluids. Photographs (Figures 8-12) reveal that the bubbly flow regime, characteristic of aerated atomization (Figure 13), is never achieved when varying the air/liquid ratio from 0 to approximately 0.4. The majority of the air mixed with the liquid flows directly to the center of the tube and collects forming large bubbles that cause the flow regime to be nearer to slug flow than to bubbly flow. At air/liquid ratios below about 0.12 the flow is in the slug flow regime and the bubbles explode at the nozzle exit plane producing droplets and ligaments. Atomization, however, is sporadic and poor since the bubbles are too far apart.

In all of the tests using glycerin-water solutions or cellulose-glycerin-water solutions, good atomization occurred when the nozzle was operating in the annular flow regime. That is, when the liquid flowed in a sheet along the walls of the nozzle while the air flowed through the core. Annular flow behavior is illustrated in Figure 12 and is characteristic of the data presented in Figures 1-7. Obviously, atomization quality in this region is excellent.

The method of atomization in the annular flow regime is in some respects very similar to air assist atomization, but there are also some significant differences. In

aerated atomization, the liquid flows in a sheet along the walls of the atomizer and, upon reaching the nozzle exit, is sheared by a jet of air that transforms the sheet into ligaments and drops. In most air assist atomizers, the air jet is brought into contact with the fluid only at the nozzle exit. Thus, the aerated atomizer differs from an air assist nozzle in that the liquid and air are mixed in a zone before they proceed to the nozzle exit. Furthermore, the air and liquid are not allowed to mix in an air assist atomizer until they reach the nozzle exit; therefore, the liquid is a single phase fluid throughout the atomization process. In the aerated atomizer, in contrast, the atomized fluid is a mixture of liquid and air and the air jet is shearing a non-homogeneous fluid at the nozzle exit. Photographs show that the air in the liquid is in the form of densely packed tiny bubbles, thus resembling a froth or foam. The bubbles do not seem to explode upon reaching the nozzle exit plane, but they do provide regions of discontinuity that enhance the atomization process.

CONCLUSIONS

The effect of viscosity on atomization quality is minimal using this nozzle design, probably because the liquid is exposed to a high velocity jet of air inside the nozzle. This promotes wave motion within the liquid long before it reaches the nozzle exit. Therefore, even a highly viscous fluid attains a significant level of fluid mechanic instability before reaching the nozzle orifice. This in turn enhances the atomization process. A further effect of premixing the liquid with the air is the formation of small bubbles within the liquid annulus. Thus, two-phase flow is present upon reaching the nozzle exit. This further reduces the effects of viscosity by introducing small regions of instability within the liquid.

FUTURE WORK

In order to reduce scatter in the data, modifications to the particle collection system are underway. These modifications will lead to an increase in the flow rate

through the test section and will minimize spray recirculation. Larger ducting is being installed in order to reduce pressure losses through the system and thereby increase the flow rate.

After installation of the new collection system, photographs will be taken of the flow inside the nozzle when polymer-glycerin-water solutions are being atomized. Sauter mean diameter data will then be collected for those fluids.

SMD vs. AIR/LIQUID
GLYCERIN WATER K=968 n=.972

* P=330
▲ P=300

Figure 1.

SMD vs. AIR/LIQUID
GLYCERIN WATER K=495 n=.995

AIR/LIQUID

Figure 2.

Figure 3.

SMD vs. AIR/LIQUID
GLYCERIN WATER K=167 n=.918

* P=225

▲ P=150

Figure 4.

SMD vs. AIR/LIQUID
GLYCERIN WATER K=22 n=.985

Figure 5.

Figure 6.

SMD vs. Air/Liquid
 Cellulose, Glycerin, Water solutions
 $K = 400$ $n = .90$

* $P = 300$
 ◆ $P = 225$
 ▲ $P = 150$

Figure 7.

Figure 8. Glycerin-water,
 $n=0.974$ $K=1004$ (cp/(sq))
 $A/L=0.118$ $P=225\text{psi}$

Figure 9. Glycerin-water,
 $n=0.974$ $K=1004$ (cp/(sq))
 $A/L=0.0475$ $P=330\text{psi}$

Figure 10. Glycerin-water,
 $n=0.974$ $K=1004$ (cp/(g^2))
 $A/L=0.0984$ $P=350$ psi

Figure 11. Glycerin-water,
 $n=0.974$ $K=1004$ (cp/(g^2))
 $A/L=0.1071$ $P=150$ psi

Figure 12. Glycerin-water
 $n=0.974$ $K=1004$ (cp/cm^2)
 $A/L=0.721$ $P=150\text{psi}$

Figure 13. Water
 $n=1.0$ $K=100$
 $A/L=0.178$ $P=250\text{psi}$

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