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EFFECT OF AIRSTREAM VELOCITY ON MEAN DROP DIAMETERS OF WATER SPRAYS PRODUCED BY PRESSURE AND AIR ATOMIZING NOZZLES

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ABSTRACT

A scanning radiometer was used to determine the effect of airstream velocity on the mean drop diameter of water sprays produced by pressure atomizing and air atomizing fuel nozzles used in previous combustion studies. Increasing airstream velocity from 23 to 53.4 meters per second reduced the Sauter mean diameter by approximately 50 percent with both types of fuel nozzles. The use of a sonic cup attached to the tip of an air assist nozzle reduced the Sauter mean diameter by approximately 40 percent. Test conditions included airstream velocities of 23 to 53.4 meters per second at 298 K and atmospheric pressure.

INTRODUCTION

Experimental tests were conducted with pressure atomizing and air atomizing fuel nozzles mounted in a duct 5 meters in length and 15.3 centimeters in diameter. Water was used to simulate fuel in this investigation of the effect of airstream velocity on the fineness of atomization. A scanning radiometer that measured the forward scattered light was used to determine the Sauter mean diameter at each test condition. Although water was used in all of the tests, the results may be compared with atomization of fuels such as Jet A by correcting for the effects of fuel density, surface tension, and viscosity on atomization as given in reference 1.

Finesse of atomization is an important factor in the design and performance of fuel injectors that will yield high combustion efficiency and low exhaust emissions when used in advanced turbojet combustors. In reference 2 and 3, it was found that air atomizing fuel nozzles improved combustion performance and reduced exhaust emissions when compared with pressure atomizing nozzles. Thus, this study was conducted to determine the degree of fineness of atomization of the various sprays. The optical system shown in figure 2 consisted of a 1-milliwatt helium-neon laser, a 0.003-centimeter-diameter aperture, a 7.5-centimeter-diameter collimating lens, a 0.025-centimeter-diameter collecting lens, a scanning disc with a 0.05 x 0.05-centimeter slit, a timing light, and a photomultiplier detector. The complete description of the scanning radiometer and the method of determining mean particle diameters are given in reference 4.

DESCRIPTION OF INSTRUMENT

The scanning radiometer, shown in figure 2, was used to determine Sauter mean diameters for water sprays atomized by the injectors. The optical system shown in figure 2 consisted of a 1-milliwatt helium-neon laser, a 0.003-centimeter-diameter aperture, a 7.5-centimeter-diameter collimating lens, a 0.025-centimeter-diameter collecting lens, a scanning disc with a 0.05 x 0.05-centimeter slit, a timing light, and a photomultiplier detector. A complete description of the scanning radiometer and the method of determining mean particle diameters are given in reference 4.

CALIBRATION TESTS

The scanning radiometer was calibrated with two different water suspensions of uniformly sized latex particles having diameters of 25.7 and 45.4 micrometers. Dynamic calibration tests were made using vaporizing sprays formed by the breakup of single jets of water injected transversely into high-velocity airstreams. One of the multiple orifice spray bars used to produce single water jets is shown in figure 3. A plot of Sauter mean diameter, D_{32}, against airstream velocity, obtained for the 0.003-inch-diameter orifice and the 0.015-inch-diameter orifice spray, respectively, is shown in figure 4. Good agreement was obtained with the volume number mean diameter, D_{30}, determined experimentally in reference 1 and plotted in figure 4. The relationship between the Sauter mean and volume number mean diameters is given as D_{32} = 1.29 D_{30} in reference 5, as determined by the Nukiyama-Tanasawa expressions for mean drop diameters.
The pressure atomizing and air atomizing fuel injectors used in this investigation are shown in figure 5. Physical characteristics of the injectors are given in Table I. Three pressure atomizing nozzles were tested having flow numbers of 0.092, 0.184, and 0.200, respectively, at a water flow rate of 90.8 liters per hour.

Three variations of air atomizing injectors were tested; namely, the air assist, splash groove, and splash cone air atomizing nozzles. The air assist nozzle was tested both with and without a sonic cup attached to the tip of the nozzle, to determine the effect of the sonic cup on the fineness of atomization. The splash groove and splash cone nozzle had been used in previous combustor studies.

RESULTS AND DISCUSSIONS

Mean drop diameters were determined for water sprays using two different types of fuel injectors and the scanning radiometer. Two types of fuel injectors consisted of conventional pressure atomizing nozzles, improved air atomizing nozzles previously tested in experimental combustors, and an air assist nozzle type tested with and without a sonic cup attached to the nozzle tip.

The first type of injector tested consisted of three pressure atomizing nozzles having flow numbers of 0.092, 0.184, and 0.200, respectively. The effect of airstream velocity and flow number on the Sauter mean diameter, D_{32}, obtained with the three pressure atomizing nozzles is shown in figure 5. Sauter and mean diameter decreased with increasing airstream velocity as follows; D_{32} = \sqrt{V}^{0.75} over an airstream velocity range of 23 to 38 meters per second. Also, the sonic cup appeared to reduce values of D_{32} by approximately 40 percent. Whether the cup actually produced acoustic oscillations or simply acted as a splash plate to improve breakup was not investigated.

Air atomizing nozzles used in previous combustor studies (splash cone and splash groove nozzles) appeared to follow the same general relationship of Sauter mean diameter decreasing with increasing airstream velocity as follows; D_{32} = \sqrt{V}^{0.75} which was previously determined for the breakup of single transverse liquid jets (ref. 1). The maximum effectiveness of this type of breakup was obtained with the liquid injected normal to the airstream.

With pressure atomizing nozzles, the Sauter mean diameter decreased with increasing airstream velocity and decreasing flow numbers as follows; D_{32} = (FN)^{0.4} \sqrt{V}. Thus, flow number, as well as airstream velocity, appeared to be very important factors in determining the fineness of atomization for pressure atomizing nozzles.

REFERENCES

TABLE I. - FUEL INJECTOR CHARACTERISTICS

<table>
<thead>
<tr>
<th>Injector</th>
<th>Orifice diameter, cm</th>
<th>Water pressure drop, N/m²</th>
<th>Flow number, (liter/hr)/(l/l²)²</th>
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</thead>
<tbody>
<tr>
<td>Spray bar</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>12 orifices</td>
<td>.012</td>
<td>2.2x10⁴</td>
<td>.611</td>
</tr>
<tr>
<td>109 orifices</td>
<td>.013</td>
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<td>Pressure atomizing</td>
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<tr>
<td>High flowrate</td>
<td>.260</td>
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<td>Low flowrate</td>
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<td>.092</td>
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<tr>
<td>Splash cone</td>
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<td>.471</td>
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<tr>
<td>Splash groove</td>
<td>.051</td>
<td>10.41</td>
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<td>.500</td>
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<tr>
<td>Sonic cup</td>
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<tr>
<td>Air assist</td>
<td>.500</td>
<td>5.38</td>
<td>.392</td>
</tr>
</tbody>
</table>

*Measured as a water flow rate of 90.8 liters per hour.
**Pressure drop and flow rate of the assist air.
³30 SCFM.
⁴35 SCFM.

Fig. 1 Test facility and auxiliary equipment. (Dimensions are in meters.)
Fig. 2 Scanning radiometer optical path.

Fig. 3 Schematic diagram of multiple-orifice spray-bar. (Dimensions are in centimeters.)
Fig. 6. Variation of Sauter mean diameter with airstream velocity for pressure-atomizing nozzles.

Fig. 5. Concluded.

(d) CONVENTIONAL AIR-ASSIST NOZZLE.
(e) SONIC AIR-ASSIST NOZZLE.
Fig. 7 Variation of Sauter mean diameter with flow number for pressure-atomizing nozzles.

Fig. 8 Variation of Sauter mean diameter with airstream velocity for splash-groove and splash-cone air-atomizing nozzles.
Fig. 9 Variation of Sauter mean diameter with orifice diameter for splash-groove and splash-cone nozzles at an airstream velocity of 30.5 m/sec.

Fig. 10 Variation of Sauter mean diameter with airstream velocity for conventional and sonic air-assist nozzles.