ATOMIZATION OF BROAD SPECIFICATION AIRCRAFT FUELS

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The atomization properties of any liquid fuel for potential use in aircraft gas turbine engines are widely recognized to be of prime importance. These properties are important because the ignition and subsequent combustion behavior of the fuel-spray/air mixture are strongly affected by the nature of the fuel spray preparation and distribution. For example, the mean size of the droplets in the spray (e.g., Sauter mean diameter, SMD), the distribution of droplet sizes present at any local position in the spray, the local fuel/air mixture ratio, the fraction of fuel vaporized, and other factors, related to the airflow/spray dynamics, for instance, may be expected to be largely established by the liquid injection devices and the arrangements for the airflow in the primary region of the combustion chamber. Clearly, the fuel properties which affect atomization behavior (viscosity, surface tension and density) will be less favorable for the broad specification fuels under consideration here, as compared with those for conventional fuels. To be sure, other operational factors such as thermal stability, storage and transport considerations, pumping behavior, and so on, must also be considered. But the fuel must ultimately be well-atomized in the engine over a suitable range of operating conditions to be at all acceptable as a fuel for aircraft gas turbines. Those conditions necessarily include extremes, such as altitude relight and cold start conditions, as well as normal operating conditions for the engine.

Fuel injectors for specific gas turbine engines are designed to atomize the fuel and to distribute the fuel in the primary air flow over a range of engine operating conditions from idle to full power. These injectors employ one or more of several characteristic types of injection schemes, such as simplex, duplex, air-assist, and airblast, for instance. They vary in their reliance on one or more of the basic mechanisms utilized to effect breakup of the liquid into fine droplets, and in the nature of the control of the processes to enable operation over a sufficiently wide range of fuel flow rates. The technology involved in the development of such injectors remains virtually an empirical art. Nonetheless, there have been some investigations of a sufficiently detailed character to anticipate the trends in the atomization produced by certain types of injectors likely to be employed for the more viscous fuels of interest.

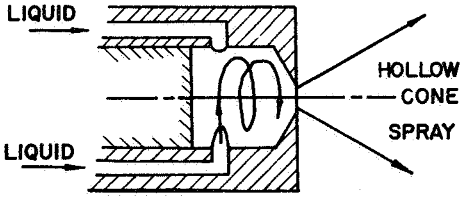
Of the numerous correlations available describing the dependence of the SMD of the spray droplets on the liquid properties, the operating conditions of the atomizer and the properties of the environment, typical relations for simplex (swirl) atomizers and airblast atomizers indicate the SMD increases with increasing viscosity and surface tension, and weakly increases with liquid density. There is evidence the SMD for the swirl atomizer is not significantly dependent on the liquid surface tension. Experimental curves for an airblast atomizer illustrating the variation of SMD with liquid viscosity, surface tension, and density show that increases in each of those fuel properties result in larger spray droplet sizes. Variations of the SMD with ambient pressure or temperature are also illustrated, showing that increases in ambient pressure and decreases in temperature yield smaller drop sizes. The experimental curves are taken from investigations on airblast atomizers conducted by one of the authors (AHL) and his former colleagues at Cranfield University. The importance of these particular results here lies in the fact that airblast atomizers appear to offer the greatest promise for fine atomization of the heavier fuels. The results shown do not exhibit the complete picture, however, insofar as operation over a range of conditions is required and there are other factors involved, such as the fuel penetration and distribution in the airflow within a particular combustion chamber. Complete data for fuels of interest are simply not available.

A research program at Purdue (NSG 3258, NASA Lewis Research Center) is to explore the atomization behavior of representative fuel injectors with fuels simulating the properties of those falling under the broad specification fuel classification. These fuels will be sprayed into nitrogen atmospheres at ambient pressures up to about 20 atm and at ambient gas temperatures up to 1000 ^{o}K. The gas flow and distribution conditions are to be chosen merely to avoid recirculation of spray droplets in the flowfield within the pressure vessel and otherwise are to be made to have minimal effect on the spray dynamics. Measurements of the spray properties (local measurements of the droplet size distribution at points in the near field of the injector) are to be made with an imaging-type spray analyzer donated to Purdue by the Parker-Hannifin Corporation. This device is capable of individual droplet size measurements from 8 microns to 512 microns. It is an automated system coupled with a PDP 11V03 computer installation.

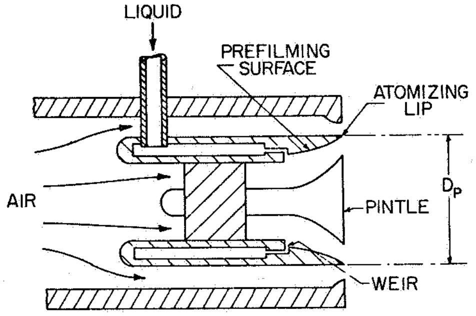
Given the results of these investigations, it should be apparent what tradeoffs are likely to be involved in utilizing each of the characteristic types of fuel injectors for the range of fuels of interest and over the range of ambient parameters of interest. These tradeoffs will involve all of the spray properties measured, including droplet size distribution data, spatial variations of that distribution, and the spatial distribution of the spray droplet density. The extent and nature of atomization properties of the broad specification fuels should then be apparent for each type of injector and the more promising attributes of injectors for specific aircraft gas turbine applications using these fuels might then be identified and incorporated in new designs.

	SPECIFIC GRAVITY	KINEMATIC VISCOSITY (M^2/S)	SURFACE TENSION (N/M)
AVIATION KEROSENE	0.79	1.6×10^{-6}	24×10^{-3}
DIESEL FUELS	0.83	6×10^{-6}	26×10^{-3}
GAS OILS	0.87	30×10^{-6}	29×10^{-3}
MARINE ENGINE FUELS	0.94	400×10^{-6}	$30^{+} \times 10^{-3}$

FIGURE 1. REPRESENTATIVE LIQUID PROPERTIES FOR PETROLEUM FUELS (293 °K)



(A) SIMPLEX SWIRL ATOMIZER



(B) AIRBLAST ATOMIZER

FIGURE 2. ATOMIZER CONFIGURATIONS

INSTABILITIES

- CAPILLARY WAVES
- SHEAR DRIVEN WAVES
- VORTEX INSTABILITIES
- ACOUSTIC INSTABILITIES
- TURBULENCE

FREE BOUNDARY INTERACTIONS

- GAS PHASE SHEAR
- ACOUSTIC FIELDS, PULSES
- LIQUID/SOLID SEPARATION
- CAVITATION PHENOMENA
- THERMAL PHENOMENA

LIQUID PHASE GEOMETRY

- JETS
- SHEETS
- FILMS
- DROPLETS
- LIGAMENTS

ENERGY CONSIDERATIONS

- EQUILIBRIUM ENERGY REQ'D LOW
- RATES OF DEFORMATION ARE NECESSARILY HIGH
- THERMAL LIMITATIONS OF FUELS

FIGURE 3. ATOMIZATION PHYSICS

$$\mathrm{SMD} = K \cdot (\mathrm{FN}) \cdot \mu_L^{0.2} \qquad \text{SMALL NOZZLES}$$

$$\mathrm{FN} = W_L / \sqrt{\Delta P_L}$$

(A) SIMPLEX SWIRL ATOMIZERS (SIMMONS)

$$\mathrm{SMD} = 0.073 \left(\frac{\sigma_L}{\rho_A U_A^2} \right)^{0.6} \left(\frac{\rho_L}{\rho_A} \right)^{0.1} D_P^{0.4} \left(1 + \frac{W_L}{W_A} \right) + 0.015 \left(\frac{\mu_L^2 D_P}{\sigma_L \rho_L} \right)^{0.5} \left(1 + \frac{W_L}{W_A} \right)$$

(B) AIRBLAST ATOMIZERS (LEFEBVRE)

FIGURE 4. SMD CORRELATIONS

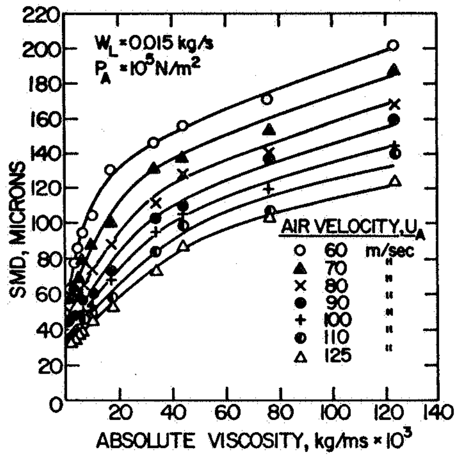


FIGURE 5. EFFECT OF LIQUID VISCOSITY ON DROP SIZE FOR A PRE-FILMING AIRBLAST ATOMIZER (RIZKALLA AND LEFEBVRE)

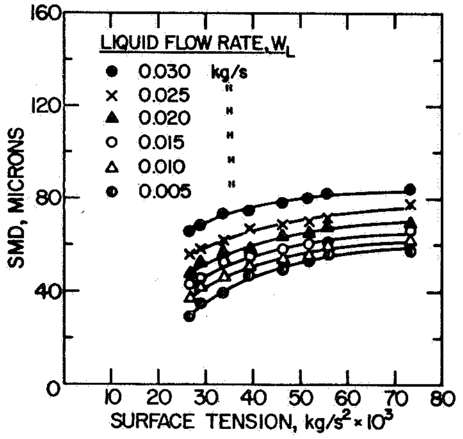


FIGURE 6. EFFECT OF SURFACE TENSION ON DROP SIZE FOR A PRE-FILMING AIRBLAST ATOMIZER (RIZKALLA AND LEFEBVRE)

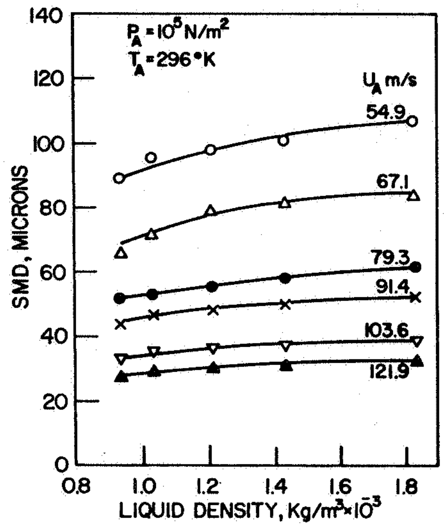


FIGURE 7. EFFECT OF LIQUID DENSITY ON DROP SIZE FOR A PRE-FILMING AIRBLAST ATOMIZER (RIZK AND LEFEBVRE)

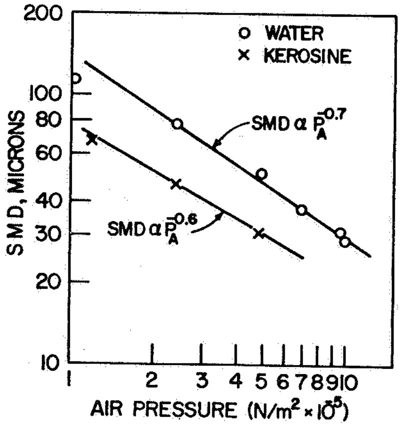


FIGURE 8. EFFECT OF AMBIENT AIR PRESSURE ON DROP SIZE FOR AN AIRBLAST ATOMIZER (RIZKALLA AND LEFEBVRE)

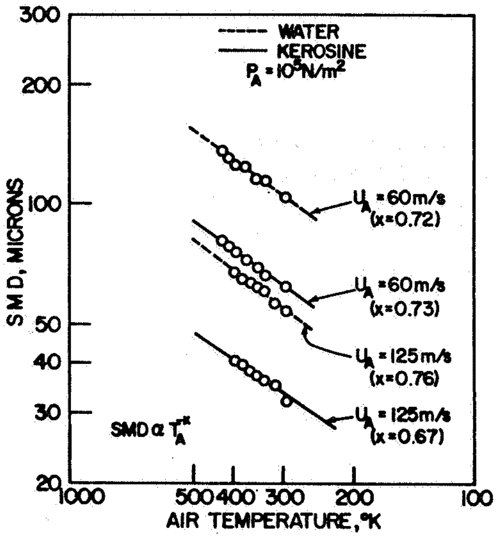


FIGURE 9. EFFECT OF AMBIENT AIR TEMPERATURE ON DROP SIZE FOR AN AIRBLAST ATOMIZER (RIZKALLA AND LEFEBVRE)

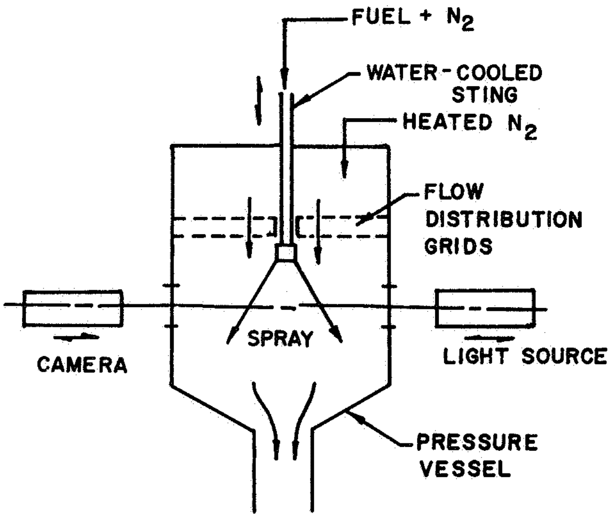


FIGURE 10. EXPERIMENTAL APPARATUS

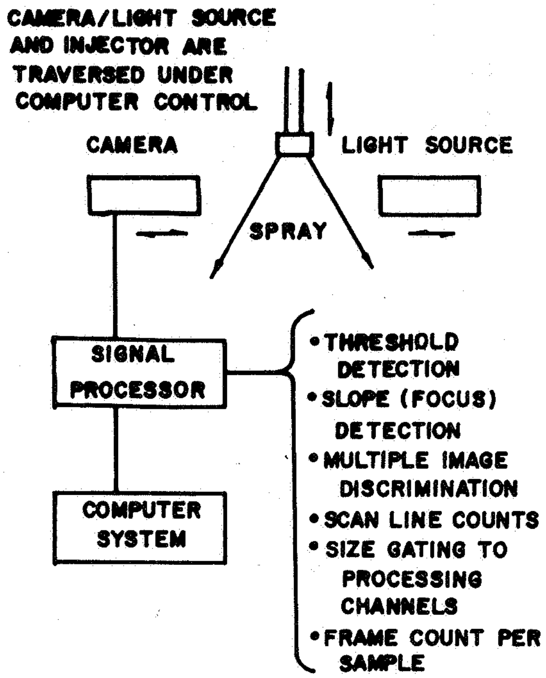


FIGURE 11. PARKER-HANNIFIN SPRAY DROPLET ANALYZER