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Technical Note

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Studies on Performance of Airblast Atomizer Under Varying Flow and Geometric Conditions

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Nomenclature

D = inner diameter of nozzle
$\dot{m}$ = mass-flow rate
V = velocity at the exit of atomizer
We = exit Weber number $(\rho_A V_R^2 D_W / \sigma)$
ρ = mass density
σ = surface tension of liquid (water)

Subscripts

A = air
R = relative, air with respect to water
W = water

Introduction

THE performance of any engine such as that of rocket or gas turbine depends on the combustion characteristics, which in turn are critically governed by the atomization of fuel/propellant. Hence, it is important to be able to measure and control spray parameters toward deriving the desired performance from an atomizer. The present study examines a typical plain-jet airblast atomizer that finds application in aerospace propulsive devices.

The performance of airblast atomizer is usually expressed in terms of variation of Sauter mean diameter (SMD) as a function of air-to-liquid mass ratio,[1,2] relative velocity,[1,2] and air-to-liquid velocity ratio. But it is not clear in literature as to which of these is the most appropriate parameter for correlation. Similarly geometric variations also need to be taken into account in order to obtain a generalized correlation. Lorenzetto and Lefebvre[2] have studied the effect of varied size of air nozzle on the mean drop size of the spray and presented a family of SMD curves in terms of mass ratio. A general trend of reduced drop size has been reported in literature[3] with the use of convergent air exit. However, no correlation is attempted for a varied size of air nozzles. Yet another effect of liquid tube recess (retraction of liquid nozzle inside the cavity of air nozzle) has been studied by many investigators,[3–7] and varied trends have been reported. The present work reexamines the effect of flow and geometric parameters on the performance of the atomizer, and further, suitable correlating parameters have been proposed for predicting mean drop size.

Experimental Arrangements

The plain-jet airblast atomizer (Fig. 1) was constructed and operated at ambient conditions with varied flow rates of fluids. Different geometrical configurations have been incorporated in the study and are denoted by a three-number code (i, j, k) as explained next. The first subscript i denotes the type of air exit, the second subscript j denotes the type of water nozzle, and the position of water nozzle exit inside the air nozzle is represented by the third subscript k. Table 1 summarizes the geometrical configurations adopted in the study. Thus a configuration of (1, 2, 1) represents a straight air exit with a tapered water nozzle with its edge flush with the exit of air nozzle. The geometric configurations adopted are shown in Fig. 1.

Calibrated rotameters (confidence level of the order of 98%) were used to measure the flow rates of air and water discharged through the atomizer. The velocity data at the atomizer exit were derived using the data of the mass-flow rate and the local cross section area at the exit.

In the current study Malvern Master Sizer-χ, an advanced version of the laser light scattering system, has been used to measure the overall drop diameters in the spray. Dodge[8] has suggested calibration methods applied to an earlier version of Malvern, which accounts for the difference in responsivity of detectors and other

Table 1 Geometrical configurations adopted in the study

Subscript	Geometric parameter	Code number 1	Code number 2
i	Type of air exit	Straight	Convergent
j	Type of water nozzle	Blunt	Tapered
k	Position of water nozzle exit inside the air nozzle	Flush	Recessed

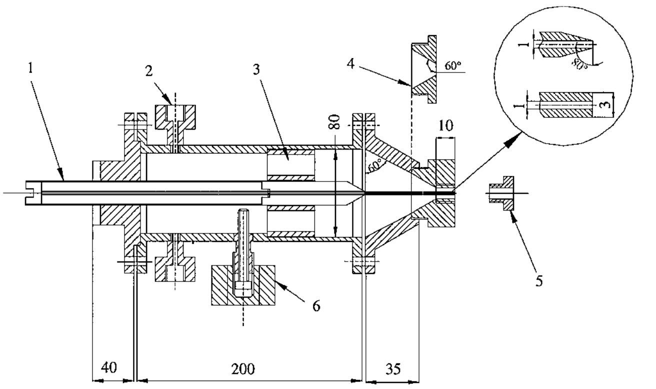

Fig. 1 Schematic of airblast atomizer: 1) liquid tube (threaded), 2) air supply port (four no.), 3) flow straightner, 4) convergent exit air nozzle, 5) straight exit air nozzle, 6) centering pin holder assembly. Inset: tips of tapered end and blunt end liquid nozzle. All dimensions in mm. The inner diameter of air nozzles (part nos. 4 and 5) vary from 4.5 to 8.0 mm.

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such problems. These are however not necessary in the current study because the present model Malvern Master Sizer-χ has already included standard calibration procedures into its software. All of the experiments were conducted with the spray being horizontal and intersecting the laser beam at 90 deg. The obscuration levels were found to be less than 55%, and hence the effect of multiple refraction in such sprays is negligible.[9] Measurements were reproducible within 2% in case of lower levels of SMD and 1.2% in case of higher levels of SMD.

At an axial location of 105 mm from the atomizer exit, the laser beam of 18 mm diameter of Malvern was found to be sufficient to scan at least about 90% of the spray width in all of the cases considered. The radial SMD variation at this location is found to be flat as a result of strong turbulent mixing and completed atomization. Hence, line-of-sight data obtained with the use of 18-mm laser beam positioned at an axial distance of 105 mm from the nozzle exit in the spray are adopted for describing the overall spray characteristics under varying geometric and flow conditions.

Results and Discussions

Influence of Flow Parameters

The effect of variation of flow parameters on the spray characteristics has been described in the literature[1,2] in terms of SMD variation with commonly used representative variables, namely, velocity ratio, mass ratio, and momentum ratio of air to liquid. However, these plots show distinct curves for different flow rates of fluids. The underlying mechanism of breakup indicates that relative velocity of liquid drop with respect to coflowing gas dictates the atomization process at varied flow rates of fluids. To support this argument, the data are plotted in terms of SMD vs the square root of exit Weber number (or indirectly the relative velocity) in Fig. 2 for varied mass-flow rates of fluids. SMD data are closely packed with respect to relative velocity for all of the flow rates of liquid revealing the importance of correlation of SMD with respect to the Weber number for a range of varied Reynolds number of water jet. The suggested correlation SMD $\sim (We)^{-2.7}$ can be used for a prior estimation of the spray quality from any similar plain-jet airblast atomizer under varying flow conditions.

Influence of Geometric Parameters

The effect of different geometric variations (viz., the size of the air nozzle, convergence given to the air nozzle, the wall thickness of the liquid tube, and recessing of liquid tube inside the air nozzle) on the atomizer performance has been studied in this investigation.

It is expected that a smaller air nozzle performs better as a result of augmented relative air velocity at similar flow rates. To investigate the effect of varied air nozzle size, air nozzles of diameter varying from 4.5 to 8 mm with the combination of liquid nozzle of 3 mm outer diameter have been incorporated. The use of convergent air exit is reported[3,10] to perform better when compared to that with a straight air exit. The direction of airflow brings into picture the relative distance over which the influence persists. In the present study the results of straight exit air nozzle are compared with those of convergent exit air nozzles of 120 deg included angle. The wall thickness of the liquid tube at the exit in the plain-jet atomizer is another parameter, whose effect on atomization cannot be ignored at least at near nozzle regions. A finite wall thickness of the liquid tube at the jet exit is expected to produce a strong recirculation region into which the small droplets are sucked in and churned to affect a better mixing. In the present study two configurations, one with a blunt edge of wall thickness of 1 mm and the other with sharp tapering edge as shown in Fig. 1, have been investigated. Conflicting results have been reported in the literature[3–7] regarding the effect of recess on the mean drop size. In the present study the liquid tube is recessed up to 4 mm, and its effect on SMD is studied for varied air nozzle diameter with straight and convergent air exit configurations.

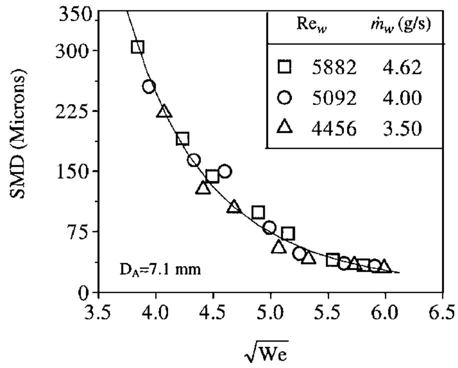

Fig. 2 SMD correlation with Weber number for varied flow rates of air and water (Correlation: SMD = 4.5e5$(We)^{-2.7}$ θm, Configuration: [1, 1, 1]).

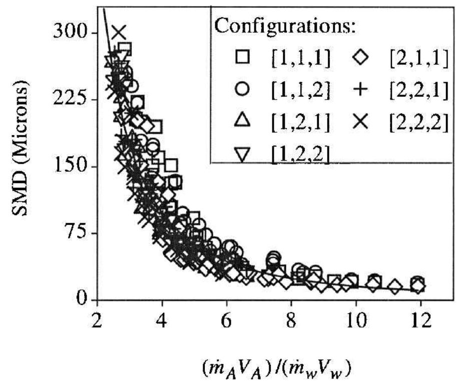

Fig. 3 Correlation of SMD data with momentum ratio of air to liquid for varied geometrical configurations. Correlation: SMD = 1585 (momentum ratio)$^{-2}$ θm, correlation coefficient: 0.96.

Any change in the geometry of the atomizer results in the situation of altered effective momentum transfer from the coflowing air to the centrally flowing liquid jet in an airblast atomizer. Although the importance of momentum transfer mechanism on the quality of the spray produced has been recognized in a few previous reports,[10] the correlation with momentum ratio is seldom seen. In the present study an effort is made in this direction, and a plot of SMD vs momentum ratio for combinations of geometric variations tested is drawn (see Fig. 3). Closely packed data shown in this plot clearly emphasize the importance of the momentum ratio as the prime parameter in estimating the atomizer performance under varying geometry of the atomizer.

Any effort of recasting these data with other nondimensional numbers such as Weber and Ohnsorge numbers does not correlate well when compared to the correlation obtained with momentum ratio. The drop-size data for varying flow rates at fixed geometry correlate well with Weber number (Fig. 2), whereas the data for varying geometry correlate well with momentum ratio of air to liquid (Fig. 3). In the absence of any such efforts in the past to represent the effect of variation in the flow rates of fluids and geometry of atomizer on drop-size data, the graphs presented in Figs. 2 and 3 are found to be useful in a rough prior estimation of atomizer performance under such conditions.

Conclusions

Performance of an airblast atomizer operated at atmospheric pressure is evaluated through the drop-size measurement using a laser light scattering system. Spray characteristics are presented for varying mass-flow rates of fluids and geometric parameters such as size of air nozzle, type of air approach passage (convergent and straight exit), liquid tube wall thickness, and liquid post recess in the air nozzle cavity.

Weber number and momentum ratio of air to liquid jet are shown to play important role in the atomization under varying mass-flow rates and geometry of the air nozzle, respectively. Hence, these parameters are proposed as the correlating parameters for the first approximation of SMD under varying conditions of mass-flow rate and the size of air nozzle.

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