Experimental Study of an Internally Mixed Liquid Atomizer for an Air-breathing Engine Application

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Abstract

This paper presents experimental results on the performance of a newly designed internally mixing atomizer. This kind of atomizer can find applications in air breathing engines such as ram jet and scramjet engines in future, as it could produce spray with finer droplet sizes at lower injection pressure. This internally-mixed twin-fluid atomizer is characterized in terms of average droplet diameter (SMD), droplet size distribution and spray cone angle for a wide range of gas-liquid ratio (GLR) and injection pressure. The droplets size was measured using Malvern spray analyzer which indicates that there is a decrease in SMD with GLR. Besides this, there is a reduction in average droplet size with the variation of radial distance about the nozzle axis and this difference becomes high for low GLR values. The spray half cone angles are found to be in the range of 7.4-10.8°, which matches well with reported data available in literature. The cone angle was observed to increase slightly with GLR that may be due to increased turbulence level inside the mixing chamber. These studies are expected to aid in the development of atomizers for air-breathing engines.

Introduction

The use of air breathing rocket engines and reusable launch vehicles has an immense potential in reducing the launch costs for satellites and other space missions. One of the crucial components of the liquid propulsion system of such a vehicle would be the liquid fuel atomizer. Furthermore, the spray formation may influence the interaction between the pressure oscillations inside the combustor and the heat released during the combustion process leading to the occurrence of combustion instabilities, which can be detrimental to the engine and its performance. Therefore, it is absolutely necessary to control or suppress these combustion instabilities in order to expand the operating envelope of an engine which can be achieved by use of internally mixed atomizer. The combustion of liquid fuels involves atomization of a bulk liquid into a multitude of droplets [1], thus increasing the liquid surface area and enhancing the rate of evaporation of liquid fuel. The formed fuel vapor then mixes with the air to form a combustible mixer. Therefore, the evaporation time, along with the mixing time and chemical reaction time, play a very important role in the performance of the engine, which, in turn, depends upon the sizes of the generated droplets. Also, non symmetrical spray flames and hot-streaks can cause serious damage to combustor liners and have serious impact on combustor exit temperature distributions [2]. Since the flame shape, flame location and pattern factor strongly depend on the characteristics of the fuel spray, controlling the spray properties has become an issue of major concern because of potential damages it can cause to the engine. Controlled atomization can lead to increase in combustion efficiency and reduction in emissions. The use of internal mixing atomizer shows promise in controlling the spray characteristics, and helps in achieving faster atomization, evaporation and mixing.

Investigations into the effect of operating conditions on the spray quality of internally mixed atomizer have been reported [3]. It was found that the SMD obtained from such an atomizer decreases on increasing the Gas-to-liquid mass ratio (GLR) with the effect being less prominent at higher GLR. They further reported that the droplet velocity increases with injection pressure. Along the radial direction, droplet velocity attains a peak value at the centerline of the spray and falls off along the radial distances on the both sides in the shape of normal distribution. It has also been noted that an increase in injection pressure enhances the spray cone angle monotonically.

The variation of mean droplet velocity with the operating conditions has also been investigated [2]. They found that the mean droplet velocity and the GLR increases on increasing the air flow rate. Also the SMD of the spray decreases on increasing the air flow rate. Investigations into the effect of atomizer geometry have been reported [4, 7]. Important geometric parameters influencing spray characteristics include the ratio of the final discharge orifice to the total area of the aerator holes (A_0/A_h) and the location of aerator holes relative to the final discharge orifice, (l_o/d_o). Low values of A_o/A_h resulted in finer sprays [5]. This is attributed to bubbly flow regime inside the atomizer. Mean drop sizes have been found to decrease when aerator holes are located farther from the discharge orifice [5].

This paper discusses the characteristics of an internally mixed twin-fluid atomizer which can be used to achieve fine atomization. In this paper an internally mixed twin fluid atomizer is designed and its performance would be evaluated in terms of spray characteristics such as SMD, droplets size distribution, and spray cone angles. It is believed that this kind of atomizer can find applications in air breathing engines such as ram jet and scramjet engines in future as it could produce spray with finer droplet sizes at lower injection pressure.

Materials and Methods

A schematic of the internal-mixing twin fluid atomizer used for the present study is shown in Fig. 1. It has a central tube through which the liquid is passed. The orifice diameter through which the liquid enters the mixing chamber is 0.7 mm. The atomizing air enters the mixing chamber through a side inlet port forming a two-phase flow inside the chamber. The exit orifice diameter of this injector is also 0.7 mm through which two-phase flow is injected forming a fine liquid spray.

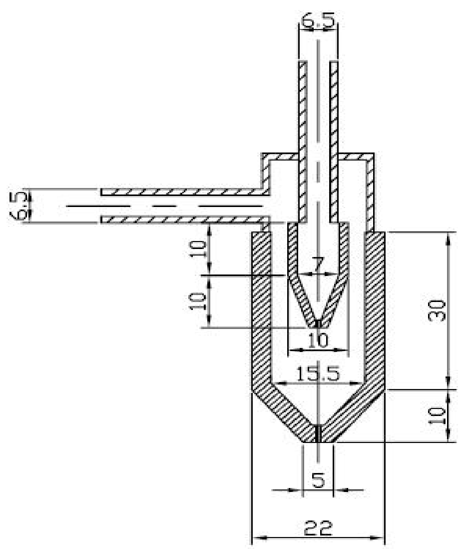


Figure 1: Schematic of the internally-mixed twin-fluid atomizer (All dimensions in mm)

The schematic of the setup to study twin fluid atomizer characteristics is shown in Fig. 2. The various components include air and water supply lines, mass flow meters, pressure gauges, pressure regulators, filters, fine control valves and the Malvern's Spraytec analyzer. A single-stage reciprocating compressor supplies compressed air for the experiments. The air supply is divided into three lines. The first is used to pressurize water in a storage tank, the second serves as a source of atomizing air being fed to the atomizer and the last is used for purging optical system of Malvern's spraytec analyzer. Pressurized water and atomizing air flows through a series of filters and fine control valves. The flow rates of the fluids were measured with mass flow meters and standard pressure gauges were employed for measuring pressure. The supply pressure of water and atomizing air were regulated at ~860 kPa (all pressures reported are gauge pressures). The atomizer was mounted on X-Y-Z traverse so as to facilitate in obtaining radial and axial drop size distributions. Drop-sizes and drop-size distribution in the axial direction were obtained with the help of Spraytec Analyzer. The Malvern Spraytec Analyzer uses a 5 mW laser beam at a wavelength of 670 nm, beam diameter of 10 mm, 200 mm focal length lens and has a measurable drop size range of 1 – 400 µm (based on the median of the drop-size range). The instrument is based on line-of-sight measurement and does not make a point measurement.

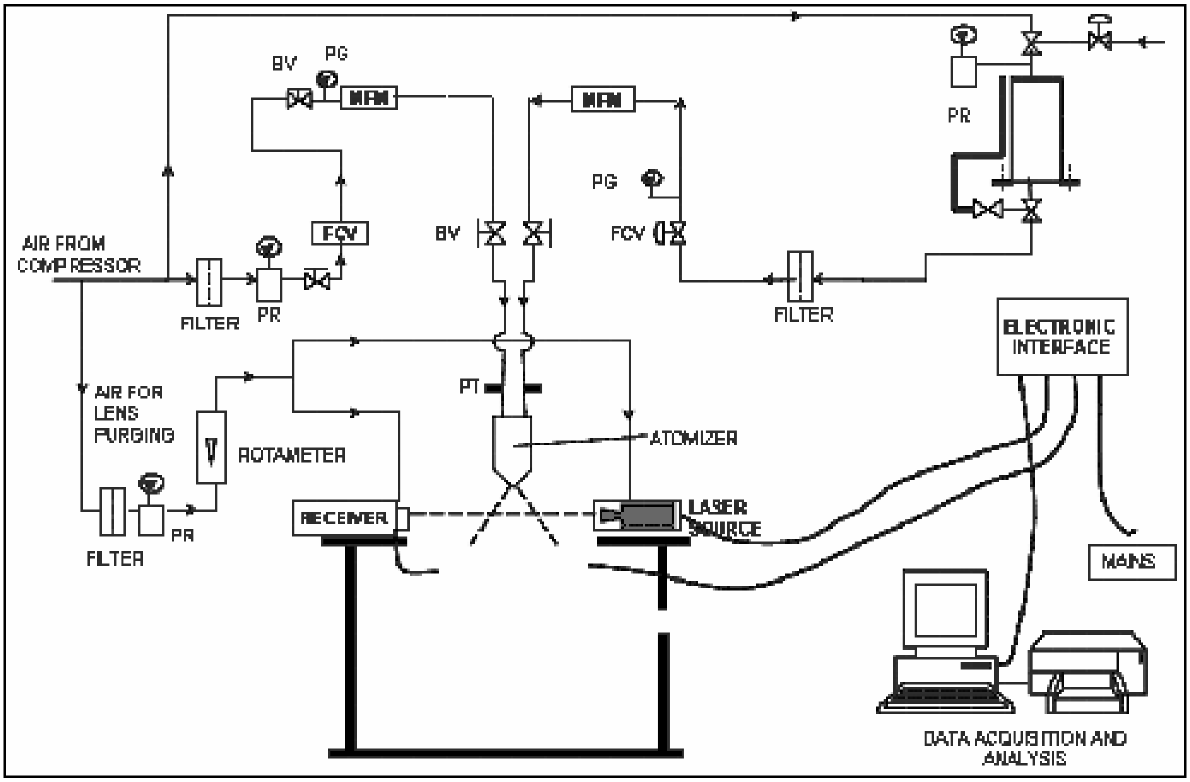


Figure 2: Schematic of the test facility for atomization studies

Figure 3 shows the various components of the setup for measuring the spray cone angle consisted of a laser source, cylindrical lens, air and water supply lines, and panel for controlling the operating conditions of the atomizer. A laser sheet was passed through the spray to illuminate it. The sheet was produced by using a cylindrical lens in front of a laser beam. A series of time averaged photographs were taken at a particular operating condition.

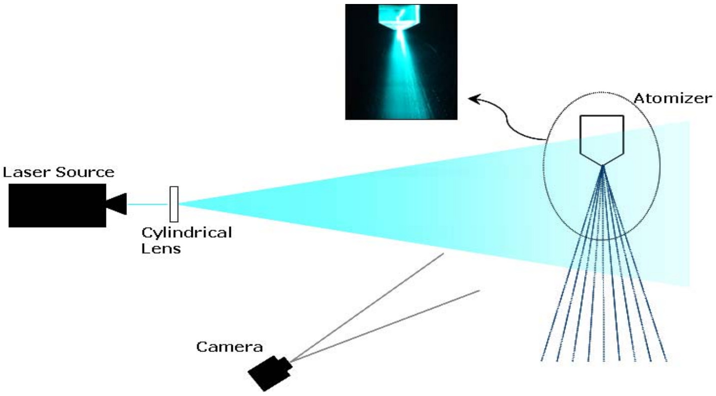


Figure 3: Setup for spray cone angle measurements

Results and Discussion

In the present work, drop size data was obtained under varying operating conditions using the Malvern Spray Analyzer. The GLR was varied between 2-25 % by varying injection pressure while maintaining a constant supply pressure at 860 kPa. Effect of GLR on droplet-size and its radial distribution have been determined. The variation of SMD with GLR for various radial locations about the nozzle axis is plotted in Fig. 4.

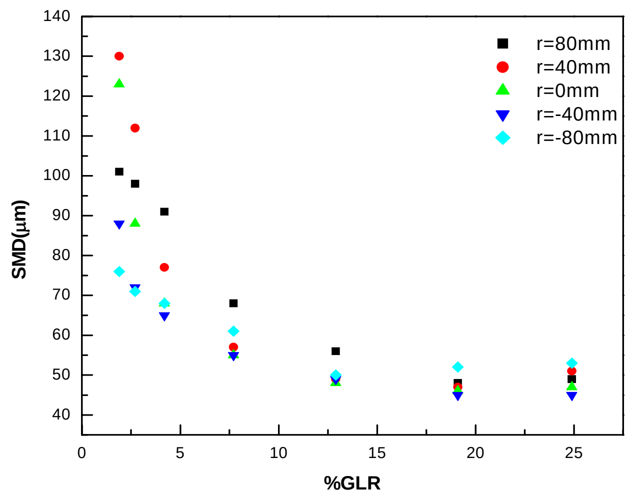
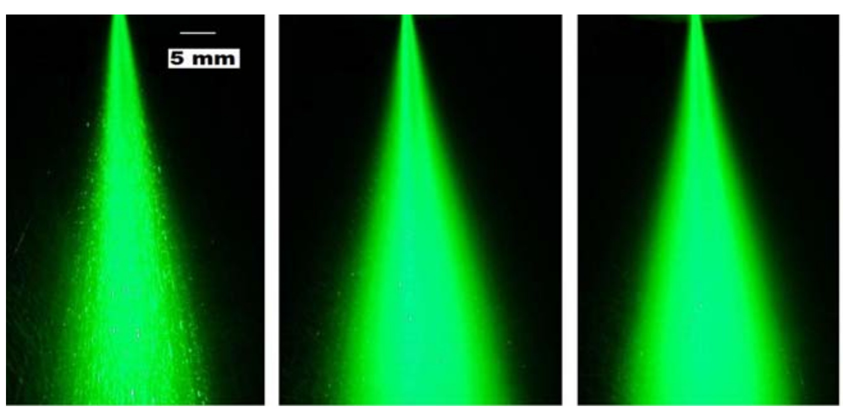


Figure 4: Variation of SMD with GLR for various radial locations at axial distance of 125 mm

It can be observed that the SMD of the spray decreases with increasing GLR. This may be due to two reasons. First, the increase in airflow rate is accompanied by increased restriction on water passage, and hence accelerating the water flow [3]. This, in turn, increases the kinetic energy of water, resulting in an improved atomization. Second, the increase in air flow rate is accompanied by an increase in air velocity and thus the shear force it exerts upon the water. Consequently, the number of droplets being stripped from the water filament increases, resulting in finer atomization. The results obtained agree fairly well with those obtained by other investigators [6, 9, 10].

Cone angles of sprays formed in the internally-mixing twin fluid atomizer used in the present work were studied. Spray was illuminated using a laser sheet from a 100 mW laser and photographs were taken using a CCD camera (SONY DCR PC350E). Spray photographs for some GLR values are shown in Fig. 5. The edges of spray cone were identified using the edge detection method with help of image processing software (Image-J).



GLR 5% GLR 15% GLR 25%

Figure 5: Spray photographs for three different GLRs

The variation of spray half cone angle with GLR, plotted in Fig. 6, indicates that the cone angle remains almost constant with GLR of the spray. On increasing the GLR, this difference between the angles gets increased marginally. It has been observed from spray photographs that after a certain distance from the exit, ripples on the surface of the spray cone are observed, which may be due to interaction between the aerodynamics forces and surface tension forces of the liquid sheet. Aerodynamic interaction of liquid sheet with the ambient air may cause waviness [1, 8] on the liquid surface that may eventually lead to disintegration of liquid sheet into droplets.

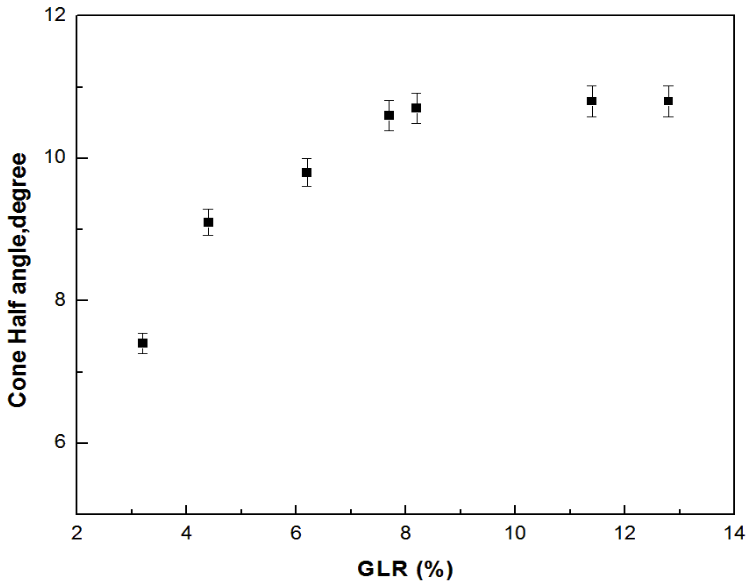


Figure 6: Variation of half cone angle with GLR

Conclusions

The present experimental work is concerned with characterization of an internal-mixing type of twin-fluid atomizer. An increase in GLR resulted in a significant drop in SMD which may be due to the increased shear force exerted by air on increasing the GLR. The average droplet sizes ranges from 130 to 42 µm, GLR is changed from 2 to 25 %. However, for a particular GLR, the SMD remains almost constant about nozzle axis which is quite useful for air breathing engines. Spray cone angles for different operating conditions were also measured which indicates that the spray cone angles remain almost invariant for high GLR.

Nomenclature

CCD charge coupled device
GLR gas to liquid ratio
SMD sauter mean diameter

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