STUDY ON SECONDARY BREAKUP PROPERTIES OF SPRAY FOR MICRO GAS TURBINE ENGINE

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Fluid: high speed flows
Visualization method(s): shadowgraph
Other keywords: air assisted atomizer, sauter mean diameter(SMD), spray, secondary breakup, micro gas turbine

ABSTRACT: This paper reports secondary breakup properties and droplet size measurement of spray through nozzle of air assisted atomizer. The atomizing air supply pressure was regulated of 169 kPa(abs) to 790 kPa (abs), correspondingly consumed 1.4×10^{-3} to 3.3×10^{-3} kg/s of water. The air mass flow rate was varied between 2×10^{-4} kg/s to 1.2×10^{-3} kg/s, in order to establish an empirical relation between the air mass flow rate and the air supply pressure. The secondary breakup properties of spray were studied by taking the flow images at different air supply pressures by using a shadowgraph method. By traversing the measurement section, the spray images were acquired at 5 axial locations of 50, 100, 150, 200 and 250 mm downstream from the atomizer. The investigated air assisted atomizer provided droplets with Sauter Mean Diameter (SMD) in the range of about 23-80 μm.

1. Introduction

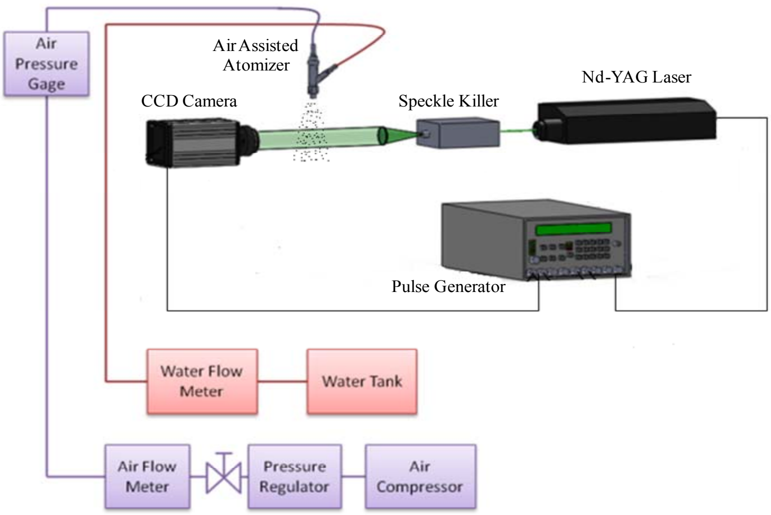
Air-blast atomizer provides the finest degree of atomization for a moderate flow capacity and supplied pressures. We can design a desirable condition such as a spread angle and solid cone[1]. In usage of air-blast atomizer, a large amount of air will be exhausted for driving force of atomization. When a driving condition is optimized, the fine droplets can be produced at even a low liquid pressure. The illustration of the present air assisted atomizer is shown in Fig. 1. The present air-blast atomizer is simple in design, so that the air-blast atomizers have been developed for a micro gas turbines which was shown in Fig.2. Since the present atomizer has an internal mixing chamber inside, a primary breakup of droplets takes place in it. Therefore a droplet characteristic of spray in a secondary breakup process was investigated by means of an optical flow visualization.

Fig. 1 Present air-blast atomizer

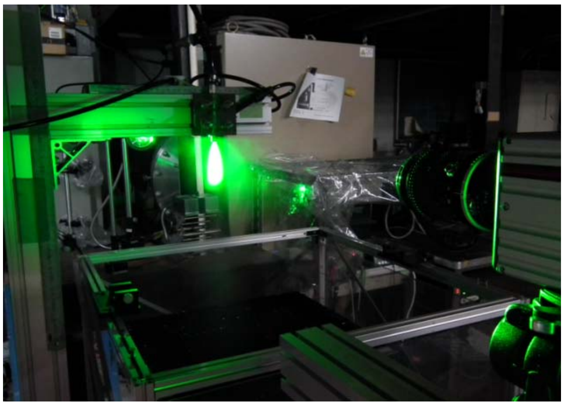
Fig. 2 Micro gas turbine

2. EXPERIMENTAL SET UP

Flow visualization was conducted by using a shadowgraph technique[2]. The setup used in the present experiment is shown in Fig. 3a. An Nd-YAG CW laser was used to illuminate the test section. Shadowgraphic images to observe the breaking up process were acquired with a high speed CMOS camera (IDT, XS-5). The focal length was 200 mm and spatial resolution 1280 x 1024 pixels. In order to minimize the influence of speckle noise, a speckle killer (Nano photon, SK-11) was used. The laser beam passing through the speckle killer was collimated with a lens of □=100 mm. The camera focused on the test section, so that a direct shadowgraphic image was captured with this setting as shown in Fig. 3b.



a) Shadowgraph technique



b) The camera focused on the test section

Fig. 3 Experimental Setup

The spray characteristics near nozzle were studied by obtaining the flow images of spray atseveral supply pressures. Traversing the measurement section, the spray images were acquired and the state of spray at 5 axial locations of 50, 100, 150, 200 and 250 mm downstream from the atomizer will be discussed in the following section.

3. RESULTS AND DISCUSSION

3.1 Performance Test of Air-blast Atomizer

The atomizing air pressure supply was regulated of 169, 514 and 790 kPa(abs), correspondingly consumed 1.4×10^{-3}-3.3×10^{-3} kg/s of water, as shown in Fig.4. In the present study, the liquid supply pressure was kept constant at the atmospheric pressure and the air flow rate was varied according to the air supply pressure. The air mass flow rate is calculated with pressure between 169-790 kPa (abs). Fig.5 shows the relation between the air flow rate and supplied pressure. In the present condtions, the air mass flow rate varied from 2×10^{-4} kg/s to 1.2×10^{-3} kg/s.

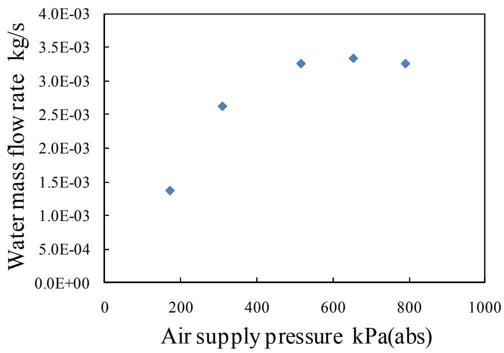


Fig. 4 Experimental value of water flow rate.

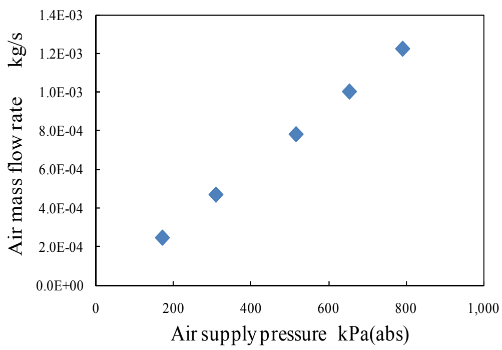


Fig. 5 Experimental value of air flow rate.

3.2 Near Nozzle Region

The formation of a spray begins with the detaching of droplets from the dense zone extending from the orifice of the injection nozzle, as shown in Fig. 6. The detaching of the dense zone into ligaments or large droplets is a remained part after primary breakup. The liquid ligaments and large droplets will further break-up into small droplets due to the interactions between the liquid ambient gas or droplet collisions. The process of this further break-up is called secondary breakup [1]. Correspondingly, the downstream region where the volume fraction of the liquid is relatively low is called the dilute spray region. The process of disintegration of liquid droplets were studied experimentally by Hirahara et al . [3] and Morgan et al. [4]

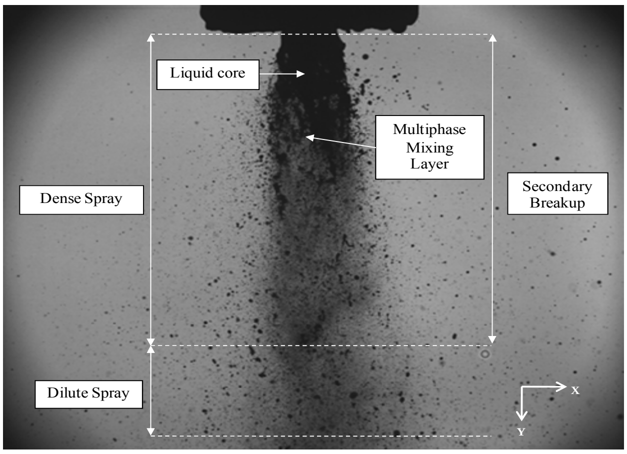


Fig. 6 Atomization regions of the spray from the air assisted atomizer at assisted pressure 514 kPa (abs)

3.3 Verification of Measurement of Droplet Size

In the caribration, the accuracy of the measurement of droplet size by the present method was verified by using the silica particles. The exact diameters of silica particles were measured with a microscope, as shown in Fig.7. The shadowgraph silica particle analyzing system measures silica particle diameter from the size of silica particle shadow captured only in focus with sharp edge images, as shown in Fig.8. The in focus image and the out of focus image are shown in Fig. 9.

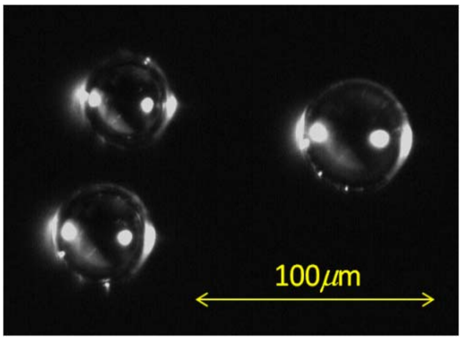


Fig. 7 Silica particle

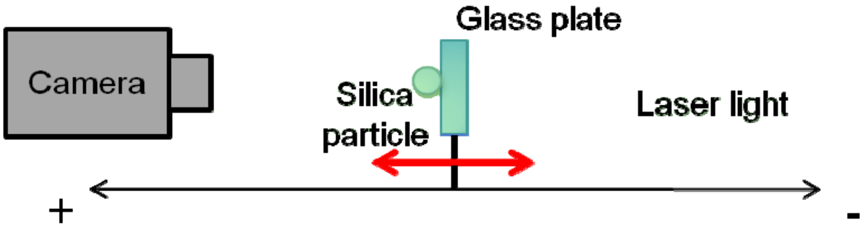
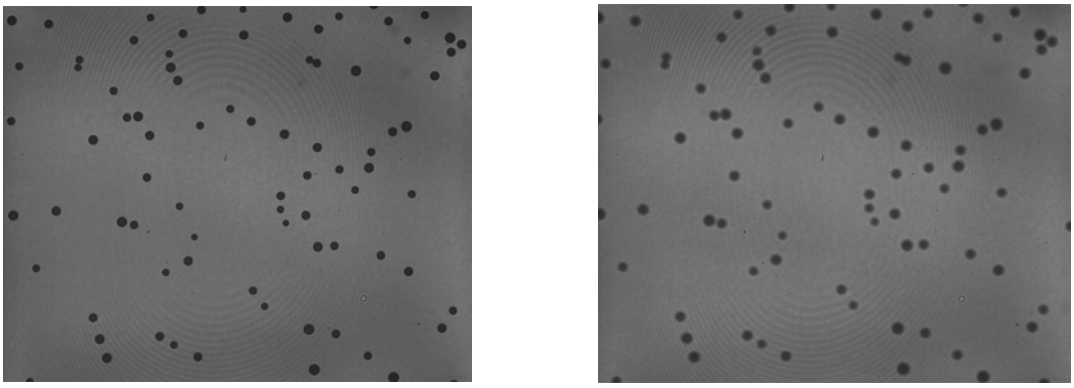


Fig. 8 Calibration with the silica particle



a) In focus image b) Out of focus image

Fig. 9 The shadowgraph image of Silica particle

3.4 Droplet size measurement

We developed the shadowgraph droplet analyzing system and measureed droplet distribution from the droplet shadow images that captured only in focus iamges with sharp edge. In estimating the particle size, the appropriate thresholds based on particle images intensity were set to get the in focus images. A spatial resolution was 1280×1024 pixel and the observation area was 2.2 mm × 1.8 mm. By traversing the measurement section, the spray images were acquired at 5 axial locations of 50, 100, 150, 200 and 250 mm downstream from the atomizer. Figure 10 shows observation areas for the droplet size measurement

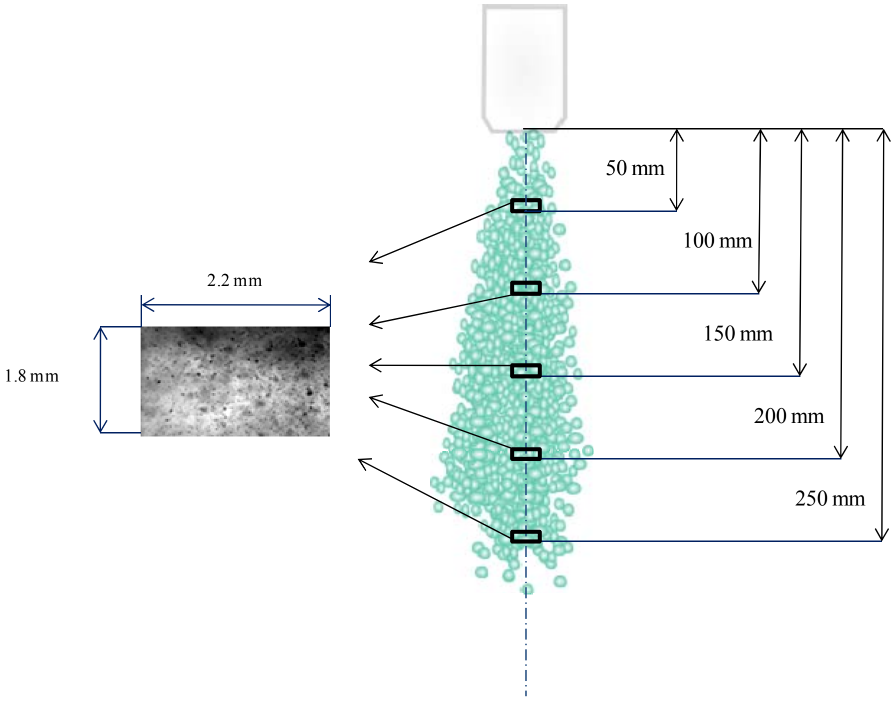


Fig. 10 Observation areas for droplet size measurement

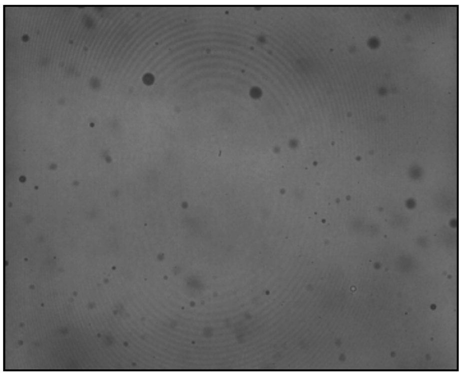


Fig. 11 Actual raw image

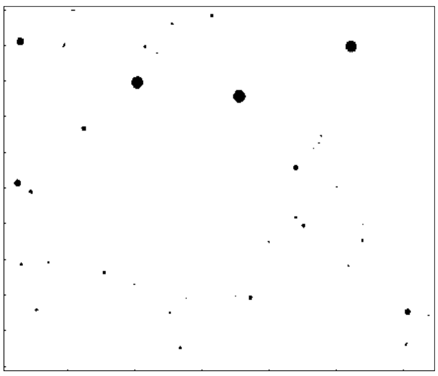


Fig. 12 Processed image

Figure 11 shows a raw shadow image taken at150 mm downstream from the atomizer . It shows that the droplets were not overlap due to the lower concentration at downstream of the atomizer exit. Furthermore, there were some blurred droplets images due to the out of focus. In order to determine an accurate drop size distribution, only in-focus image drops were selected during the image segmentation process.

Figure 12 demonstrates the extracted droplet by processing the raw image. The acquired raw image was enhanced and segmented to produce image, as shown in Fig. 12. Image enhancement was applied to improve the image by changing the brightness and contrast as well as applying the filter function. After the image enhancement, it was segmented to separate the particles from the background by applying a threshold function. Volume-based drop size distributions are present in Fig.13-Fig.15.

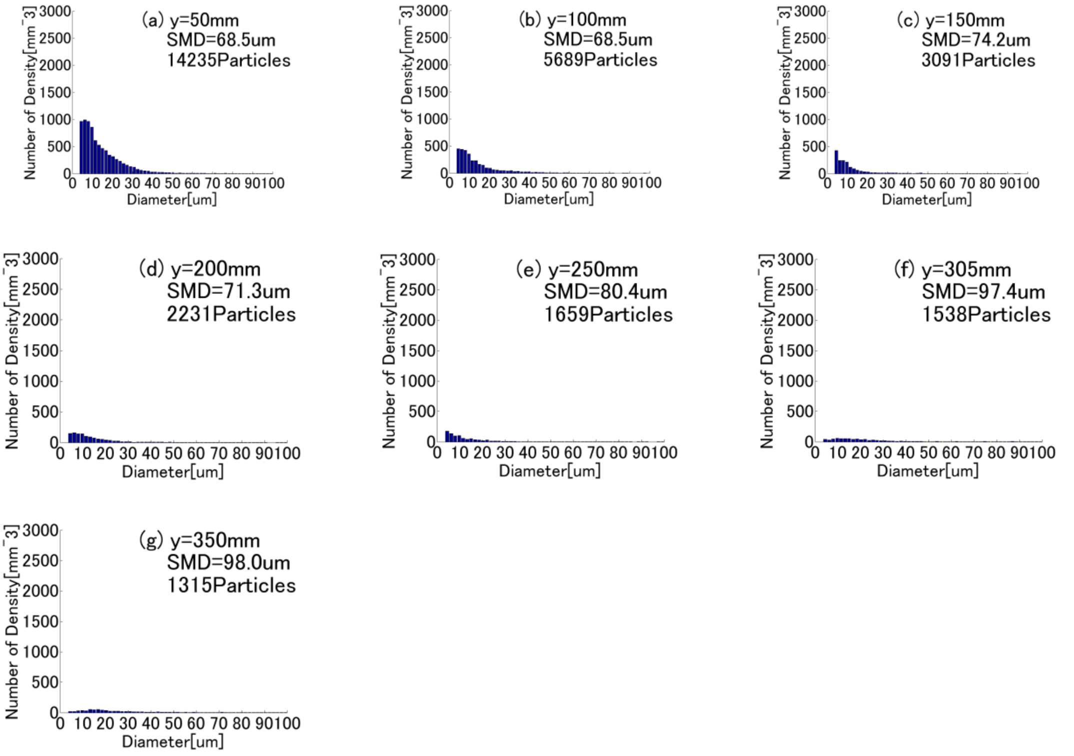


Fig. 13 Particle size distribution at 169 kPa(abs)

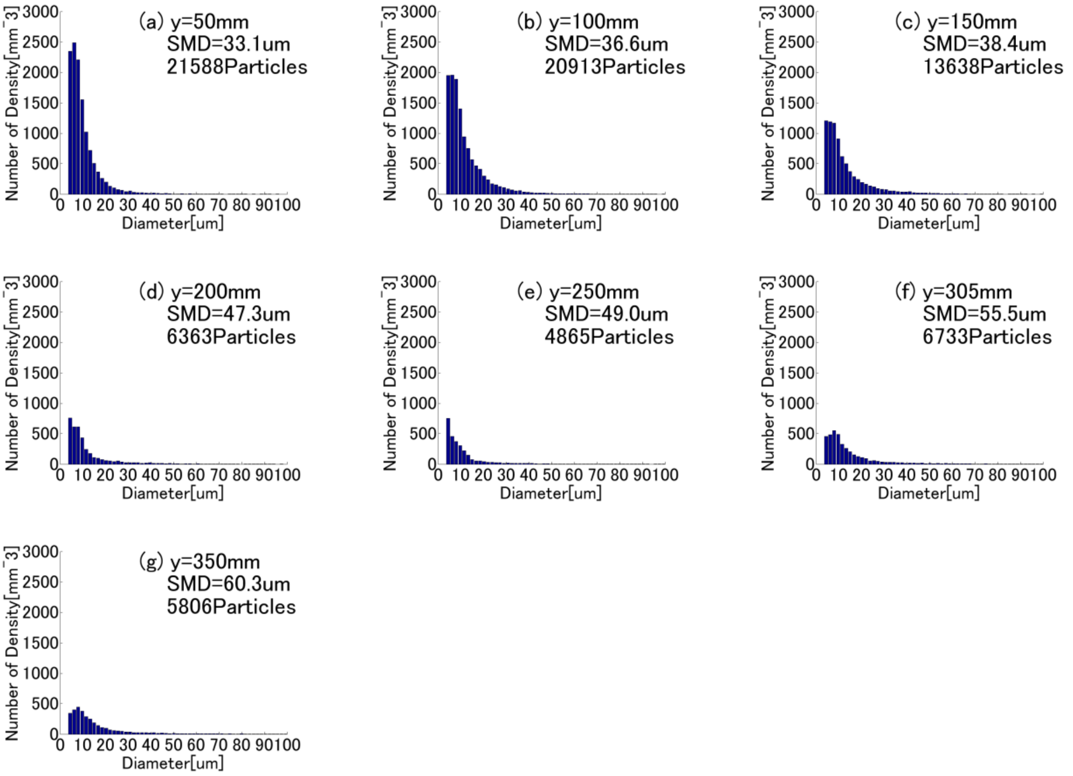


Fig.14 Particle size distribution at 514 kPa(abs)

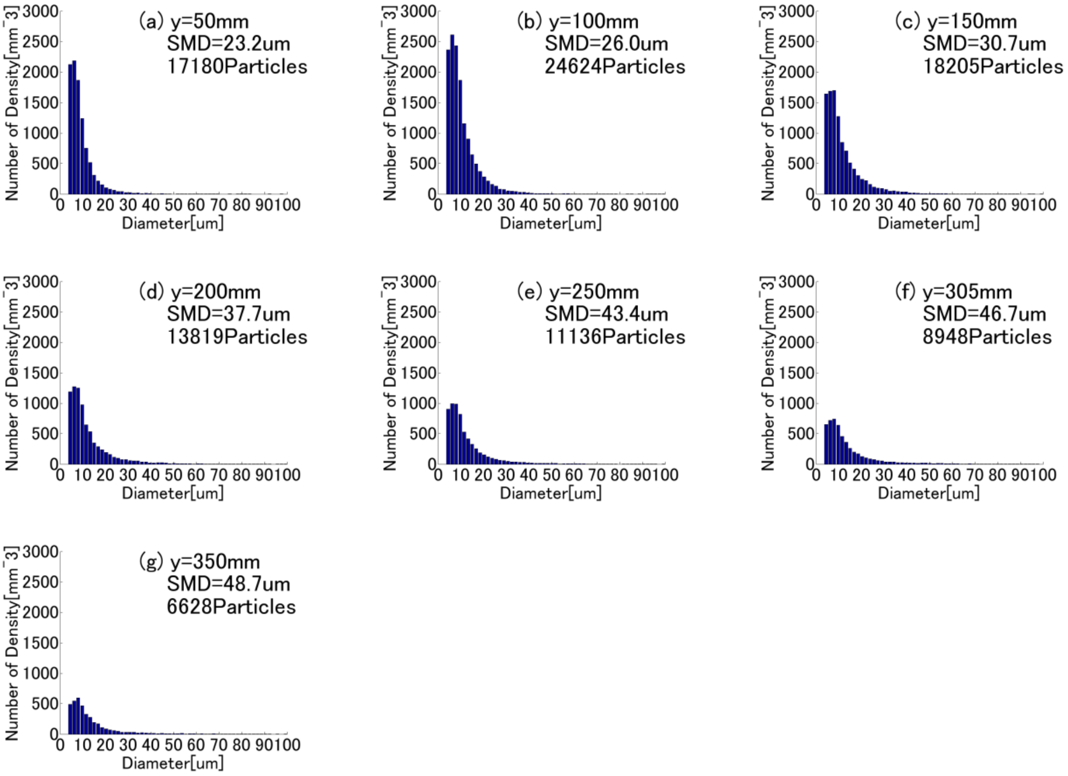


Fig.15 Particle size distribution at 790 kPa(abs)

Figure 16 shows smd versus axial distance for the 5 locations of 50, 100, 150, 200 and 250 mm downstream from the atomizer. Droplet size (SMD) inceasese with increasing of downstream axial distance from the discharge orifice along the centerline. Droplet size (SMD) from air assisted atomizer had various sizes in the range of about 23-80 µm. Similar trend of smd versus axial or radial distance has been reported by Whitlow and Lefebvre [5] and Panchagnula et al. [6].

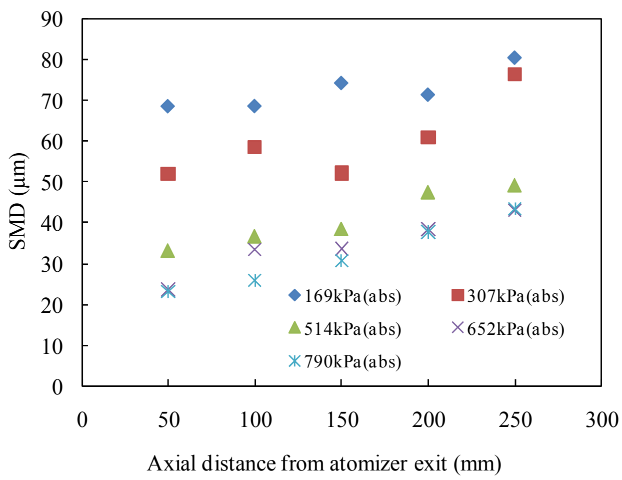


Fig.16 SMD versus axial distance for the 5 axial locations of 50, 100, 150, 200 and 250 mm downstream from the atomizer.

4. Concluding Remarks

An air assisted atomizer for micro gas turbine systems was developed. The primary scope of the present atomizer is that it can feeds a fine spray at a relatively low pressure. The atomizing air supply pressure was regulated of 169 kPa(abs) to 790 kPa (abs), 1.4×10^{-3} to 3.3×10^{-3} kg/s of water. The air mass flow rate was varied between 2×10^{-4} kg/s to 1.2×10^{-3} kg/s. The secondary breakup properties of spray were studied by taking the flow images at different air supply pressures by using a shadowgraph method. The droplets distribution was obtained and Sauter Mean Diameter (SMD) at downstream of the spray flow regime was shoen. Droplet size (SMD) inceasesed as being apart from the discharge orifice along the centerline.The present air assisted atomizer has a parformanec to provide the droplets with SMD in the range of about 23-80 μm.

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