Sauter Mean Diameter Profiles of Droplets in a Continuous Spray Stream

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Abstract. In this study, a modified starch solution was heated up to 80°C and continuously sprayed into ambient air with an axi-symmetric full cone nozzle operated at two different load pressures 3 and 5 bar. The generated sprays were characterized for axial Sauter Mean Diameter (SMD) by using a non-intrusive Phase Doppler Anemometry (PDA) technique. A monotonic decrease in SMD downstream to the nozzle exit was noticed at 5 bar load pressure. At 3 bar load pressure, initially, SMD decreased between 10-20 mm downstream, then increased between 20-40 mm and finally reached to its lowest values at 100 mm downstream. Overall, the SMD measured at 3 and 5 bar load pressures was decreased from 99 to 66 µm and 85 to 57 µm respectively after moving 100 mm downstream.

Introduction

Although, a large portion of the past scholarly works has focused the droplet size and velocity distributions in near and far nozzle spray regions, the generation and characterization of airless sprays of Non-Newtonian solutions is still a complex phenomenon and very little known [1]. Buckner and Sojka [2] generated sprays of highly viscous glycerin-water solutions (400-970cP) and characterized the SMD at different locations downstream of the nozzle exit. The SMD was nearly independent of liquid viscosity when measured at axial distance of 150 mm. Sutherland et al. [3] studied the sprays of the liquids having viscosities in the range of 1–80 cP and nominal viscosity effects were noticed on droplet sizes at a distance of 150 mm. Lund et al. [4] also measured the droplet sizes at similar distance and found that SMD was increased about 15% with an increase in viscosity from 20 to 80 cP. However, other researchers drew different conclusions. Loebker and Empie [5] studied the atomization phenomena of high viscosity liquids (7000 cP) and found that the SMD increases with an increase in distance from the nozzle exit. At a very far measuring axial station of 1300 mm, a sharp increase in SMD with viscosity was evident compared with other axial stations. Chen et al. [6] elevated the solution viscosity from 1-100 cP, pressure from ambient air to 0.6 MPa and measured the droplet sizes in the main spray patterns. An increasing trend in SMD was noticed with an increase in viscosity. It indicates that the available information on spray parameters of non-Newtonian solutions is incomplete and dispersed. It forces the researches to further their studies on non-Newtonian solutions for getting better insight into their atomization phenomena.
Materials and Methods

The native tapioca starch was modified with borax/di-sodium tetraborate (Na$_2$B$_4$O$_7$.10H$_2$O) and urea. The starch was commercially available, whereas, the modifiers were supplied by R & M Chemicals. The starch-urea-borax solution was prepared by reacting 50 g starch, 20 g urea and 4.5 g borax in 1000 mL of water [7]. The solution heating was carried out for 3 hours at 80°C. The prepared starchy solution was atomized into top to bottom full cone spray patterns. The schematic of the setup used for spray generation and characterization is shown in Fig. 1. An axi-symmetric full cone spray nozzle was used to atomize the solution at 80°C heating temperature and two load pressures 3 and 5 bar. Below 80°C, the solution was exhibiting very high viscosity and surface tension which were not allowing the solution breakup into fully developed spray patterns. The nozzle orifice and maximum free passage diameters were 1.19 and 0.64 mm, respectively. The spray pulse on-off duty cycle was controlled by a PROVAL pneumatic double actuated solenoid valve and a programmable digital time relay (SIGMA, PTC-15). The desired temperature within the feed tank and spray feed line to spray point was acquired by using a liquid immersion heater and heat tracing cables.

A dual PDA from Dantec Dynamics was used to measure the droplet size in the main spray stream [8]. A CW Argon Ion Laser generator and optical splitter were used to generate green (U1) and blue (U2) beams with a spacing of 60 mm. The fringe spacing of U1 and U2 was 6.87 µm and 6.51 µm, respectively. The focal length of the beam transmitter was 500 mm with a beam intersection angle of 4.3°. In order to minimize the noise and reflected light contributions, the beam receiver was fixed at 30° to the forward scattered direction. The focal length of the receiving optic was also 500 mm. The transmitting and receiving optics were mounted on an auto-controlled 3D traversing system allowing the measurements at different locations downstream of the nozzle exit. In these studies, the SMD of the spray droplets was measured between 0 to 140 mm along the centerline of the spray stream.

Results and Discussion

At 80°C heating temperature, very dense spray patterns were coming out and obscuring the PDA signals especially at 5 bar load pressure. Therefore, the solution temperature was fixed at 80°C, load pressure at 3 and 5 bar and the correspond spray patterns were scanned from 0 to 140 mm downstream to the nozzle exit as shown in Fig. 2. The detailed information on the axial
SMD profiles and variational trend is provided in Figs. 2 and 3. These figures show quantitatively the PDA data for the droplet size measurements. The SMD data was collected for 30 seconds at each measurement point [8]. A 3D traversing system was employed to move from one spatial postions to another. The SMD data in Fig. 3 reveals that for continuous spray injection mode, the SMD measured at 3 and 5 bar load pressures was decreased from 99 to 66 µm and 85 to 57 µm respectively after moving 90 mm down from the nozzle exit.

Fig. 2. Axial SMD profiles measured on a vertical grid at 3 and 5 bar load pressures.

Fig. 3. SMD as a function of axial distance from the nozzle exit.

Fig. 3 reveals that the axial SMD distribution significantly decreases along the spray centerline. At 80°C heating temperature, the starch slurry was having low viscosity and high Weber and Reynolds numbers were revealing fast growth of the surface waves. The inertial forces were dominating the viscous and surface tension forces. The surface waves caused by rotation motion quickly propagated and started to grow spatially and temporally. As a consequence, the amplitude of the wave oscillations on the jet surface started to increase and the solution sheet became very thin. At this point, the sheet started to break into ligaments. By moving down from the nozzle, these ligaments were changed into fine droplets. Fully developed spray patterns were obtained at 5 bar load pressure and 90 mm downstream to the nozzle exit.

A monotonic decrease in SMD downstream to the nozzle exit was noticed at 5 bar load pressure. At 3 bar load pressure the modified starch was exhibiting fast breakup at early and late injection stages and relatively slow break up at the middle stages. Fig. 2b confirms that initially the SMD decreased between 10-20 mm downstream, then increased between 20-40 mm and
finally reached to its lowest values at 100 mm downstream. Overall, the SMD measured at 3 bar load pressure was relatively large than that measured at 5 bar. This behavior was understood due to higher solution viscosity and slow growth of the surface waves. At 3 bar load pressure, viscous and surface tensions forces were dominating the inertial forces, consequently, the amplitude of the wave oscillations on the jet surface was increasing slowly as compared to unmodified starch solution [7]. It means, the surface waves were taking time to grow completely and to destabilize the liquid sheet. As a result, the sheet surface was not enough thin to initiate the breakup at near nozzle points.

Conclusions

In this detailed note, the jet breakup of modified starch solution in a continuous spray mode was studied as a function of load pressure and axial distance from the nozzle exit. The starchy solution was run through an axi-symmetric full cone nozzle at 3 and 5 bar load pressures and 80°C heating temperature. The corresponding spray patterns generated in a continuous mode were investigated by using non-intrusive PDA techniques. A monotonic decrease in SMD downstream to the nozzle exit was noticed at 5 bar load pressure. At 3 bar load pressure the modified starch was exhibiting fast breakup at early and late injection stages and relatively slow breakup at the middle stages.

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References