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Study of Axial and Radial Spray Droplet Size Distribution of Modified Starch Slurry

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ABSTRACT

The use of starch as a material in urea granules coating industry is a recent development. However, the native starches do not meet the standards set by many industrial processes. The objective of the work was to understand the unusual physical and atomization properties of the complex derived from native tapioca starch by addition of borax and urea. The starch-urea-borax solution was prepared and tested with an axi-symmetric full cone nozzle. The imaging and Phase Doppler Anemometry (PDA) studies of the developing spray revealed that the unheated solutions were forming only spinning jets. No jet breakup was seen in the near and far-nozzle imaged regions except at 5 bar load pressure, where minor spreading in the jet was seen after 80 mm downstream of the nozzle exit. The axial droplet size distribution revealed that SMD decreases significantly along the spray centerline at early injection stages and becomes almost constant after 120 mm downstream of the nozzle exit. At 40, 80 and 120 mm downstream, SMD decreases with an increase in radial distance from the stream centerline. However, an increasing trend in radial SMD was noticed at 60 and 100 mm downstream.

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INTRODUCTION

Use of starches as a coating material for slow release urea applications is a recent development (Meinke, Mayo *et al.* 1989). However, the native starches are poor in terms of their tacking ability, viscosity and workability; therefore, do not meet the standards set by many coating processes. Significant improvements in their physico-chemical properties are possible after modifying them with other chemicals (thickeners and cross-linkers) (Naz and Sulaiman 2014; Widiarto 2005). The additives like urea and borax can also be used to enhance their viscosity, tacking and mechanical strength required for uniform and fracture free coatings (Jin, Wang *et al.* 2012; Karen and Matthias 2013). However, the enhanced viscosity and other physical properties of the modified starches may have some adverse effects on their flow and associated coating mechanism, specially, when the coatings are being performed via hydraulic/airless spray nozzles. Rather using a compressed air facility, the hydraulic nozzles utilize the pumping/hydraulic pressures to disintegrate the liquid jets into fully developed spray patterns. These nozzles can be considered as a cheap alternative to the conventional liquid atomizing techniques. However, the practical spray nozzles are designed for use in water systems and manufacturers characterize them using water as a standard spraying medium. When these nozzles are used to spray very complex non-Newtonian polymer liquids containing different chemicals (Mun, Young *et al.* 1999), the resultant combination of coating medium and spraying system then often fails to meet the manufacturer's specification. Most probably, it happens when non-Newtonian solutions are pushed through the spraying systems designed for Newtonian fluids. Although, the past studies have been focused on the jet disintegration of both Newtonian and non-Newtonian liquids, it is hard to find any literature on the developing sprays of native and modified starch solutions. Therefore, extensive experimental investigation is needed to gain an insight into atomization behavior of high viscosity non-Newtonian starchy solutions.

In this detailed note, starch-urea-borax complex solution was prepared and sprayed into bottom to top full cone spray patterns at elevated temperature (20-80°C) and pressure (1-5 bar). The generated spray patterns were visualized by using a high speed camera, whereas, PDA was used to scan the spray along its axial and radial directions and to measure the corresponding droplet sizes and velocities.

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Methodology:

The starch-urea-borax solution was prepared by reacting 50 g starch, 15 g urea and 3.5 g borax in 1000 mL of water. The solution heating was carried out for 3 hours at 80°C. The prepared starchy solution was atomized into bottom to top 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 starchy solution at elevated temperature (20-80°C) and pressure (1-5 bar). 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.

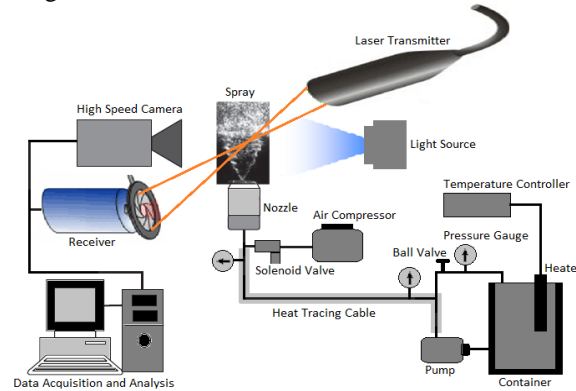


Fig. 1: Schematic of the spray mechanism and characterization.

The spray jet breakup was studied by using non-intrusive high speed imaging and PDA techniques. A dual PDA from Dantec Dynamics was used to measure the droplet size and velocity vectors in the main spray stream. 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 along the axial and radial directions downstream of the nozzle exit. In these studies, the PDA measurements were performed between 0 to 140 mm along the axial direction and between 0 to 39 mm from the stream centerline along the radial direction. The acquisition time for each measurement was set to 15 seconds with sample size of 2000.

RESULTS AND DISCUSSION

The jet breakup dynamics at different temperatures and pressures have been illustrated in Fig. 2. Having very high viscosity at ambient temperature (20°C), the starchy solution did not exhibit any jet breakup even at high load pressure values. It necessitated the pre-spray heating of the solutions. Therefore, the pre-spray heating of the solutions was performed and fully developed spray patterns were obtained at a certain high temperature (80°C). The well known solution viscosity decreases with an increase in heating temperature which not only eases the flow through the supply line and nozzle orifice but also boosts the surface wave oscillations and instabilities. These instabilities help in breaking the solution stream into fully developed spray patterns even at reduced load pressures as shown in Fig. 2. The unheated solutions were forming only spinning jets or streams when injected through nozzle at different load pressures. No jet breakup was seen in the near and far-nozzle imaged regions. These results reveal that the fluid viscosity plays a key role in determining the degree of atomization and corresponding spray structure. It has been noticed that the solution viscosity decreases with an increase in temperature and pressure (Naz, Sulaiman *et al.* 2014). At room temperature and in the absence of any external shear rate, the overall solution viscosity was ranged from 2035-3030 cP which was decreased to 455-638 cP when the solution temperature was elevated to 80°C. Therefore, this temperature range was used to atomize the solutions at load pressure of 5 bar. The spray cone length which is the axial distance between nozzle exit and complete jet breakup point was also found to decrease with an increase in the solution viscosity.

At high temperature (80°C) and pressure (5 bar), dense spray patterns were coming out and obscuring the signals. In PDA study, the solution temperature was fixed at 80°C, load pressure was fixed at 5 bar and the correspond spray patterns were scanned from 0 to 140 mm along the axial direction and from 0 to 39 mm along the radial direction. The detailed information on the measurement points can be depicted from the 6th image in Fig. 2, where the measurement points have been shown with horizontal and vertical grid. The half spray image

frames and corresponding droplets size-velocity field plots for completely developed spray cones have been shown in Figs. 5a and 5b. It is the most effective way to present the spatio-temporal characteristics of the spray development. These figures show qualitatively the spray patterns together with the covariance Laser Doppler Anemometry (LDA) data for the droplet velocity vectors field and PDA data for the droplet size field. The vectors and circles reveals that the diameters were centered on the measurement position.

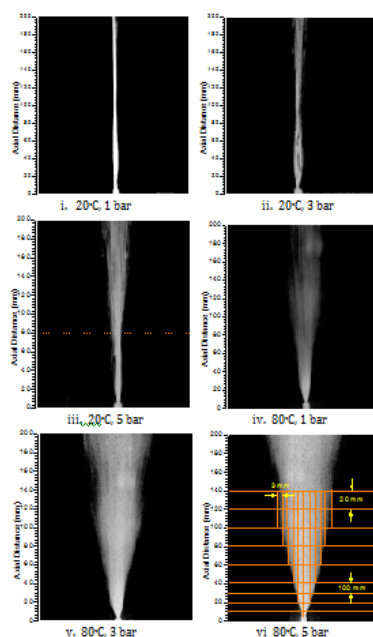


Fig. 2: Photographic view of the spray jet breakup after 400 ms of injection time.

The data in Figs. 3a and 3b were collected from up to 75 injections at each measurement point. A 3D traversing system was employed to map the spatial profiles droplet size and velocity vectors in the main spray stream. The axial distribution reveals that SMD decreased significantly along the spray centerline at early injection stages and became almost constant after 120 mm downstream of the nozzle exit. It reveals that the solution physical properties and viscosity in particular play a crucial part in breaking up the solution stream into fully developed spray patterns. Lower is the viscosity, finer will be the spray pattern (Naz, Sulaiman *et al.* 2014).

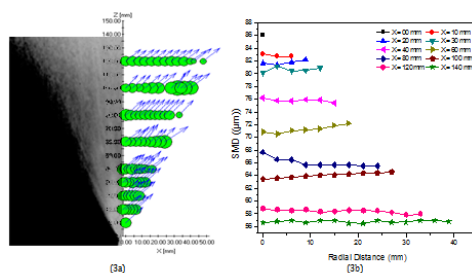


Fig. 3: (3a) Droplets size-velocity vector profile and (3b) axial and radial droplet size distribution plot after 400 ms of injection time.

The radial droplet size distribution is also an important parameter for mapping the spray behavior. The profiles in Fig. 3 also reveal the radial distribution of SMD from the spray centerline. It was seen SMD obtained with modified by PDA was varying appreciably while moving away from the stream centerline. Fig. 3b shows considerable variations in radial SMD during the middle stages of the jet breakup. These variations were started after 30 mm and continued until 120 mm downstream of the nozzle exit. Hereinafter, the SMD started gaining the constant values. It was noticed that the SMD increases and decreases radially in an alternative fashion at different axial stations (Naz, Sulaiman *et al.* 2013). At 40, 80 and 120 mm downstream, it decreases with an increase in radial distance from the stream centerline. However, an increasing trend in radial SMD was noticed at 60 and 100 mm downstream. It predicts that the developing phase of the spray prolongs to 120 mm,

thereafter, solution stream changes into fully developed spray patterns. An appreciable breakup was started after 30 mm downstream and completed at 140 mm (Nuyttens, Taylor *et al.* 2009).

Conclusion:

This paper reports the results on the transport of droplets and velocity vectors in the main spray stream of tapioca starch based non-Newtonian solution. The imaging and PDA studies revealed that the unheated solutions were forming only spinning jets or streams when injected through nozzle at different load pressures. No jet breakup was seen in the near and far-nozzle imaged regions except at 5 bar load pressure, where minor spreading in the jet was seen after 80 mm downstream of the nozzle exit. At high temperature (80°C) and pressure (5 bar), dense spray patterns were coming out and obscuring the signals. The axial droplet size distribution revealed that SMD decreases significantly along the spray centerline at early injection stages and becomes almost constant after 120 mm downstream of the nozzle exit. In contrast, the radial size distribution showed that SMD varies appreciably while moving away from the stream centerline.

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