



AENSI Journals

Journal of Applied Science and Agriculture

ISSN 1816-9112

Journal home page: www.aensiweb.com/JASA



Time Dependent Droplet Size Transport Along the Spray Centerline of Non-Newtonian Solution

¹Muhammad Yasin Naz and ²Shaharin Anwar Sulaiman

¹Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

²Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

ARTICLE INFO

Article history:

Received 25 July 2014

Received in revised form

8 July 2014

Accepted 15 September 2014

Available online 17 October 2014

Keywords:

Starch Slurry Spray imaging

Phase doppler anemometry

Sauter mean diameter

ABSTRACT

The available literature on the atomization of non-Newtonian solutions is incomplete and dispersed. It necessitates further experimentation for getting better insight into their atomization phenomena. In this study, the spray jet breakup of modified starch slurry was studied as a function of jet injection time in the range of 100–400 ms. The starchy solution was run through an axi-symmetric full cone nozzle at 1–5 bar load pressure and 80°C temperature. The corresponding spray patterns were investigated by non-intrusive high speed imaging and Phase Doppler Anemometry (PDA). Marked improvements in the jet breakup parameters were noticed above 4 bar load pressure. The mean spray cone angle was increased from 32°–57° with an increase in load pressure from 1–5 bar. However, an inverse relation was found between spray cone length and load pressure, where the cone length was decreased from 472–447 mm with an increase in pressure from 1–5 bar. The PDA investigations revealed that for fixed injection time of 400 ms, the Sauter Mean Diameter (SMD) was decreased from 86–61 µm after moving 140 mm down from the nozzle exit. The time dependent jet breakup studies confirmed that no further breakup and SMD changes were happening after 400 ms of injection time. At zero axial station, the SMD was decreased from 98–86 µm after 400 ms from the start of injection time.

© 2014 AENSI Publisher All rights reserved.

To Cite This Article: Muhammad Yasin Naz and Shaharin Anwar Sulaiman., Time Dependent Droplet Size Transport Along the Spray Centerline of Non-Newtonian Solution . *J. Appl. Sci. & Agric.*, 9(18): 41-46, 2014

INTRODUCTION

A number of key parameters is taken into account for explaining the liquid spray jet breakup dynamics (Naz, Sulaiman *et al.* 2013). These includes spray cone width, spray cone angle, spray length, spray tip penetration, Weber number, Reynolds number, spatio-temporal droplet size distributions and droplet velocities. The droplet sizes and velocities are of special interest in many industrial applications and slow release urea coatings in particular (Naz, Sulaiman *et al.* 2013). Normally, the spray patterns come out with a range of droplet sizes. Different statistical methods are being employed for describing the overall distribution of the droplet sizes in the entire spray patterns (Mun, Young *et al.* 1999; Naz, Sulaiman *et al.* 2013). SMD is the most authentic way to explain the size distribution with a single parameter. It is defined as the diameter of a hypothetical droplet having volume to surface area ratio equal to that of entire spray distribution and it is the best measure of the fineness of the spray patterns (Chen, Lefebvre *et al.* 1990).

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 hydraulic/airless sprays of Non-Newtonian solutions is still a complex phenomenon and very little known. (Buckner and Sojka 1991) generated the 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, Sojka *et al.* 1997) 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, Sojka *et al.* 1993) 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 1997) 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

Corresponding Author: Muhammad Yasin Naz, Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.
Tel: 60 13 5065302; E-mail: yasin603@yahoo.com

stations. (Lefebvre 1989; Chen, Lefebvre *et al.* 1990) 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 atomization phenomena. In addition, it would also be hard to find any literature on the jet breakup and atomization studies of the starch based carbohydrate polymer solutions. In this study, the spray jet breakup of modified starch slurry was studied as a function of injection time in the range of 100-400 ms and load pressure in the range of 1-5 bar.

Methodology:

Food grade tapioca starch with degree of substitution 0.80 was modified with borax/di-sodium tetraborate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) 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 (Naz and Sulaiman 2014). 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 1-5 bar load pressure. 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.

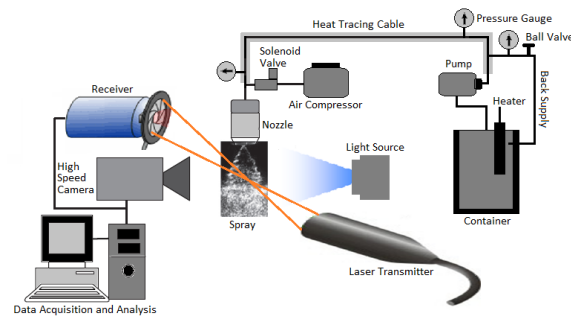


Fig. 1: Schematic of the spray mechanism and characterization.

The spray jet breakup was studied by using non-intrusive high speed imaging and PDA techniques. The imaging part was composed of a high speed digital camera and chamber side illuminating arrangements. The transparent spray chamber was illuminated from all sides using 9 spotlights of 300 Watts each and the jet movements were visualized using a Phantom v9.1 digital camera. A dual PDA from Dantec Dynamics was used to measure the droplet size 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 SMD measurements were performed between 0 to 140 mm along the axial direction/centerline of the spray stream. The measurements were started from 10 mm downstream and this point was considered as a zero point on the measurement grid. The developing spray was scanned with PDA after 100, 200, 300 and 400 ms of injection time. 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).

RESULTS AND DISCUSSION

Imaging of Spray Development:

The visual study on the developing spray patterns was conducted with a high speed camera. The jet breakup dynamics at different load pressures were captured and illustrated in Fig. 2. At ambient solution temperature, no jet breakup was seen for all possible load pressures. The unheated solution was forming only spinning jet/streaks when injected through nozzle at different load pressures as expressed in 1st image of Fig. 2. At high

temperature (80°C), the solution viscosity was reached to its lowest value (651 cP), therefore, this solution temperature was maintained in PDA study of time dependent SMD. At this temperature, the surface waves caused by rotation motion of the solution were quickly propagating and growing spatially and temporally. The amplitude of the wave oscillations on the sheet surface started to increase and the solution sheet became very thin. At this point, the liquid sheet was atomized into fine droplets spray. In this work, the prepared solution was run through an axi-symmetric full cone nozzle at 1-5 bar load pressure and 80°C temperature. Marked improvements in the jet breakup parameters were noticed above 4 bar load pressure (Naz, Sulaiman *et al.* 2013).

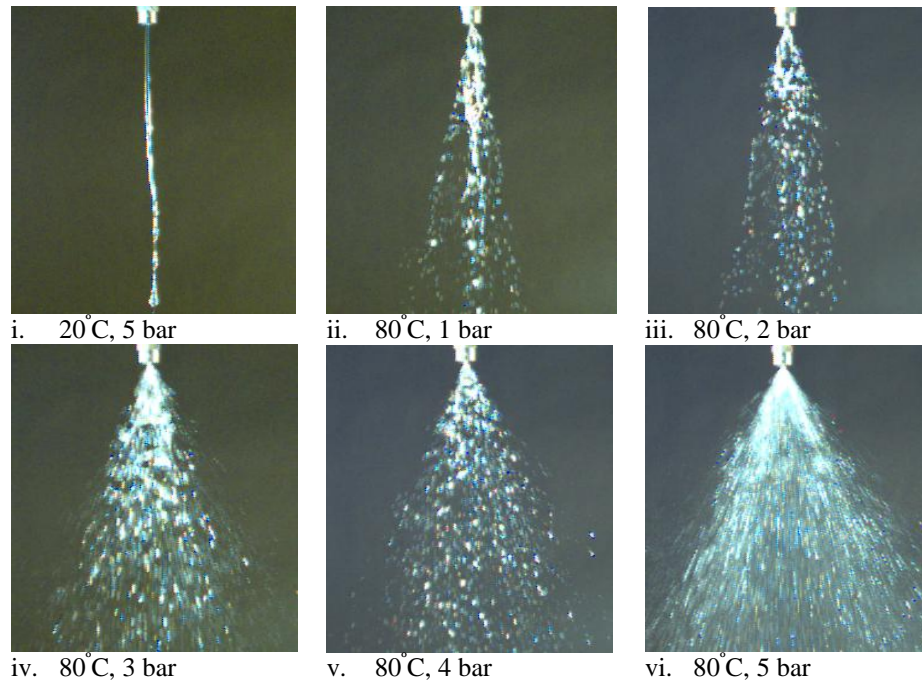


Fig. 2: Images of developing spray captured at different load pressures.

The well know solution viscosity decreases with an increase in load pressure and 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 2th, 3th, 4th and 5th image of Fig. 2. The mean spray cone angle was increased from 32° -57° with an increase in pressure from 1-5 bar. However, an inverse relation was found between spray cone length and load pressure, where the cone length was decreased from 472-447 mm with an increase in pressure from 1-5 bar (Naz, Sulaiman *et al.* 2014). The above discussed spray parameters also involve the flow within the nozzle and the solution jet-ambient air interactions (Naz, Sulaiman *et al.* 2014). The flow within the nozzle can be explained by the dimensionless flow parameters call the Weber ($We = \rho d v^2 / \sigma$) and Reynolds ($Re = \rho d v / \mu$) numbers. At 80°C, these parameters were significantly increased due to a decrease in solution viscosity. This behavior leads to an improved atomization and reduced spray cone length. For different heating temperatures, the Weber and Reynolds numbers were remained in the 2379-2968 and 10796-11682, respectively.

Axial SMD Distribution:

At high temperature and load pressure, 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. The PDA scanning from 0-40 mm downstream was performed with step size of 10 mm, thereafter, the step size was increased to 20 mm. The detailed information on the axial droplet size measurements has been provided in Figs. 3 and 4. It is the most effective way to present the spatio-temporal characteristics of the spray development. These figures show quantitatively the PDA data for the droplet size field. The SMD data was collected from up to 75 injections at each measurement point. A 3D traversing system was employed to map the spatial profiles of SMD in the main spray stream. These studies revealed that for fixed injection time of 400 ms, the SMD was decreased from 86-61 μm after moving 140 mm away from the nozzle exit.

Fig. 3 reveals that the time dependent axial SMD distribution significantly decreases along the spray centerline. At room temperature, the starch slurry was having 3217 cP viscosity which was reduced to 651 cP at

80°C. The 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, and 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 120 mm downstream of the nozzle exit.

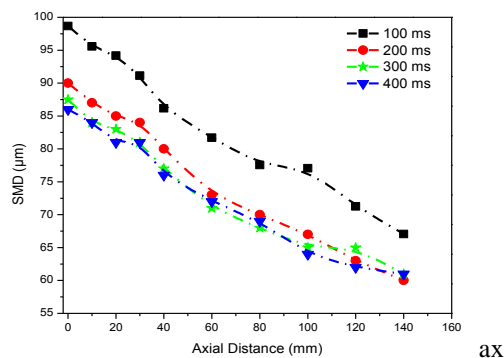


Fig. 3: SMD as a function of axial distance from the nozzle exit at 5 bar load pressure and 80°C solution temperature.

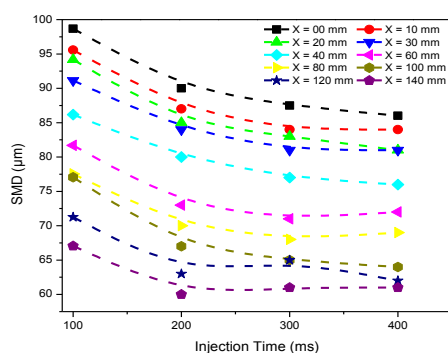


Fig. 4: SMD as a function of jet injection time at 5 bar load pressure and 80°C solution temperature.

Fig. 4 reveals the variational trend of SMD with jet injection time. It was noticed that SMD decreases at early injection stages and becomes almost constant after 300 ms from start of injection. It confirms the fast growth of the surface waves and jet breakup at early injection time ranging from 100-300 ms. The SMD was reached to its steady state after 300 ms and the breakup process was reached to an end after 400 ms. No further breakup and SMD changes were noticed after 400 ms of injection time. These studies revealed that at zero axial station, the SMD was decreased from 98-86 µm after 400 ms from start of injection time.

Conclusion:

In this detailed note, the spray jet breakup of modified starch slurry was studied as a function of injection time. The starchy solution was run through an axi-symmetric full cone nozzle at 1-5 bar load pressure and 80°C temperature. The corresponding spray patterns were investigated by using non-intrusive high speed imaging and PDA techniques. Marked improvements in the jet breakup parameters were noticed at 80°C solution temperature and above 4 bar load pressure. The mean spray cone angle was increased from 32°-57° with an increase in pressure from 1-5 bar. However, an inverse relation was found between spray cone length and load pressure, where the cone length was decreased from 472-447 mm with an increase in pressure from 1-5 bar. The PDA investigations revealed that for fixed injection time of 400 ms, the SMD was decreased from 86-61 µm after moving 140 mm down from the nozzle exit. The time dependent studies, confirmed that no further breakup and SMD changes were happening after 400 ms of injection time. At zero axial station, the SMD was decreased from 98-86 µm after 400 ms from the start of jet injection time.

ACKNOWLEDGMENTS

This research project is partially funded by the Longterm Research Grant Scheme (LRGS) of the Ministry of Higher Education Malaysia No. 15-8200-137-4-3.

REFERENCES

- Buckner, H.N. and P.E. Sojka 1991. "Effervescent atomization of high-viscosity fluids. Part 1: Newtonian liquids." *Atomization Spray*, 1(3): 239-252.
- Chen, S. K., A.H. Lefebvre, *et al.*, 1990. "Influence of Geometric Features on the Performance of Pressure-Swirl Atomizers." *J. Eng. Gas Turbines and Power*, 112: 579-584.
- Lefebvre, A.H., 1989. "Atomization and Sprays." Hemisphere, New York.
- Loebker, D. and H.J. Empie, 1997. "High mass flowrate effervescent spraying of a high viscosity Newtonian liquid." Proceedings of the 10th annual conference on liquid atomization and spray systems, Ottawa, Canada.
- Lund, M.T., P.E. Sojka, *et al.* 1993. "Gosselin PG. Effervescent atomization at low mass flow rates. Part I: The influence of surface tension." *Atomization Spray*, 3(1): 77-89.
- Mun, R.P., B.W. Young, *et al.*, 1999. "Atomization of dilute polymer solutions in agricultural spray nozzles." *J. Non-Newtonian Fluid Mech.* 83: 163-178.
- Naz, M.Y. and S.A. Sulaiman, 2014. "Testing of starch-based carbohydrate polymer coatings for enhanced urea performance." *Journal of Coatings Technology and Research*, 11(5): 747-756.
- Naz, M.Y., S.A. Sulaiman, *et al.*, 2013. "Experimental study of airless spray jet breakup at elevated temperature and pressure." *Applied Mechanics and Materials*, 393: 711-716.
- Naz, M.Y., S.A. Sulaiman, *et al.*, 2013. "Investigation of vortex clouds and droplet sizes in heated water spray patterns generated by axisymmetric full cone nozzles." *ScientificWorldJournal*, 796081.
- Naz, M.Y., S.A. Sulaiman, *et al.*, 2014. "Visual study of hollow cone water spray jet breakup process at elevated temperatures and pressures," *Applied Mechanics and Materials*. 465-466: 485-489.
- Naz, M.Y., S.A. Sulaiman, *et al.*, 2014. "Characterization of Modified Tapioca Starch Solutions and Their Sprays for High Temperature Coating Applications." *The Scientific World Journal*, Article ID 375206.
- Sutherland, J.J., P.E. Sojka, *et al.*, 1997. "Ligament-controlled effervescent atomization." *Atomization Spray* 7(4): 383-406.