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Liquid Spray Characteristics In Burner System: A Short Review

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Abstract: It is important to have a thorough understanding of the fluid flow and spray characteristics in air-assisted atomizers, since this will affect the efficiency of atomization and the performance of combustion. Previous researchers have established many factors that influenced the spray of many types of atomizers. This project reviews the main factors which can affect the spray characteristics of the atomizers. The main parameters considered are spray penetration, spray angles, spray droplets and spay break-up. The first part is analysis recaps the efficiency of the spray atomization can be enhanced by increasing the basic surface area of the liquid bulk to achieve high levels of evaporation. The air inlet geometry in the air assisted atomizer therefore plays a crucial role in improving the quality of the sprays. The second aspect is the length of the internal mixing chamber was varied to see the results of their atomisation. The nozzle efficiency was investigated, and the internal mixing chamber's efficacy was discussed. The final section is the performance of the nozzle was investigated and the efficacy of an internal mixing chamber was discussed. The air and fluid flow levels were calculated in absolute from 170 kPa to 790 kPa under the air plenum condition. In addition, to test the spray characteristics, flow past nozzle and downstream was visualised. Though unstable flow near the critical condition of assisted-air pressure was observed, the nozzle showed steady flow beyond the critical condition. The results show that the efficiency was adequate for the present atomizer. In addition, the density of SMD and spray droplets is the highest in the center of the spray field and slowly decreases along the radial direction. The outcome of this work provides a better understanding of spray characteristics and its related parameter to the improvement of spray system in the future.

Keywords: Spray, Burner, Droplets, Atomizers

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1. Introduction

The atomizer was designed to spray liquid through the tiny nozzle. The low-pressure airflow could therefore induce fuel through siphoning and break oil into small, fine droplets delivered through the outlet. Single-fluid atomizers allow the creation of fine spray by high pressure. Twin-fluid atomizers can provide a relative lower supply pressure for a fine spray. The air-assisted atomizer provides the finest degree of atomization under a given flow capacity and the supplied pressure. In addition, we can make the desired pattern of a spray such as solid, hollowed, and flat cone, and can control a spreading angle by designing the twin-fluid atomizer nozzle geometry for controllability. As the velocity of atomizing air is controlled, the spray pattern can be specified in the required form. The atomizing air interacts with the liquid within the injector in an internally mixed, air-assisted atomizer, and assists in the atomization process (Kawaharada et al., 2017).

1.1 Spray characteristics

Spray nozzle is a highly engineered and precision component designed specifically to perform liquid dispersion into a spray. In the combustion process, the use of unsuitable spray nozzles results in re-spraying and decreases the efficiency (Foqué & Nuyttens, 2011). The spray characteristics therefore exhibit important impact on the cycle of combustion, as it has often been used to evaluate the efficiency of combustion. Essentially, the study of spray can be separated into macroscopic and microscopic properties. The macroscopic characteristic describes the relation between the volume of the control and the volume from which it is mixed (Martínez-Martínez et al., 2010). The physical parameter of the macroscopic characteristics can be defined with the break-up length, penetration of the spray tip and angle of the spray cone (Xie et al., 2015). Figure 1 shows the macroscopic characteristics of spray.

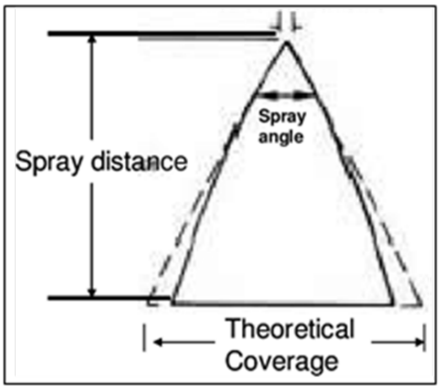


Figure1: Macroscopic characteristics of spray (Wahhab *et al.*, 2017)

1.2 Spray angle and spray length

The angle of the spray differs or converges in relation to the vertical axis. As shown in the Figure 2, the angle of spray tends to collapse or diverge, with increasing distance from the orifice. Water coverage varies according to the angle of water. The theoretical distribution, C, of spray patterns at different distances can be determined for spray angles less than 180 degrees with the equation below. The angle of spray is supposed to stay constant over the entire span of the spray. The air-assisted atomizer provides the finest degree of atomisation at a given flow efficiency and supplies pressure (Chong & Hochgreb, 2015).

The spray angle is an important atomizer spray characteristic since a wider spray angle provides a wider dispersion of the spray. For various applications, such as food coating, spray painting, and pesticide sprays, this is an important spray feature (Ghaffar, Kasolang, & Hamid, 2014). The successful spray angle in actual spraying varies with the distance from the spray. Liquids that are more viscous than water form relatively smaller spray angles (or even a solid stream), depending on viscosity, capacity of the nozzle, and pressure of spray. Liquids with surface tensions lower than water will produce spray angles relatively wider than those listed for water (Lambosi *et al*., 2015).

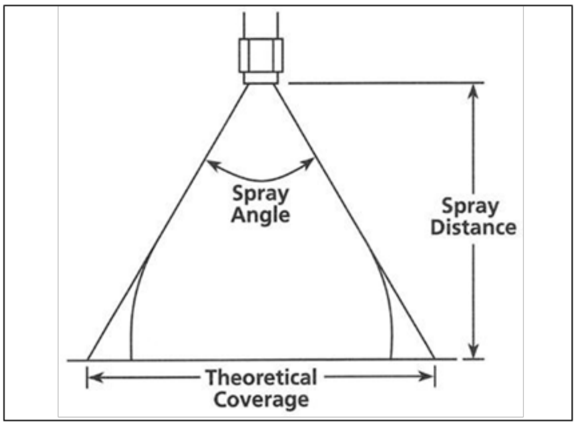


Figure 2: Spray angle (Lambosi *et al*., 2015)

1.3 Spray droplets

The potential energy of liquid along the nozzle geometry produced by mixing the liquid with the air pressure for twin-fluid nozzle will spread in small ligaments during the atomisation process. Then those small ligaments can break further into smaller parts. Spray droplets are the tiny particles of liquid that typically have a more or less spherical shape. This formation of spherical shape of spray droplets are due to the surface tension phenomena of liquid. This creation of spherical shape of spray droplets is due to the phenomenon of liquid surface tension. The adjacent water molecules will attract or pull down the liquid molecules which are lying on the surface. Therefore, because of the cohesive forces, the liquid droplets tend to be attracted or pulled into spherical form. Spray droplets are very important in deciding the drift of spray and spray coverage rate (Chong & Hochgreb, 2015).

An experiment conducted by Movahednejad *et al*., 2013 to determine size distribution and velocity of droplets occurs at the primary breakup edge area. They found that the primary breakup or downstream of the jet breakup regime will form the size of droplet size and velocity distribution while the breakup of the droplet will occur in the next stage, which is secondary breakup. Figure 3 show difference type of nozzle and the drop size.

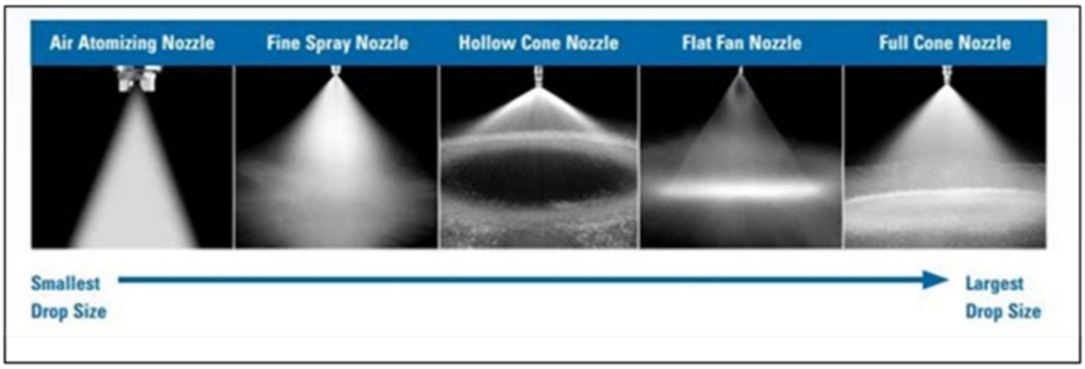


Figure 3: Difference type of nozzle and the drop size (Watanawanyoo et al ., 2012)

1.4 Spray break-up

In usual atomizers, a spray formation begins with the detachment of droplets from the outer surface of a continuous liquid core that extends from the injection nozzle orifice. Here, the detachment of the liquid core into ligaments or large droplets is called the primary breakup, involving the action of internal forces in the liquid jet. Owing to the interactions between the liquid and atmospheric gas or droplet collisions, the liquid ligaments and large droplets further split up into small droplets. The successor process of such further disturbance is called secondary breakup. Figure 4 indicates the cycle of primary breakup and secondary breakout. These forces will overcome the superficial stress and deform the spherical form splitting the droplet into smaller-sized parcels again. Quantitatively, these two kinds of acts that work on droplets are related by the Weber number. The secondary breakup may be classified in different regimes according to the We number (We).

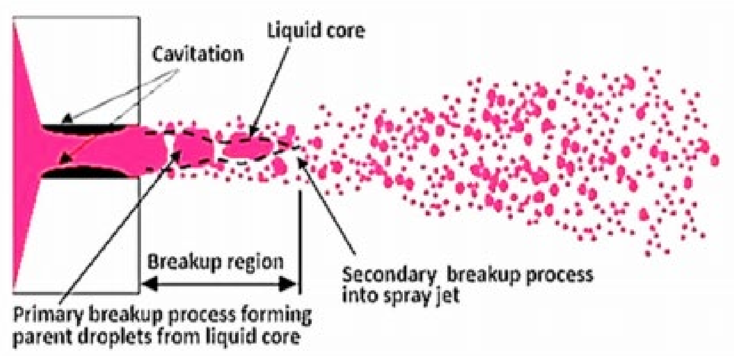


Figure 4: Primary breakup and secondary breakup process (Duronio *et al.*, 2020).

2. Air Assisted Atomizer

Atomization is usually achieved by discharging a high velocity liquid into a relatively slow moving stream of air. Typical examples include the various forms of pressure atomizers and rotary atomizers that eject the liquid from the periphery of a rotating cup or disk at high velocity. An alternative approach is to inject an air stream with high velocity to a comparatively slow moving liquid. The latter approach is commonly referred to as twin-fluid, air assisted, or air blast atomization. The air-assisted atomizer is one of the typical twin-fluid atomizers (other types are air blasting and effervescent nozzles), where compressed air is supplied to atomize the liquid, while the liquid is supplied by one of the three ways, the pressure feed, the gravity feed and the siphon principle. The air-assisted atomizer offers the finest degree of atomisation under a given flow power and pressure supplied (Yao et al., 2013)

2.1 Twin fluid air assisted atomizer

With a given flow capacity and supplied pressures, the twin-fluid atomizer, i.e. the air assisted atomizer, provides the finest degree of atomisation. A desirable choice is available; i.e. wide angle of solid, full and hollow cone or flat spray. The spray pattern remains in such a defined shape only as the velocity of the atomizing air is maintained. Depending on their size, exposure time, relative humidity, and other ambient conditions, the droplets in spray may evaporate fully. The classification of atomizers depends on various techniques; i.e., pressure atomizer, twin-fluid atomizer, rotary atomizer, electrostatic and ultrasonic atomizer. These are all widely used in the applications for combustion. Unlike single fluid atomizers which require high pressure to produce fine sprays, twin fluid atomizers can provide a fine spray at relatively lower supply pressures (Watanawanyoo et al., 2011b).

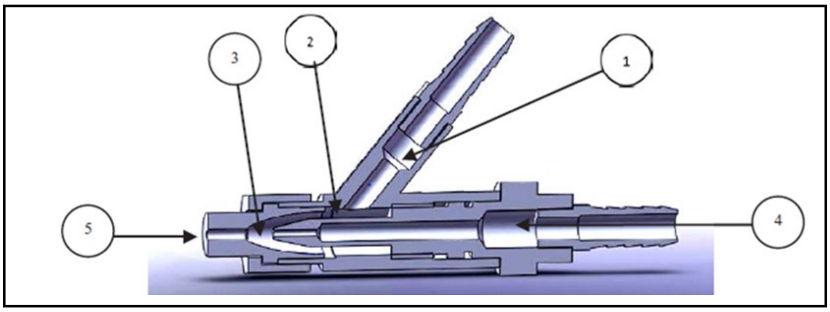


Figure 5: Twin fluid air assisted atomizer (Watanawanyoo *et al*., 2011b)

The atomizer structure used in this analysis is shown in Figure 5. Liquid enters the water chamber (2) through an inlet port for water (1). Because of the pressure difference created by air pressure at the tip of the needle the liquid is sucked through the tip of the taper needle (3). The air is supplied via air inlet port (4) and injected through a small hole at the upstream entrance point of the river. Two streams, air and water, interact through the atomizer 's interior mixing chamber and droplets are discharged through the outer chamber (5). At last, this two-phase flow comes from the atomizer's injection orifice (2.5 mm in diameter) (Watanawanyoo *et al*., 2011b).

2.3 Experimental equipment setup

Information about the test equipment is necessary to determine how to use the tool before conducting an experiment. To avoid any accident that requires the experimentation of equipment information. Figure 6 shows the schematic of the experimental equipment.

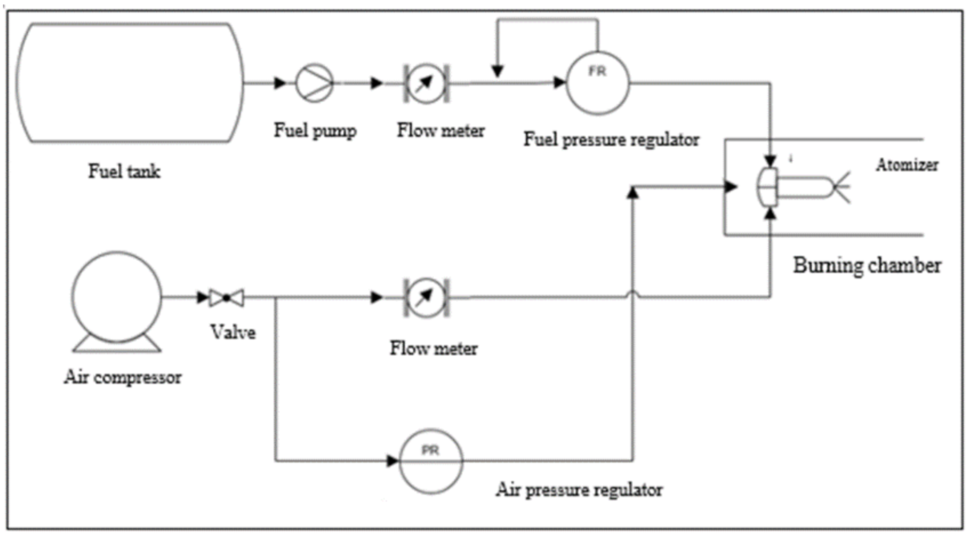


Figure 6: Schematic of the experimental equipment.

3. Results and Discussion

This chapter addresses previous experimental work related to the spray of the atomizers. The next section also describes the effects of geometries on the spray characteristics and the operating conditions. The study focuses on the spray penetration, spray angle, spray droplets and the spray breakup in the experiments. In addition, to study the spray characteristics, flow near nozzle and downstream was visualised.

3.1 Spray penetration

Where S is the real spray tip penetration in mm, S' is the spray tip penetration estimated from spray images from the tip of the spray nozzle to the farthest axial point of the spray boundary in mm, as shown in Figure 7 and α is the spray cone angle in radians (Mohan et al., 2014).

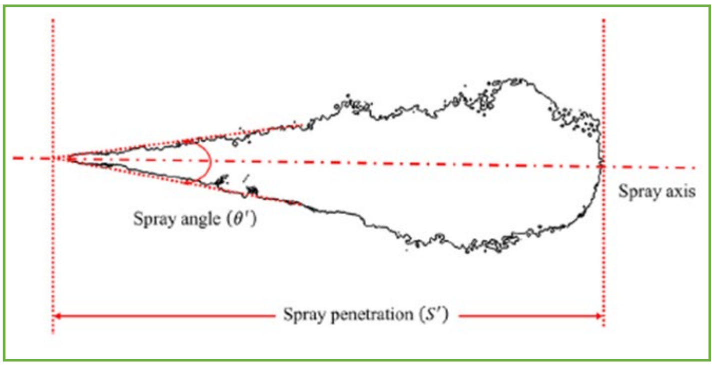


Figure 7: Actual spray tip penetration (Mohan *et al.*, 2014)

In order to predict the spray characteristics in the combustion phase, Yii et al . (2016) carried out an investigation on the efficiency of turbulence generators, which involves fractal grids and swirler. The result shows that the length of the spray penetration can be easily controlled by a swirler to avoid contact with the chamber wall of the combustor. The combustion in swirler was predicted to be more complete; as the breakup of the spray is shorter. The study also concludes that an increase in spray area and length of penetration will result in high turbulence intensity being produced by the fractal grids. Figure 8 shows the penetration of the spray against the equivalent ratio of three distinct plates.

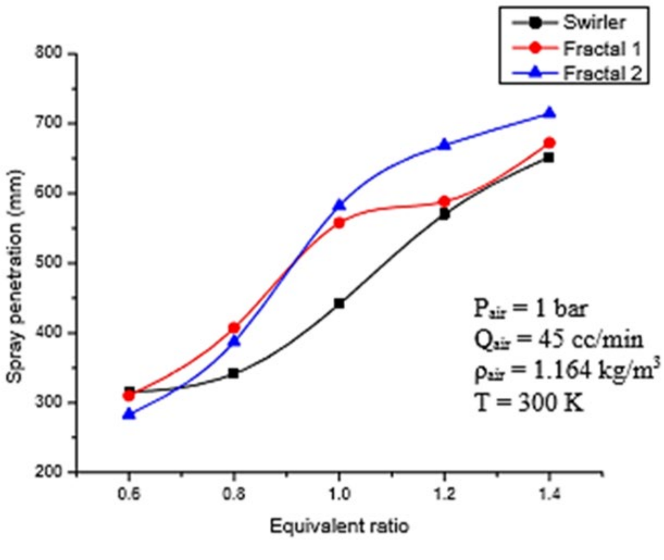


Figure 8: Spray penetration against equivalence ratio (Yii et al., 2016)

3.2 Spray angle

Figure 9 indicates measurement of the angle of water. Figure 10 shows the spray angle as a function of the pressure in the air supply. It was found that the spray angle remained nearly constant although it increased slightly with the air supply pressure elevation. The present atomizer has a broad length-to-diameter ratio, L2 / D2 = 4 for the secondary nozzle, relative to ordinary atomizers. Hence the angle of spray is relatively smaller than the usual atomizers. Additionally, the spray angle remained nearly the same while the air supply pressure increased. Thus, the current atomizer could produce the spray stably at an almost constant angle (Watanawanyoo et al., 2012).

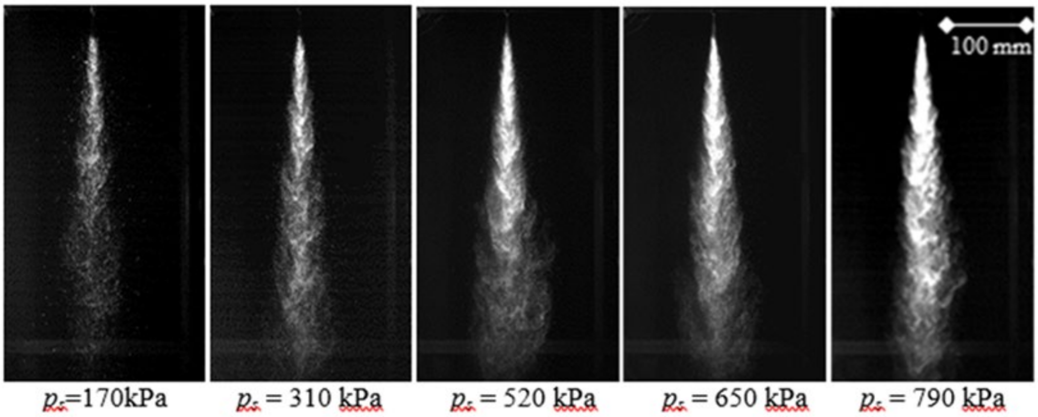


Figure 9: Spray images at various air supply pressures, ps (Watanawanyoo et al., 2012)

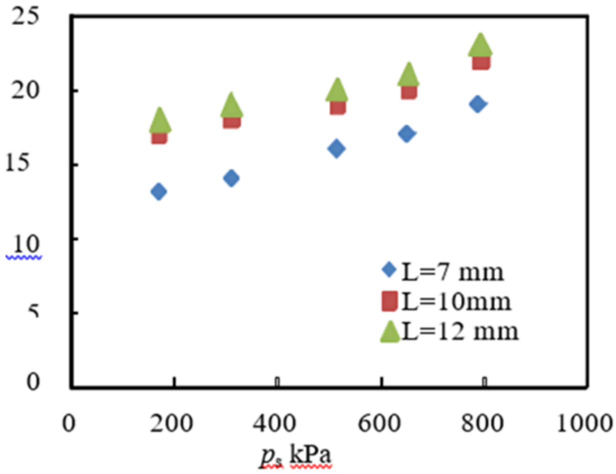


Figure 10: Air supply pressure impact on spray angle (Watanawanyoo et al., 2012).

Lincheta et al. (2002) studied four nozzle types with different geometry and water injection pressure. It is observed that the spray angle increases with water pressure in nozzle 1 and 2 (commercial design) and decreases when the air pressure decreases. Nozzle 3 and 4 (new design) demonstrate that spray angle decreases as the water pressure increases at the high air pressure. It is proved that the nozzle geometry is influenced by the angle of spray and the quality of atomisation; each geometry has its own characteristics (Figure 11).

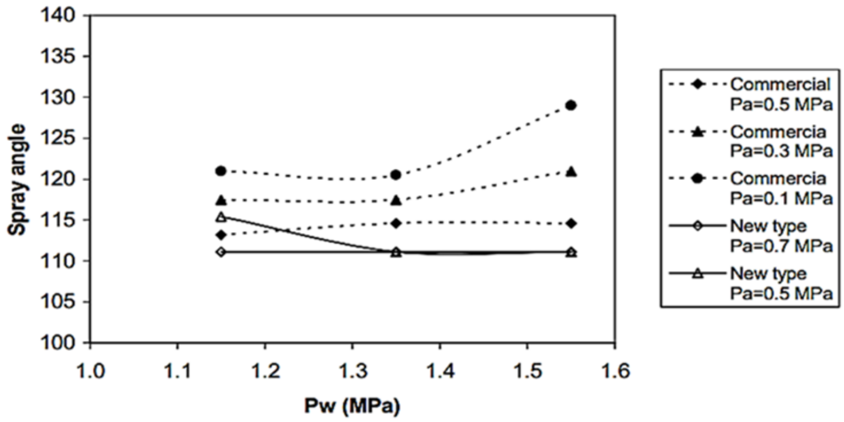
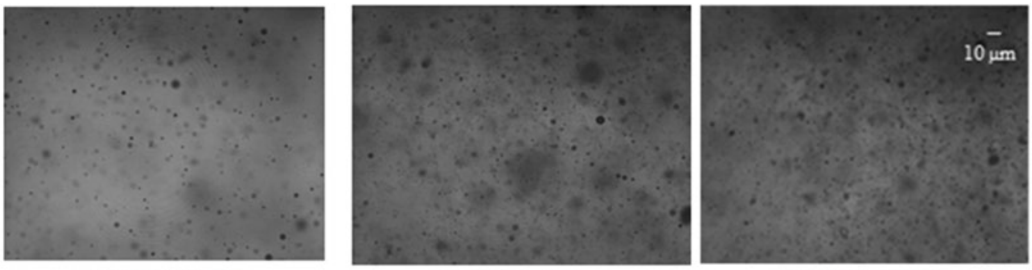


Figure 11: Spray angle behaviour versus pressure atomizing water (Lincheta et al., 2002).

3.3 Spray droplets

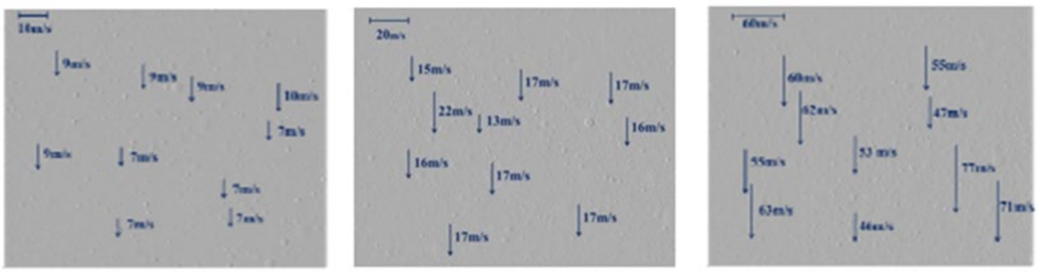
The droplet velocity was measured in this experiment through a frame straddling photography technique used in velocimetry for particle tracking. The droplet velocity can then be calculated by calculating a moving distance of each droplet from the successive images and dividing it between the two digital images by time intervals. As regards the central axis of spray, the direction of the velocity vector can also be determined directly from the image as a flight angle. Figure 12 shows typical droplet speeds of 170 kPa, 311 kPa and 790 kPa at 50 mm downstream of the nozzle exit (Watanawanyoo et al., 2012).



(a) p_a=170 kPa (b) p_a=311 kPa (c) p_a=790 kPa

Figure 12: Typical droplet speeds from the nozzle exit at 50 mm downstream (Watanawanyoo et al., 2012).

Due to the sparseness of droplet number density, the droplet images were manually coupled at two different points in time. The range of droplet speeds ranged from 8 m/s to 60 m/s approximately. The water velocity at nozzle exit and air mass flow rate were calculated in this experiment. The air speed was approximately 42-210 m/s. Using these estimates, we found Weber 's number ranged from 0.17 to 6.2, which is less than Weber 's critical number, 16, We=15. Thus, small droplets with a diameter of several 10 µm flowed in a vibration mode. Figure 13 shows the water droplet vectors (Watanawanyoo et al., 2012).



(a) p_a=170 kPa (b) p_a=311 kPa (c) p_a=790 kPa

Figure 13: Velocity of water droplets (Watanawanyoo et al., 2012).

Li et al. (2013) used heavy fuel oil to test an internal twin-fluid mixing atomizer. Sauter mean diameter (SMD) is measured with different liquid viscosity, gas supply, and GLR at the different axial distance. The finest sprays are obtained at an axial distance of 50 mm. In Figure 14, GLR affects SMD in large part but is independent of viscosity and strain. However, Figure 15 shows that droplet size is high at 120 mPa.s and has taken more proportion while the spray consistency has decreased but SMD is only slightly altered. The result shows that SMD increases at a greater distance (250 or 400 mm), as the viscosity increases, which can be seen with higher GLR and higher pressure. At greater viscosity, the decay of axial velocities along the centreline of the spray is higher. A change in viscosity in the radial direction causes SMD distributions, and velocity flatters. It is inferred that an increase in GLR has produced smaller droplets compared with pressure effects, thus improving the consistency of the spray.

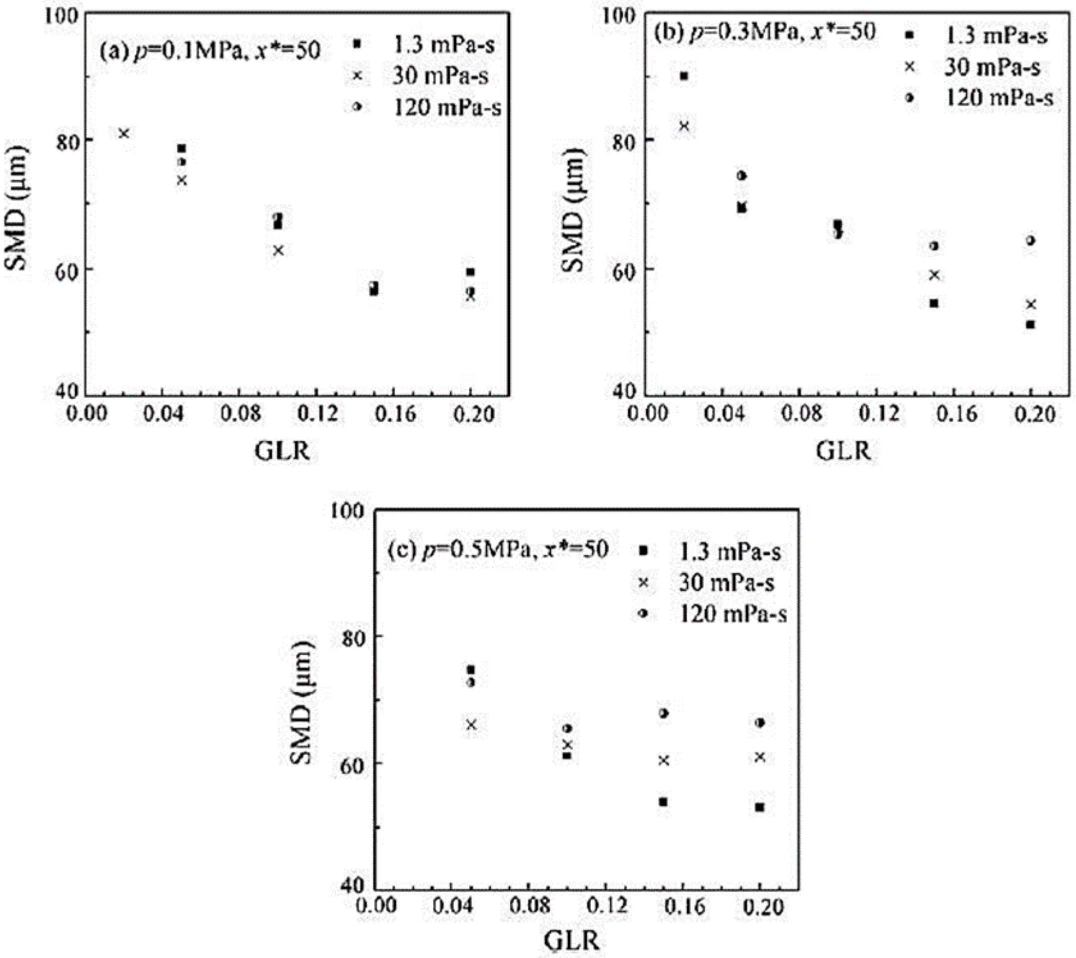


Figure 14: SMD versus GLR when x*= 50 for different μ and p (Li et al., 2013).

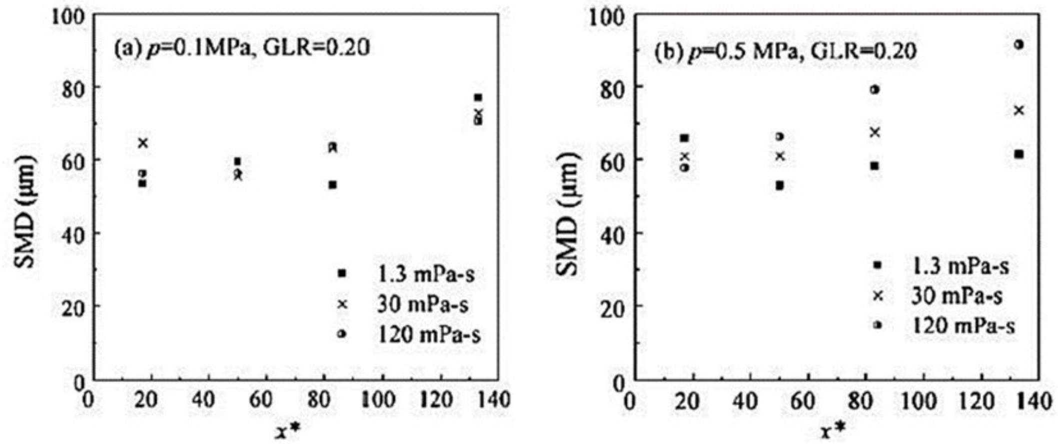


Figure 15: SMD versus x * for various SMD (Li et al., 2013).

3.4 Spray break-up

The experiment was conducted in three conditions of pressure, which is ps = 170 kPa, ps = 520 kPa and ps = 790 kPa as shown in Figure 16. At ps = 170 kPa, before breaking up, water jet held longer distance from the nozzle. The liquid phase broke up promptly into large ligaments, and large non-spherical droplets were observed. The liquid phase broke up into large ligaments promptly, and large non-sphere droplets were observed. At ps = 520 kPa, the initial filaments get shorter as the pressure increases and the filament breaks up into droplets near the nozzle. A further increase in the supplied air pressure caused prompt atomisation at ps = 790 kPa. The formation of non-sphere droplets in the atomizer downstream could be attributed to two factors (i) droplet deformation and breakdown resulting from the interactions between the liquid and the gas (ii) droplet interactions. (Watanawanyoo et al., 2012).

(a) p_s=170 kPa (b) p_s=520 kPa (c) p_s=790 kPa

Figure 16: Three shadowgraphs at nozzle exit pressure levels for air flow rates (Watanawanyoo et al., 2012)

In addition, Faeth et al., 2012 addressed the importance of near region structure in droplet breakup properties. They noted that the effects of the interaction between droplets would be small when the atomised flow was sparse. Moreover, according to Hiharaha et al., 2011, when the number of droplets in Weber is smaller than the critical number in Weber, atomized droplets do not break down (Watanawanyoo et al., 2012).

4. Conclusion

The goals of this study were presented, which brings to the conclusions that will be discussed in this section. The results were carried out the spray penetration, spray angle, spray droplets and spray break-up process. The investigations include the effects of geometries on the spray characteristics and the operating conditions. For the study of spray penetration, an increase in fuel momentum can result in greater penetration of the spray. In addition, the fuel's properties, such as surface tension, viscosity and density, also affect the penetration of the spray. This study also concludes that an increase in spray area and length of penetration will result in high turbulence intensity being produced by the fractal grids. The results of experiment studied showed that the spray angle remained nearly constant although it increased slightly with the air supply pressure elevation. Hence the angle of spray is relatively smaller than the usual atomizers. For the studied of spray droplets, the SMD is measured with different liquid viscosity, gas supply, and GLR at the different axial distance. The result shows that SMD increases at a greater distance (250 or 400 mm), as the viscosity increases, which can be seen with higher GLR and higher pressure. At greater viscosity, the decay of axial velocities along the centreline of the spray is higher. For the studied of spray breakup, the experiment studied were conducted in three conditions of pressure. The higher the pressure, the smaller the break-up length. The formation of non-sphere droplets in the atomizer downstream could be attributed to two factors (i) droplet deformation and breakdown resulting from the interactions between the liquid and the gas and (ii) droplet interactions.

References

Amirnordin, S. H., Khalid, A., Sapit, A., Salleh, H., Razali, A., & Fawzi, M. (2016).

Spray formation of biodiesel-water in air-assisted atomizer using Schlieren photography. *IOP Conference Series: Materials Science and Engineering*, *160*(1).

Aworanti, O. (2013). Statistical Optimization of Process Variables for Biodiesel Production from Waste Cooking Oil Using Heterogeneous Base Catalyst. *British Biotechnology Journal*, *3*(2), 116–132.

Azahar, W. N. A. W., Bujang, M., Jaya, R. P., Hainin, M. R., Mohamed, A., Ngadi, N., & Jayanti, D. S. (2016). The potential of waste cooking oil as bio-asphalt for alternative binder – An overview. *Jurnal Teknologi*, *78*(4), 111–116.

Beddu, S., Shafiq, N., Nuruddin, M., Kamal, N., & Sadon, S. (2016). Effects of Used Engine Oil as an Admixture in Concrete Durability. *British Journal of Applied Science & Technology*, *15*(6), 1–10.

Chong, C. T., & Hochgreb, S. (2015). Effect of atomizing air flow on spray atomization of an internal-mix twin-fluid atomizer. *Atomization and Sprays*, *25*(8), 657–673.

Foqué, D., & Nuyttens, D. (2011). Effects of nozzle type and spray angle on spray deposition in ivy pot plants. *Pest Management Science*, *67*(2), 199–208.

Ghaffar, Z. A., Kasolang, S., & Hamid, A. H. A. (2014). Characteristics of swirl effervescent atomizer spray angle. *Applied Mechanics and Materials*, *607*(July), 108–111.

Kozdrach, R., Technologii, I., & Radom, E. (2017). The physiochemical and ecological properties of diesel oils. (February).

Lambosi, L., Khalid, A., Manshoor, B., Hisyam, S., & Hao, L. K. (2015). Effect of Nozzle Angle to Combustion Characteristic in Biodiesel Burner. *Applied Mechanics and Materials*, *773–774*, 585–589.

Method_for_producing_base_lubricating_oil_from_was.pdf. (n.d.). Nagy, E. (2011). *Properties of diesel-alcohol blends*. (October 2015).

PNR UK LTD. (n.d.). Air Assisted Atomizers. *Www.Pnr-Nozzles.Com*. Retrieved from

Sies, M. F., Mustaffa, N., Zakaria, H., Salleh, H., Manshoor, B., & Khalid, A. (2014). A review of the concept of fuel-water internally rapid mixing injector in burner system. *Applied Mechanics and Materials*, *465–466*(April 2015), 296–301.

Watanawanyoo, P., Mochida, H., Furukawa, T., Nakamura, M., & Hiraharab, H. (2012).

Experimental study on the spray characteristics of an air assisted atomizer with internal mixing chamber. *European Journal of Scientific Research*, *84*(4), 507–521.

Yao, J., Tanaka, K., Kawahara, A., & Sadatom, M. (2013). Performance evaluation of an air assisted atomizer with liquid siphon. *Journal of Applied Sciences*, *13*(22), 4985– 4993.