Spray Characterization of Palm Olein/Diesel Blends under Various Injection Pressures

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Abstract

The Sauter Mean Diameter (SMD) and spray cone angle are two important parameters that characterize spray performance. The objective of this study is to characterize palm olein/diesel blends spray in terms of spray angle and SMD under different injection pressures using a hollow cone pressure swirl atomizer. The physical properties of five diesel/palm olein blends, namely B5, B10, B15, B20 and B25 were measured and their spray characteristics were tested at injection pressures of 0.8 MPa, 1 MPa, and 1.2 MPa under ambient atmospheric condition. The results were compared to spray established using petroleum diesel fuel. The SMD was measured using a phase Doppler analyzer (PDA). The spray cone angle was visualized using a digital single-lens reflex (DSLR) camera. The results indicated that petroleum diesel fuel had the widest cone angle followed by B5, B10, B15, B20 and B25 under the same injection pressure. Additionally, when the injection pressure increases from 0.8 MPa to 12 MPa, the spray cone angle widen accordingly. It is concluded that high content of palm olein in the palm biofuel blends increases viscosity and surface tension and hence higher value of SMD and narrower spray cone angle was generated. An increase in injection pressure resulted in smaller droplet SMD and wider spray cone angle.

1.0 Introduction

The palm oil resources were abundant in the tropical countries especially in Malaysia and Indonesia. Palm oil has high potential as future fuel due to the economical value and reliable supply [1]. In addition, the variability of palm oil as a source of renewable fuels either in the form of crude or processed (methyl esters) makes it attractive as fuel for internal combustion engine [2-4]. The use of palm oil in Malaysia as fuels in combustion engine had started in 1980s by Malaysian Palm Oil Board (MPOB) [5]. In 2006 the then Prime Minister of Malaysia launched Malaysian first biofuel, Envodiesel [6] which consists of 95% petroleum diesel and 5% processed liquid palm oil (palm olein). The palm olein was chosen instead of palm methyl ester is because the palm olein is much cheaper compared with palm methyl esters.

The performance of the Envodiesel in diesel engine is comparable as petroleum diesel fuel while in the same time emit less pollutant gases such as carbon monoxide and unburned hydrocarbon (UHC) to the atmosphere [7]. In addition, several field trials conducted by MPOB showed no major technical problem to the engine utilizing Envodiesel. Since Envodiesel utilize only 5% of palm olein in the blends, it is also possible to use higher blending ratio in the blends for applications in the gas turbine engine. In this study, the spray characteristics of five blends of palm olein and petroleum diesel are evaluated. The ratio of the palm olein in the blends is 5%, 10%, 15%, 20% and 25% (by volume), which is denoted as B5, B10, B15, B20 and B25 respectively. The main characteristics of spray that affect combustion performance and emissions in the gas turbine engine are the spray cone angle and Sauter Mean Diameter (SMD) [8-9].

Sauter Mean Diameter is defined as the diameter of a droplet having the same volume/surface ratio as the entire spray and its application is mainly for mass transfer application [10]. Previous research found that SMD is mostly affected by liquid viscosity, surface tension and injection pressure [11-14]. Good quality of atomization should have small size in SMD to allow higher volumetric heat release rates, easier light up, a wider burning range and lower exhaust concentration of pollutant emissions [7]. In addition, small SMD size allows less amount of energy to ignite the air-fuel mixture [9].

The spray cone angle is defined as the angle formed by drawing two straight lines from the tip of injector to the outer side of the spray. The spray cone has curved boundaries, due to the effects of air interaction with the spray. The parameters that affect spray cone angle are atomizer design (dimension of the discharge orifice), liquid properties (viscosity and surface tension) and injection pressure [8, 15-18].

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2.0 Experimental Setup

The palm olein blends were prepared using lab scale mixer. The blending process took two to three hours with slow moving twin propeller stirrer at the rotation speed of 50 rpm to ensure the blend of palm olein and petroleum diesel was properly homogenous. A hydrometer was used to check the specific gravity (SG) of the blends. The SG of the blends was monitored for every half hour interval. The blends were considered homogenous when the specific gravity (SG) of the blends remained constant.

Three properties of palm olein blends that affect the characteristics of the spray were measured: kinematic viscosity, density and surface tension. The kinematic viscosity of the blends was measured using a Viscometer Bath (TV 4000). The surface tension was measured using a tensiometer (Dataphysics DCAT 11) while the density was determined using a density meter (Anton Paar DMA 5000). The uncertainties for these equipments are ±5%.

Figure 1 illustrates a schematic diagram of the experimental setup consisting of a pressure swirl atomizer (Spray System Co) with a fuel orifice diameter of 1.6 mm. This type of atomizer was selected since it is widely used in gas turbine engine [9]. In addition, a 3D Dual phase Doppler particle analyzer (PDPA) by Dantec Dynamics [19] equipped with water-cooled Argon-ion laser was used for droplets size measurement.

The fuel flow was controlled using a Hydra Cell multi piston pump at designated pressure. The multi piston pump is able to pressurize the fuel flow with low pressure pulsation fluctuation. The pressure of the fuel line was controlled using a regulating valve. The flow rate of the fuel was measured using a flow meter. Before it reaches atomizer, it will fill the surge tank. The surge tank was used to stabilize the pressure to reduce fuel instabilities that create vibration to the atomizer. As the liquid leave the atomizer, a droplet collection basin was used to collect excessive sample fuel and return it back to the tank using submersible electrical pump.

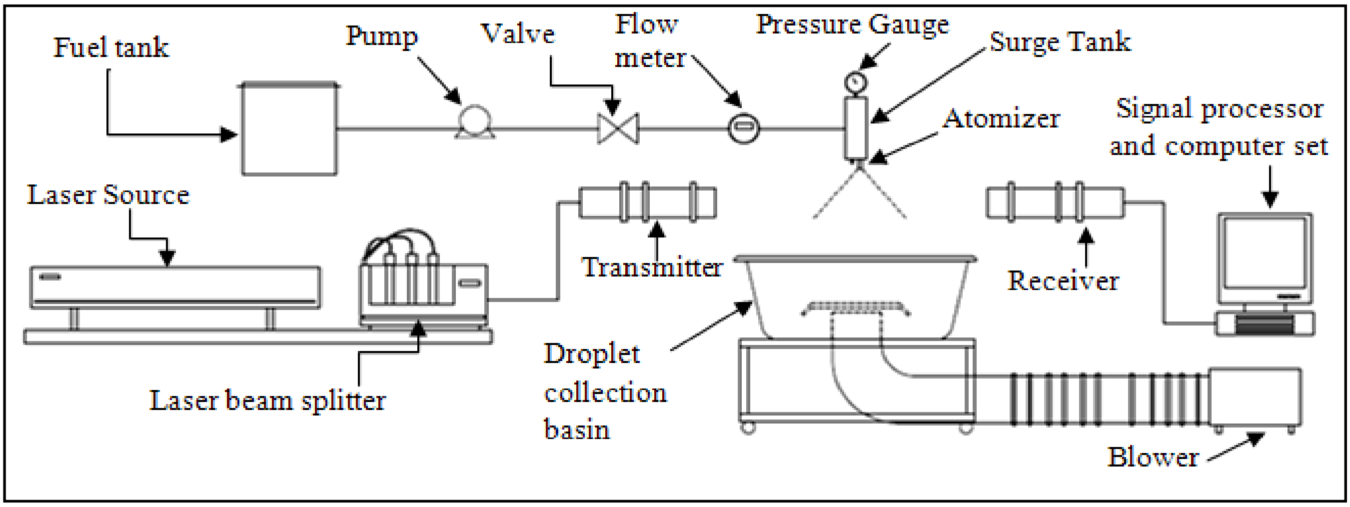


Figure 1: Experimental Set Up

Figure 2 shows the locations of the SMD measurement in this study. A total of 96 measurement points were measured along radial and axial direction as shown in Figure 2. Measurements were performed at 25mm, 40 mm, 65mm and 80mm from the injector tip. The spray was visualized using digital single-lens reflex (DSLR) camera. The digital images were processed to determine the spray cone angle.

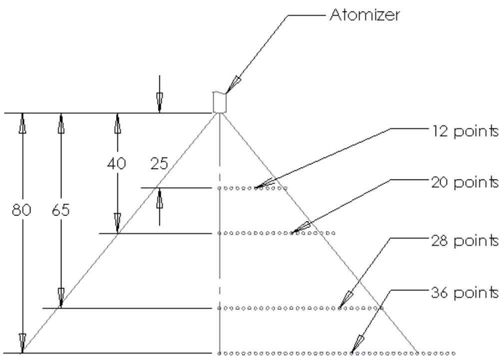


Figure 2: Location of Measurement Point and Cone Angle

3.0 Results and discussion

3.1 Physical Properties of Palm Olein Blends

Table 2 shows the result of physical properties measurement. It shows that the density, kinematics viscosity and surface tension of the palm olein blends increase relative to the increment of palm olein content in the blends. The viscosity of palm olein is higher than petroleum diesel by a factor of 10. The difference in density and surface tension of petroleum diesel and palm olein was about 8% and 13% respectively. Therefore, the blending of palm olein and petroleum resulted to change dramatically in viscosity compared with density and surface tension.

Table 2: Physical Properties of Petroleum Diesel, Palm Olein and Palm Olein Blends

Samples	Density (kg/m^3) (ASTM D1298)	Kinematics Viscosity (Cst) (ASTM D445)	Surface Tension (N/m)
B0*	831.6	3.472	0.0300
B5	836.6	4.083	0.0302
B10	840.6	4.65	0.0303
B15	844.6	5.442	0.0303
B20	849.6	5.809	0.0305
B25	853.5	6.422	0.0305
B100**	905.5	35.14	0.0345

*diesel ** Palm Olein

3.2 Visual Observation

The sprays were image using a DSLR camera. Figure 3 showed the photograph of a spray which was taken at high shutter speed of the DSLR camera. The centrifugal pump generates high potential energy to the liquid, forcing the liquid through the atomizer orifice which resulted in a thin liquid film leaving the injector tip. The kinetic energy of the liquid and geometry of the nozzle causes the liquid to emerge as small ligaments. Then these ligaments break up further into very small droplets.

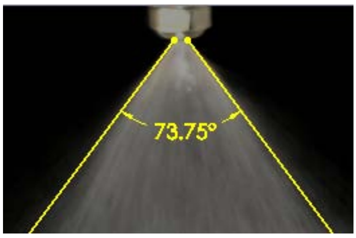
Figure 3: Spray Visualization during the Experiment of Diesel Spray at 8Bar

3.3 Spray Cone Angle

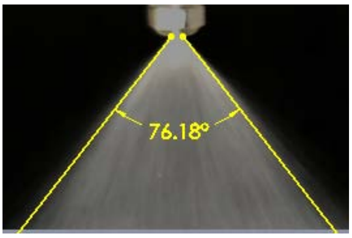
Figure 4 illustrates a series of spray cone angles for diesel fuel and palm olein blends at different injection pressures. The uncertainties of the spray cone angle measurement are ±1°. The results clearly showed that the increase in palm olein quantity in the blends make the cone angle getting narrower. The diesel spray cone angle (B0) shows the widest cone angle, followed by B5, B10, B15, B20 and B25. This is anticipated since the more content of palm olein in the blends resulted in the increase of viscosity thus reducing its cone angle. This was agreed from the previous researcher such as Chen et al., [16] and Yao et al., [14].

In the same time, the angle of the spray cone widened when injection pressure was raise from 8 bar to 10 bar and lastly to 12 bar and this is applied for all blends. For the swirl atomizer, the increase in spray cone angle will increase the extent of the surrounding air, leading to improve atomization and an increased in the proportion of drops thus help to promote better mixing between the fuel and air leading complete combustion and reduced formation of soot during the combustion [8].

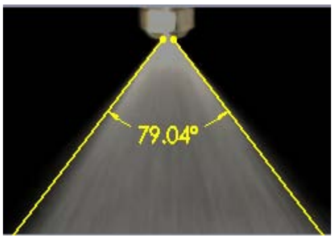
B0



8 Bar

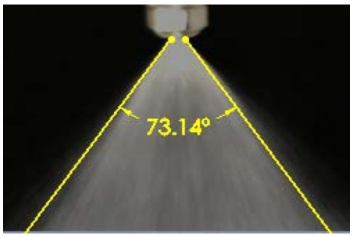


10 Bar



12 Bar

B5



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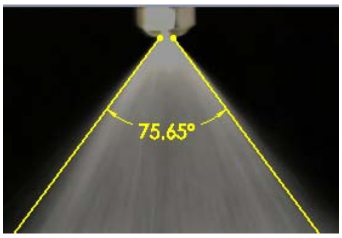
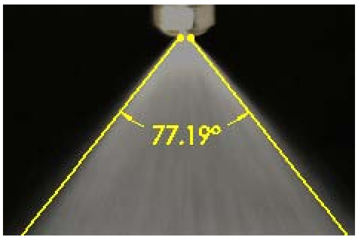
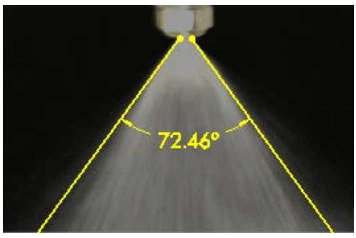


10 Bar



12 Bar

B10



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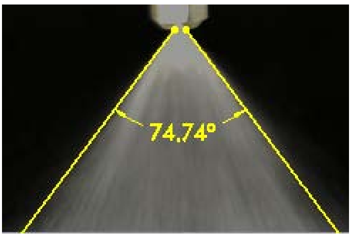

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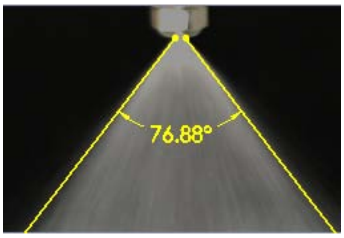
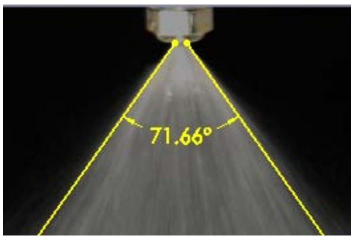


12 Bar

B15



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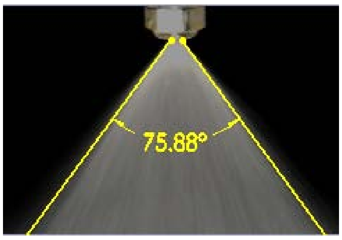
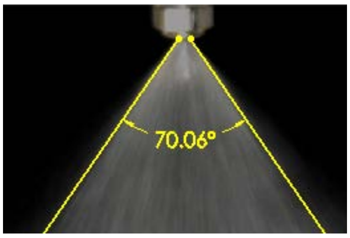


12 Bar

B20



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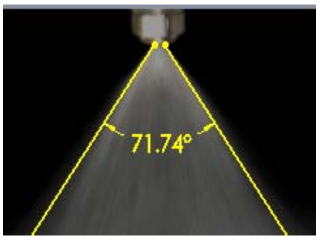

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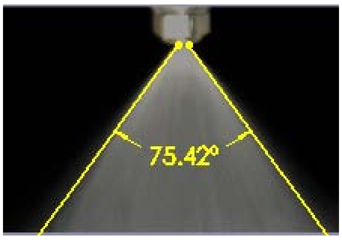
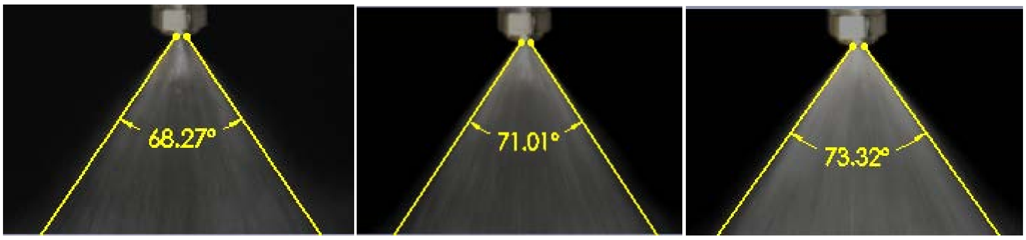


12 Bar

B25



8 Bar 10 Bar 12 Bar

Figure 4: Spray Cone Angles at Different Pressures and Different Blending Ratios

3.4 SMD at Constant Pressure of 8 bar

Figures 5 shows the measured SMD of palm olein blend spray at constant pressure of 8 bars. Generally, it can be observed that the droplet size is not uniform inside the spray cone. The SMD of the droplet varies from one point to the other. The larger droplets are located at the boundaries of the spray. This phenomenon is attributed to the centrifugal force gained from the tangential motion of the droplets discharged from the atomizer in circulating motion. The large drops with higher mass attain higher centrifugal force, placing itself at the spray periphery while smaller droplets with lower mass are concentrated near the spray centerline.

From Figure 5, it showed that petroleum diesel fuel has the smallest SMD followed by B5, B10, B15, B20 and lastly B25. This is agreed at all axial locations of the spray. The bigger droplets size produced by the palm olein blends sprays is due to higher density, viscosity and surface tension of the palm olein compare to diesel fuel. As the amount of palm olein increases, the value of these properties increases which consequently increases the SMD. It is noted that the measured SMD of B25 were 2.0 to 2.7 times than those of diesel fuel at the centerline of the sprays. At the same time, the SMD of B5 is slightly larger than diesel by just 3-5%, while the difference in SMD between B0 and B10 recorded much higher with 30% in difference.

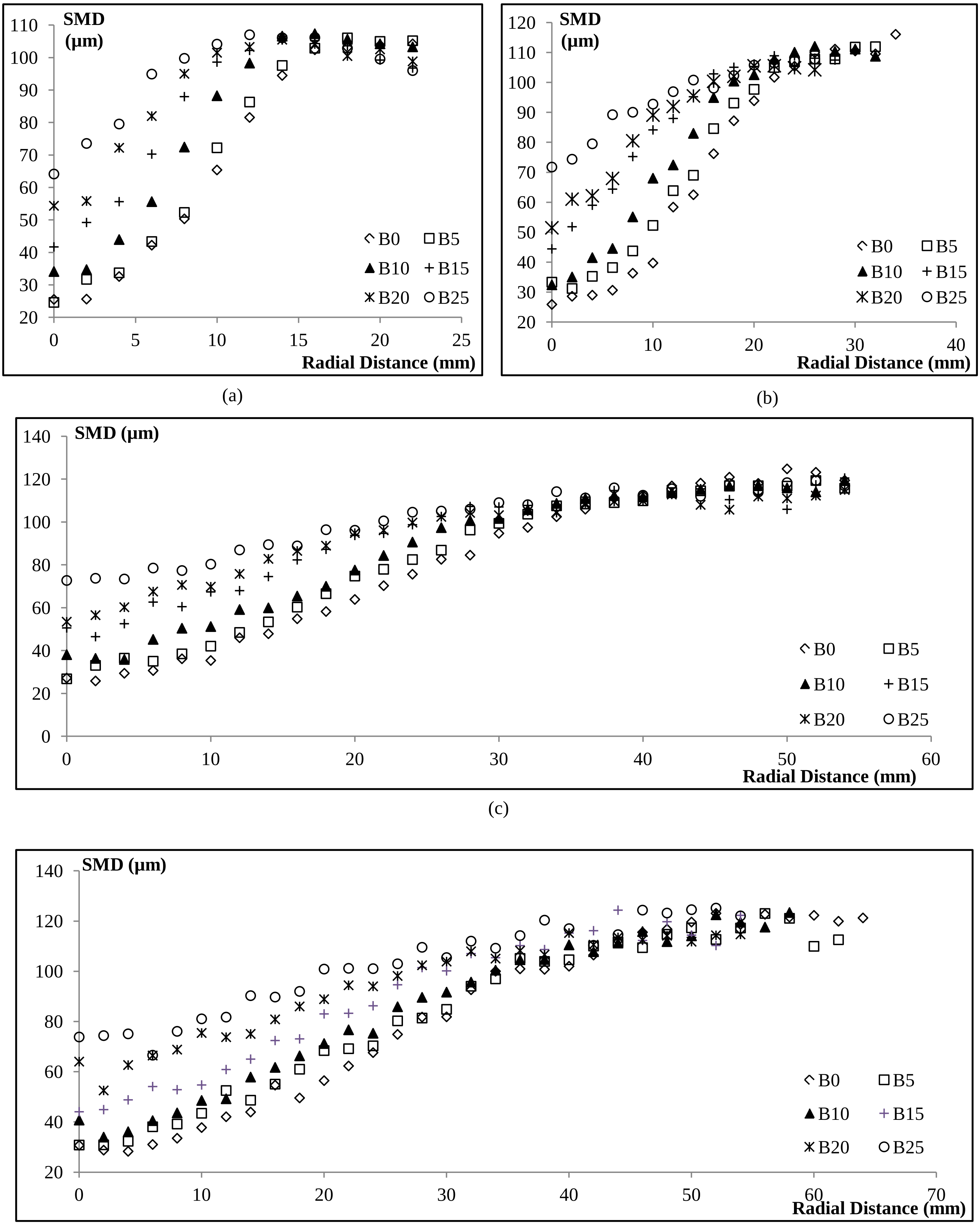
From the SMD perspective, the B5 are suitable to replace petroleum diesel compared to the other blends due to the comparable size of the blend and diesel. The other blends would require extra work to reduce its SMD in order for it to be used in the present gas turbine engines without major modification. The fuel blends could be preheated before being injected into the engines combustion chamber. The preheating would reduce the viscosity and surface tension, consequently reducing its SMD.

3.5 SMD at Different Injection Pressures

To investigate the effect of pressures on the SMD of palm olein blends sprays, the measurement was concentrated at single location which is at 40mm axially from the injector tip. Figures 6 shows the SMD of different injection pressures along radial distance for different blends. It is observed that, all palm olein blends demonstrate higher quality sprays in term of smaller SMD when higher injection pressures were applied. The improvements in quality of the sprays were obvious in the case of B15. At the centerline of the spray, the SMD of B15 sprays reduce from 47.5µm at 8 bar to 24.5µm at 12 bar. The average improvement of SMD for B15 at the measurement points is about 45%. The least improvement recorded was for B25 with only 7% average improvement. In addition, the second highest improvement was diesel with 43% followed by B20 with 27%, B5 with 23% and B10 with 16% improvement.

These tests showed that the SMD of palm olein blends could be improved by increasing the injection pressure. Therefore, in order to get the same quality of SMD with petroleum diesel, the atomization pressure could be increased to compensate the rise in viscosity and surface tension of the palm olein blends. The same suggestion was also given by Park [20] and Park et al., [21].

The increasing injection pressures increases the energy of spray liquid turbulence to overcome the restraining forces of the liquid’s surface tension. When the liquid surface tensions are overcome by the energy of the liquid, smaller droplets are generated, thus contributing to smaller SMD. The small SMD is particularly important in combustion because smaller SMD increases specific surface area of the fuel and thereby would achieve high rates of mixing and evaporation.



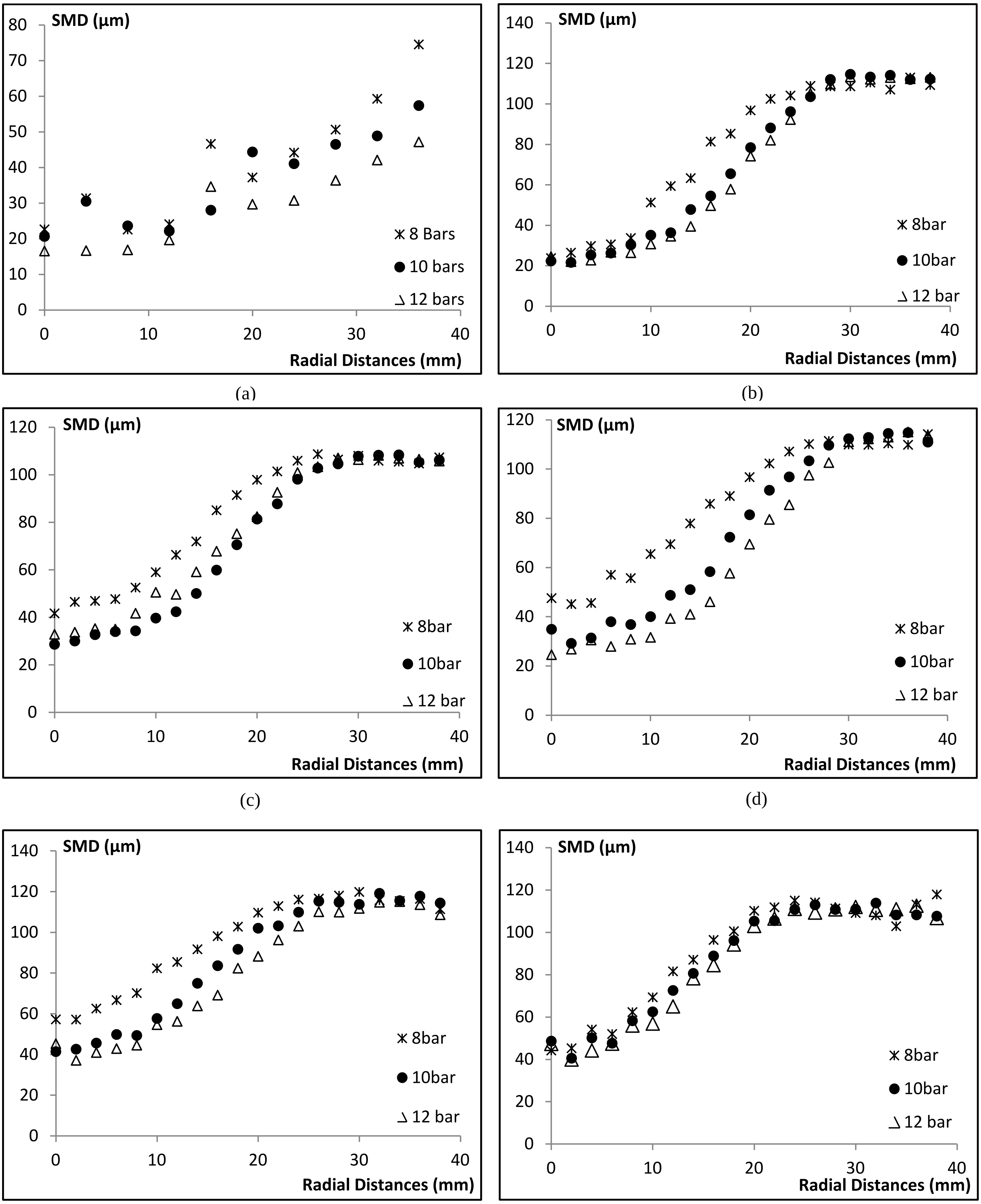
(a)

(b)

(c)

(d)

Figure 5: SMD Profile of Petroleum Diesel, Palm Olein and Palm Olein Blends at
(a) 25mm (b) 40mm (c) 65mm and (d) 80mm Downstream of the Atomizer



(a) (b) (c) (d) (e) (f)

Figure 6: Effect of Pressures on SMD at 65mm Axial Distance from Atomizer for (a) Diesel; (b) B5; (c) B10; (d) B15; (e) B20 and (f) B25

4.0 Conclucions

The spray characterization of palm olein blends was conducted under ambient and unconfined spray conditions using a pressure swirl atomizer. Various palm olein blends (B5, B10, B15, B20 and B25) as well as diesel fuel sprays were examined using a PDPA and DSLR camera under variable injection pressures. From this study, the following conclusions could be drawn:

1. The spray cone angle reduces with increasing palm olein content in the blends (B0 to B25). The increase of injection pressures from 8 bar to 10 bar and finally to 12 bar resulted in wider spray cone angles. For instance, the diesel spray cone angle increases from 73.75° at 8 bar to 79.04° at 12 bar.
2. The SMD of the fuel increases with the blending ratios. This was attributed to the higher viscosity and surface tension of the palm olein. Increasing injection pressures resulted in better quality of sprays for all blends.

5.0 Acknowledgment

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