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Full Length Research Paper

Experimental investigation of spray characteristics of refined bleached and deodorized palm oil and diesel blends using phase Doppler particle analyzer

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The unstable oil prices in the world market lead many countries to seek an alternative fuel to substitute petroleum oil. Palm oil derived fuel is one of such alternatives, which can be used as fuel in several methods, such as preheating, blending with other petroleum fuels, trans-esterification and etc. The objective of this paper is to characterize the spray of the refined, bleached, and deodorized palm oil (RBDPO) and diesel blends. Five blends B5, B10, B15, B20 and B25 were physically blended using lab scale dynamic double propeller mixer and the main physical properties (density, viscosity and surface tension) that have the main effect on the spray pattern were measured. A phase doppler particle analyzer (PDPA) was used to characterize the spray including particles Sauter mean diameter (SMD). Direct photography was used to determine the spray angle for the different blends. Results show that as the percentage of RBDPO increases in the blend, the SMD increases and the spray angle decreases. The percentage increase in the SMD from B0 to B25 was approximately 15% while the decrease in the spray angle is 9.44°. It can be concluded that the blends B5 and B10 could be used in the power engines without fuel system modification. However evaluation of the combustion performance should be done for all blends.

Key words: Phase Doppler particle analyzer (PDPA), refined, bleached, and deodorized palm oil (RBDPO), diesel, biomass, spray, atomization.

INTRODUCTION

Biomass derived fuels was shown to be a promising alternative to fossil fuels because they are renewable fuels with lower pollutant level. Emissions of particulate matter (PM), unburned hydrocarbons (HC), carbon monoxide (CO) emissions (Haas et al., 2001), as well as carbon dioxide are reduced substantially in the range of 20 to 80% when biofuel is used compared to conventional fossil fuels. However, the biofuel has the disadvantages of lower fuel volatility, high viscosity and surface tension and flame stability issues.

Due to the high viscosity of vegetable oils which normally introduces the growth of gumming, the injector deposits, ring sticking, as well as incompatibility with conventional lubricating oils (Pryde, 1983; Ryan et al., 1984). In order to make vegetable oils a suitable alternative fuel for power generation engines, a reduction in their viscosity have to be done. The difficulty of high viscosity could be overcome in several ways, such as preheating, blending with other petroleum fuels, trans-esterification and thermal pyrolysis (Longwic et al., 2001; Forson et al., 2004).

The atomization characteristics of biodiesel-blended fuels were investigated by Lee et al. (2005) in terms of spray tip penetration, Sauter mean diameter (SMD), and mean velocity distributions by using a spray visualization system and phase Doppler particle analyzer. Their results indicated that the mean size of the droplets increases in accordance with the mixing ratio of the biodiesel because the viscosity and surface tension of the biodiesel are higher than those of the conventional diesel fuel.

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Erazo et al. (2007) compared the spray characteristics of a canola methyl ester (CME) biodiesel and diesel fuel under ambient conditions using a phase Doppler particle analyzer (PDPA). Their results showed that the CME biodiesel droplets were 5 to 24% larger in Sauter mean diameters than the petroleum based diesel fuel droplets in the near nozzle area and the spray edges.

Geng et al. (2009) analyzed biodiesel/diesel blends spray using high resolving power digital camera. In addition, they calculated the cone angle of the sprays, droplet size number distribution of the sprays, cumulative droplet size distribution based on volume, mean diameter, representative diameter and dispersion boundary. The results indicated that when biodiesel mixed ratio increases, cone angles decrease, mean diameters of the fuel droplet of the sprays increase. The results also showed that the higher the biodiesel mixed ratio is the worse the spray quality.

Gao et al. (2009) studied experimentally and numerically the spray characteristics of Jatropha oil which included the spray penetration, spray cone angle and spray tip speed which were measured at different biodiesel ratios in a constant volume vessel using a high-speed camera. The experimental results showed that, as the ratio of biodiesel in the blends increased, spray penetration and spray speed increased, but the spray cone angle decreased. The results also showed that the Sauter mean diameter of blend fuels was greater than that of diesel, and spray was more concentrated, due to the higher viscosity and surface tension of the biodiesel, compared with conventional diesel fuel. The macroscopic and microscopic spray properties of blended fuels containing 5, 10 and 20% biodiesel were similar to diesel.

Investigations of palm methyl ester (PME) atomizing characteristics using a laser diffraction spray analyzer (LDSA) were conducted at atmospheric pressure by Hashimoto et al. (2008). The results showed that changing trends of NO_x emission level with atomized particle size for PME are similar to that for diesel fuel. At the same SMD or fuel kinematic viscosity, the NO_x emission level for PME is lower than that for diesel fuel. It was concluded from their results that PME is considered to be a promising alternative fuel for gas turbines.

Palm oil is mainly used as edible oil in many Asians country and its usage as alternative fuel is considered low, which is currently 20% from palm oil total production (Basiron and Choo, 2007). Therefore, Malaysian government which considers palm oil as strategic product is working all out to increase this percentage usage. This effort was spearheaded by Malaysia Palm Oil Board (MPOB). The application of palm oil as fuel is already well known with the palm oil methyl ester (POME) already considered as diesel substitute. On June 2011, the B5 which contains 5% palm methyl ester and 95% petroleum diesel will be mandatory sale in petrol pump nationwide (Muthiah, 2010). In addition, the usage of processed palm oil RBDPO as biofuel has also been conducted by MPOB. 5% of RBDPO was blended on volume basis with 95% petroleum diesel to get B5 blend which was fully tested in 130 vehicles and it was reported that there was no major problem appearing during the test (Basiron and Choo, 2007). Besides that, the usage of crude palm oil (CPO) as biofuel in the boiler has been done by MPOB and it was proved that CPO was feasible, however a little modification in the fuel system should be considered. In Prai Power Station, a power plant own by Tenaga Nasional Berhad, a sole electricity provided in peninsular Malaysia, the blended CPO and medium fuel oil was used to fire one of the boiler in the power plant and it was observed that there was no problem during the operation of the boiler. Apart from that, recent study of using a blend of RBDPO and petroleum diesel in industrial burner system showed that the performance of palm biofuel was on par with diesel up until 10% of RBDPO with respect to temperature profile along the combustion chamber (Mantari and Jaafar, 2009).

Although there are a lot of research on the spray characteristic of the methyl ester biodiesel, there are a shortage in the research on the spray of direct blended vegetable oils with the diesel fuel. Therefore, this research aims to characterize the spray of RBDPO/diesel blends to show their feasibility to be used as alternative fuel.

Main physical properties of RBDPO and its blends compared to diesel fuel

The physical properties such as viscosity and surface tension can provide good information regarding spray characteristics. Neat fossil diesel fuel important physical properties compared to neat RBDPO and five RBDPO/diesel blends fuels are given in Table 1. The diesel fuel is referred to ‘B0’ and B5 is referred to 5% RBDPO and 95% diesel on volume basis. The density and surface tension of the diesel fuel and RBDPO blends were comparable to each other.

Among these properties given in Table 1, the viscosity is considered as essential parameter since it plays a significant role in fuel atomization. It can be noticed that the kinematics viscosity of RBDPO is approximately 10 times of that for diesel fuel. Therefore, in this research, the blending method was used to reduce the RBDPO viscosity to that of diesel to ensure that the fuel injector atomizes the fuel in the correct pattern for efficient combustion. The blending method has the advantages as follows:

1. It does not need any chemical processes or special equipments;
2. It can easily be done in the farms area and rural places;
3. Until some extent of blending ratio, the blending fuel can be used in the engines without any modification.

Table 1. Fuel properties of RBDPO blends and Diesel Fuel (B0).

Sample	Specific gravity (ASTM D1298)	Density (kg/m^3) (ASTM D1298)	Kinematics viscosity (Cst) (ASTM D445)	Surface tension (N/m)
B0	0.8321	831.6	3.472	0.0300
B5	0.8371	836.6	4.083	0.0305
B10	0.8412	840.6	4.65	0.0305
B15	0.8452	844.6	5.442	0.0305
B20	0.8502	849.6	5.809	0.0305
B25	0.8542	853.5	6.422	0.0305
B100	0.915	905.5	35.14	0.0345

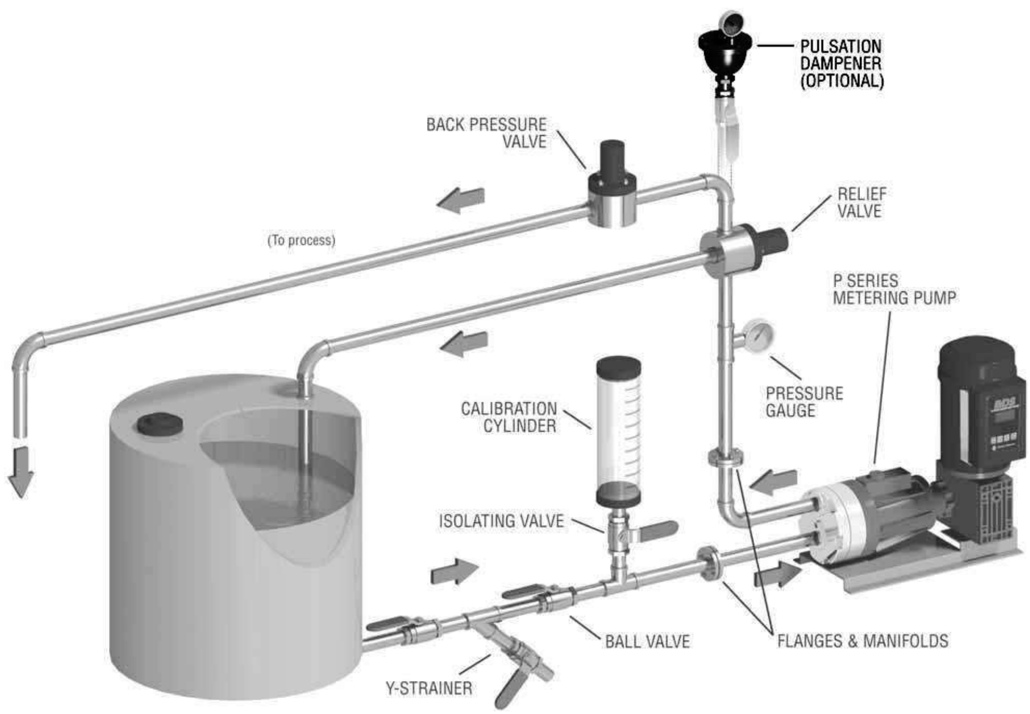

Figure 1. Schematic of spray rig.

METHODOLOGY

Test rig description

The spray test is shown in Figure 1 in which the fuel is drawn from fuel tank and delivered to the fuel atomizer through Hydra cell multi diaphragm pump. A pressure pulsation dampener was used to steady fuel pressure and reduces the system vibration; in addition, surge vessel immediately before the atomizer was used to damp the pressure fluctuation which makes the spray steady for reliable and accurate measurement. In order to keep the pressure at constant desired value during testing, a pressure regulator valve was used after the fuel pump. The design of the test rig considered it to be reliable, can be used for multiple fuels, simple and cheap. The injector was a Spray System pressure swirl atomizer with a 1.6 mm orifice diameter. A photograph of the injector is presented in Figure 2. The atomizing pressure was kept constant at 8 bar for all the tests. The experiments were conducted in unconfined space at ambient pressure and room temperature (22°C). The fuel flow rate was maintained at 0.60 l/min for diesel and RBDPO blends.

PDPA setup

A phase Doppler particle analyzer (PDPA) manufactured by Dantec Dynamics (2006) was utilized to measure the droplet diameter distributions. The advantage of using the PDPA is that it provides simultaneous, non-intrusive measurements of droplet diameter from the light scattered by the droplets. The light source was a water cool, Argon-Ion laser at a wavelength of 632.8 nm. A forward scattering orientation was used; both transmitter and receiver were diffracted by 60° forward scattering angle. The measurements were number-averaged over 3000 droplets. Each measurement point was repeated three times for uncertainty analysis. The PDPA transmitter and receiver were each mounted on a traverse that could be moved in the horizontal, vertical and transverse directions.

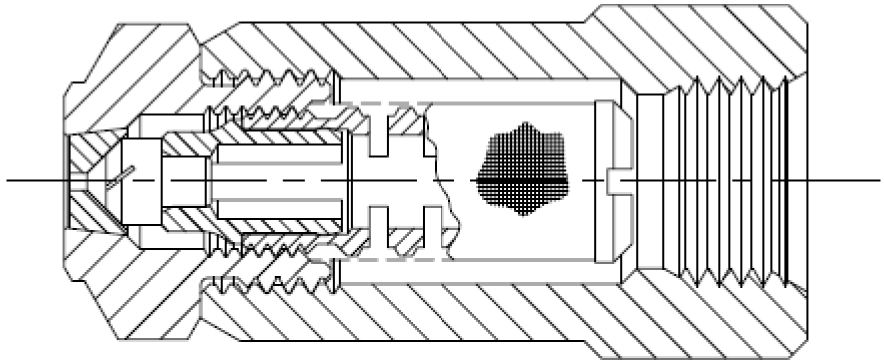

Figure 2. Pressure swirl atomizer.

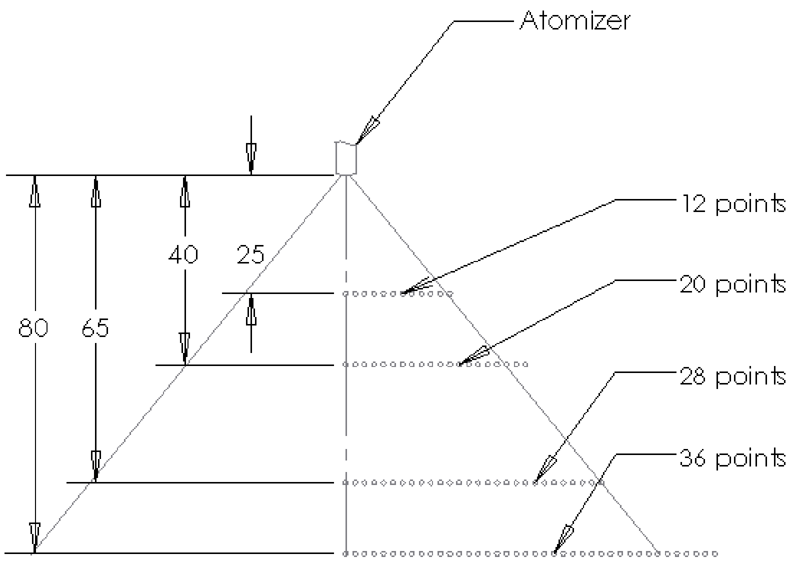

Figure 3. Measurement locations for cold spray and spray flame conditions.

The measurement locations downstream of the atomizer are shown in Figure 3.

RESULTS AND DISCUSSION

Visual observation

Photographs of the spray were taken using a digital camera. Figure 4 indicates the general pattern of the spray. Due to the velocity of rotation of the fuel inside the atomizer swirl chamber, an air core is created and the fuel extends into the atomizer orifice in the form of rotating tube spin around the air core in the middle. Consequently, the generated centrifugal force immediately expand the fuel rotating into a cone shape sheet downstream the atomizer as can seen from Figure 4. The fuel sheet emerging from the orifice stretches to the point where it ruptures and throws off the droplets.

Figure 4. Photograph of diesel spray.

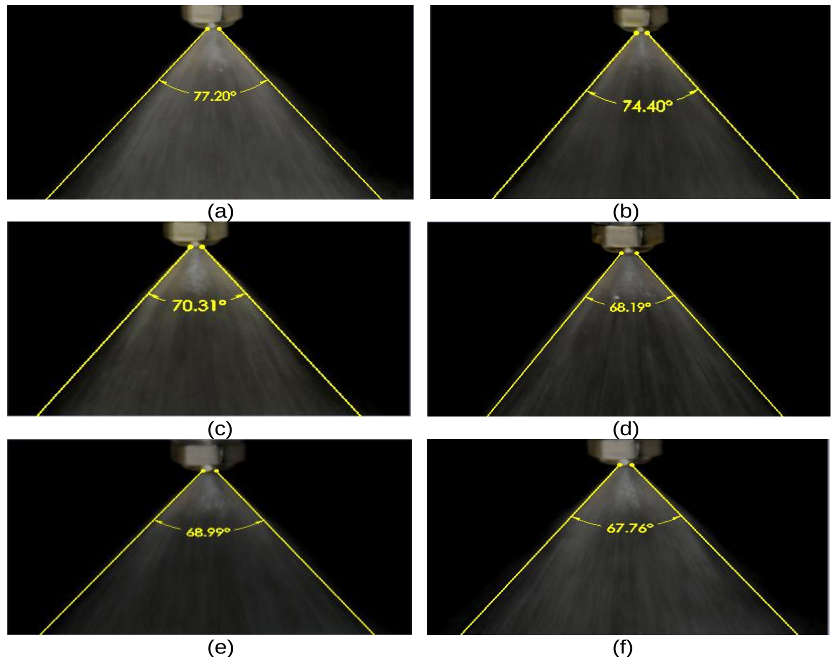

Figure 5. Photographs of B0, B5, B10, B15, B20 and B25 sprays.

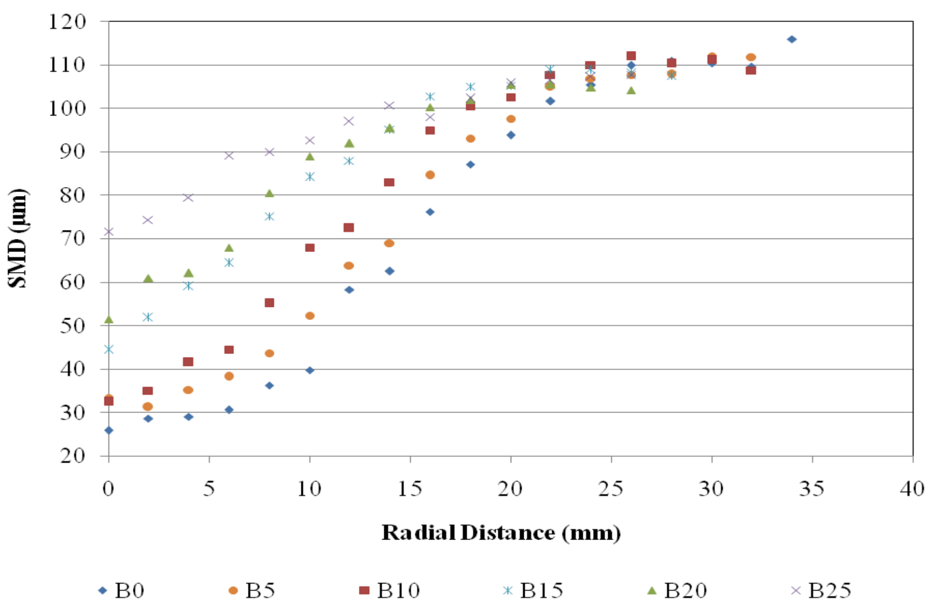

Figure 6. Spray SMD profile 40 mm downstream of the fuel atomizer.

Figure 5 depicts the spray cone shape for diesel fuel and RBDPO blends. It can be noticed that when the RBDPO ratio increases in the blend, the spray cone angle becomes narrower, that is, the spray cone angle of B25 is the narrowest among the other blends compared to diesel fuel spray. This shows that the spray angle decreases as the viscosity of the fuel increases. In general, the smaller the cone angle is, the smaller the surface cone area. In such case, the air entrainment is also reduced, hence leads to poor air mixing and incomplete combustion.

SMD

The measured SMD profiles are presented in Figures 6

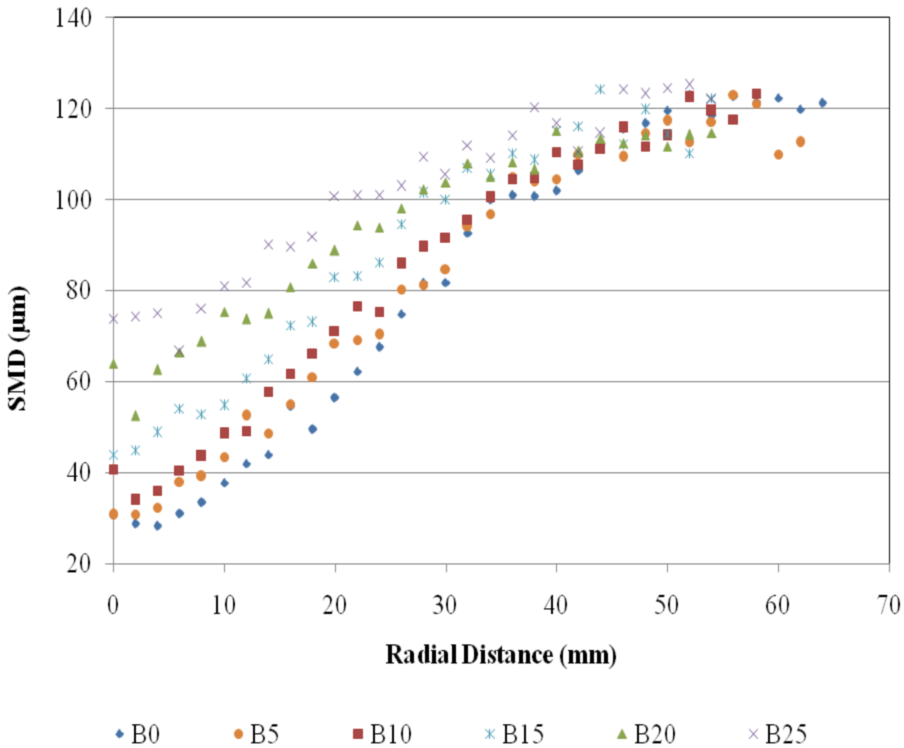

Figure 7. Spray SMD profile 80 mm downstream of the fuel atomizer.

and 7. Generally, it can be observed that the bigger droplets are located at the boundaries of the spray due to the centrifugal force gained from the tangential motion of the droplets discharged from the pressure swirl atomizer, while the smaller droplets are concentrated near the spray centerline. It can be also seen from Figures 6 and 7 that B5 spray had slightly larger droplet than that for the diesel fuel spray and as the amount of RBDPO increases in the blend, the droplet diameters as consequence increase. At the centerline, the B25 droplet diameters were 2 to 2.7 times of those for the diesel fuel. Whereas at the spray boundaries, the B25 and diesel fuel droplet diameters were close in the size. The presence of larger droplets at the edges of the spray is attributed to the swirl imparted to the spray by the nozzle. The swirl produces a centrifugal force which throws the larger droplets out of the spray due to their greater mass. The bigger droplet size produced by the RBDPO blends spray can be attributed to the higher viscosity of the RBDPO compared to diesel fuel. The maximum uncertainties in these measurements were less than 8.7% of the measured value.

Analytical calculation of SMD

The SMD is calculated analytically as a function of the fuel viscosity, density, and surface tension through the following equation.

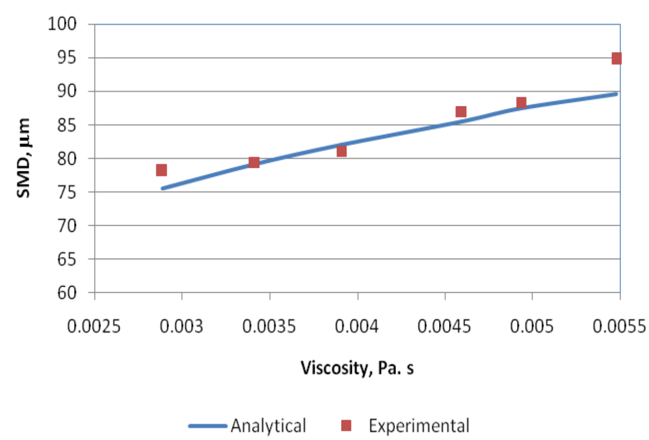

Figure 8. Comparison between analytical and experimental SMD results.

$$SMD = 2.25\sigma^{0.25}\mu_L^{0.25}\dot{m}_L^{0.25}\Delta P_L^{-0.5}\rho_A^{-0.25}$$

This equation was derived by Lefebvre (1989). The dependency of the drop size on the fuel density is represented implicitly through the fuel mass flow rate. The analytical results of SMD were compared with the experimental results as shown in Figure 8. It can be seen that the analytical and experimental results of SMD are in a good agreement with each other.

Conclusion

RBDPO biofuel blends B5, B10, B15, B20 and B25 as well as pure diesel fuel sprays were examined under ambient unconfined spray conditions using a PDPA. The SMD and mean spray cone angle indicated that the B25 had a 15% higher SMD and 9.44° lower spray angle when compared to commercial diesel fuel. The larger diameter droplets were concentrated at the boundary of the spray cone while the smaller ones were located in the vicinity of the atomizer centerline for all the downstream locations owing to the swirl imparted to the spray by the nozzle.

It can be concluded that the larger SMD and the lower spray angle of the RBDPO blends compared to the diesel fuel was due to the higher viscosity of RBDPO.

Generally, the atomization characteristics of the lower mixing ratio RBDPO blends B5 and B10 comparable to that of the diesel fuel can be used directly to power generation engines without any engine modification, however, combustion and emission test have to be done.

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