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SPRAY CHARACTERISTIC OF PALM BIOFUEL BLENDS

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ABSTRACT

The present numerical study on spray characteristic of biofuels, which is the blend of Refined, Bleached and Deodorized Palm olein (RBDPO) and Commercial Diesel Fuel (CDF) in gas turbine, is important. This type of study is a major concern all over the world due to global issues for example pollution, shortage of fuel and economic crisis. This study is mainly focused on spray characteristic for various palm olein biofuel blends. Spray characteristic of various biofuel blends will be analyzed and compared to pure diesel. Biofuel blends that have different blending ratio - B5, B10, B15, B20, and diesel will be studied and the chemical properties of various biofuel blends can be determined after having several measurements in laboratory. Numerical study was conducted by using Gambit and FLUENT software to observe the spray characteristic such as Sauter Mean Diameter (SMD) and penetration for different biofuel blends. Verification and validation is an important way to ensure that the mathematical model can be used in this case studies. The k-epsilon model has successfully predicted the spray characteristic of all biofuel blends such as Sauter Mean Diameter and penetration of droplet particle and a correlation has been established.

Keywords: Sauter Mean Diameter, cone angle, computational fluid dynamic, biodiesel blends.

1.0 INTRODUCTION

Biofuel can be defined as liquid combustible substance or liquid fuel made out of biomass. Biofuel can be divided into two route which are petrol route and diesel route. There are several sources to obtain biofuel (Hwa A. Lim, 2006). Mainly vegetable oils from soya, rapeseed, jatropha, palm and sunflower are used as major sources. Palm oil is a superior biofuel source due to its availability (MPOB, 2003), and it is able to produce on a positive energy balance, compared to other vegetable oils. Refined, Bleached and Deodorized (RBD) Palm Olein is obtained by fractionating refined palm oil to separate liquid parts (olein) from solid parts (stearin). At room temperature, it is a clear yellow liquid. RBD palm olein is used as cooking oil as well as frying oil for food industries such as snack food and ready-to-eat food (Kanury, 1975). The process of generating a large number of droplets is called atomization. The process of atomization begins by forcing liquid through a nozzle. The potential energy of the liquid (measured as liquid pressure for hydraulic nozzles or liquid and air pressure for two-fluid nozzles) along with the geometry of the nozzle causes the liquid to emerge as small ligaments. These ligaments then break up further into very small "pieces", which are usually called drops, droplets or liquid particles.

A droplet is a small particle of liquid having a more or less spherical shape. Droplets are also known as particles. The reason particles are round is due to the liquid's surface tension. Surface tension is the property of a liquid that causes droplets and soap bubbles to pull together in a spherical form and resist spreading out. This property causes sheets or thin ligaments of liquid to be unstable; that is, they break up into droplets, or atomized. Sprays are formed when the interface between a liquid and a gas becomes deformed and droplets of liquid are generated. These then migrate out into the body of the gas. Sometimes the gas plays a negligible role in the kinematics and dynamics of the droplets formation process. The spray characteristics to combustion performance include mean drop size, drop size distribution, patternation, cone angle, and penetration. Mean drop size, drop size distribution and patternation are almost dependent on atomizer design while cone angle and penetration are partly dependent on atomizer design and partly on aerodynamic influences (Lefebvre, 1978). The Sauter mean diameter (SMD) is the one most widely used. It is defined as the diameter of a drop having the same volume over the surface ratio as the entire spray (Lefebvre, 1990).

$$SMD = \frac{\Sigma nD^3}{\Sigma nD^2} \qquad (1)$$

Penetration of spray is defined as the maximum distance it reaches when injected into stagnant air and it is governed by the relative magnitudes of two opposing forces:

a) The kinetic energy of the initial fuel jet.

b) The aerodynamic resistance of the surrounding gas.

In general, a compact, narrow spray will have high penetration, while a well-atomized spray of high cone angle, incurring more air resistance, will tend to have low penetration. A variety of factors affects the droplet size and how easily a stream of liquid atomizes after emerging from an orifice. Among these factors are fluid properties of surface tension, viscosity, and density (Allen and Watts, 2000).

2.0 METHODOLOGY

Fuel Properties

The physical properties of the petroleum diesel, palm olein and biodiesel blends are listed in Table 1. These results were obtained from tests done at UNIPEM laboratory, Faculty of Chemical Engineering and Petroleum Engineering, Universiti Teknologi Malaysia.

Table 1: Physical Properties of Petroleum Diesel, Palm Olein and Biodiesel Blends

Types of Fuel	Density (kg/m^3)	Surface Tension (N/m)	Dynamic Viscosity (kg/m-s)	Flash Point (°C)	Pour Point (°C)
Diesel	828.7	0.0300	0.00324	79	-16
B5	832.2	0.03045	0.0038	78	-18
B10	836.1	0.03048	0.0041	78	-20
B15	838.9	0.03054	0.0046	79	-24
B20	842.0	0.03055	0.00504	80	-24
RBDPO	901.2	0.03450	0.0352	280	-9.7

Various biofuel types that will be discussed are B0, B5, B10, B15, B20 and B100. B0 is 100% diesel, B5 is 5% RBDPO + 95% diesel, B10 is 10% RBDPO + 90%diesel, B15 is 15% RBDPO + 85% diesel, B20 is 20% RBDPO + 80% diesel and B100 is 100% RBDPO. Blends such as B30, B40 and so on were not investigated because the properties of the fuel itself. Since the blends were obtained by splash blending of RBDPO (of certain percentages) with CDF. Thus, the blends were not produced through any kind of chemical processes. The viscosity of the blends increase as the amount of RBDPO was increased. Meanwhile, the blends that consist more than 20 percent RBDPO are very hard to combust in a liquid fuel burner as demonstrated by previous researchers (Sawarimuthu and Jaafar, 2008; Mantari and Jaafar, 2009).

Computational fluid dynamic

Computational fluid dynamic (CFD) is one of the field in fluid mechanics using numerical method to solve and analyze the problems related to fluid flows, heat transfer, mass transfer, chemical reactions, and related phenomena by solving mathematical equations that represent physical laws. The examples of problems are conservation of mass, momentum, energy, species and etc. The use of CFD to predict internal flow and external flow are widely recommended. This technique is widely used in industrial and non-industrial sectors (Versteeg and Malasekera, 1995). Physical aspects of any fluid flows are governed by three fundamental principles:

a. Mass is conserved.
b. Momentum is conserved (Newton's second law).
c. Energy is conserved (First law of thermodynamic).

Geometry Modeling

Figure 1 shows the model of the present study and its relevant geometry dimensions. The area within the outer diameter which is 50mm and 30mm inner diameter act as a swirler while the middle point act as a injector. Figure 2 shows the meshing of the combustor with 322,608 nodes.

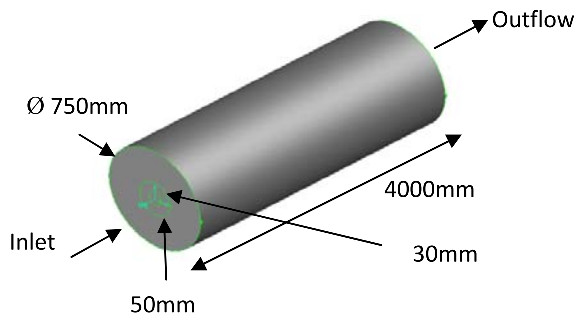

Figure 1: Combustor Geometry

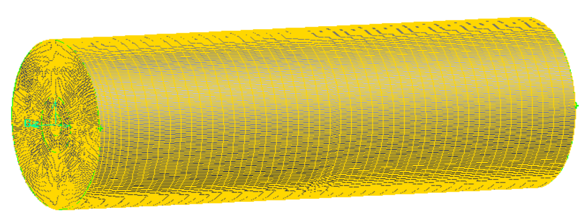

Figure 2: Computational mesh

Numeric

The numerical simulation is carried out using CFD software FLUENT 6.3 to solve the governing equation (GAMBIT Modeling & Tutorial Guide). Solid model and grid creation were conducted using GAMBIT 2.3 GAMBIT Modeling & Tutorial Guide. The convergence criterion is satisfied when the residuals of the entire variable are less than 10. The procedure using FLUENT can be summarized as in Figure 3.

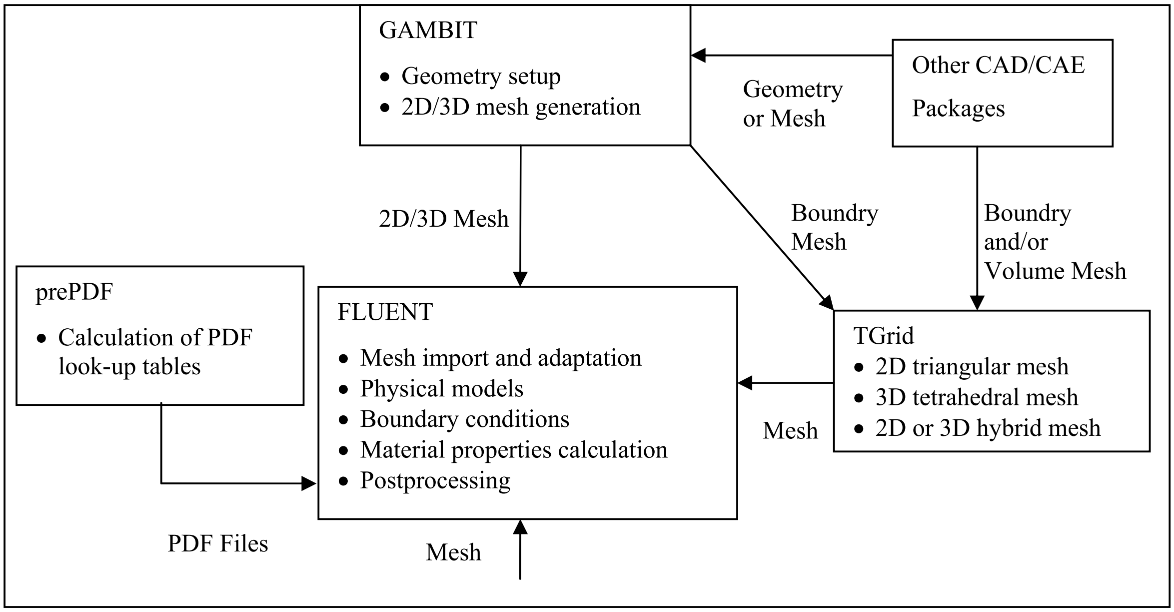

Figure 3: Basic FLUENT Program Structure (FLUENT Modeling & Tutorial Guide)

3.0 RESULTS AND DISCUSSION

The fuel properties that were selected such as density, viscosity and surface tension in FLUENT simulation for various biofuel blends were tested in chemical lab (UNIPEM). The k-epsilon model has successful predicted the spray characteristic that consists of Sauter Mean Diameter and penetration of droplet particle.

Figure 4 shows the graph of particle size versus various biofuel blends. From this graph, 100% RBDPO produced the maximum diameter of particle that is 1mm, and diesel produced the smallest diameter of particle that is 0.0375mm. RBDPO has the largest diameter because the fuel properties itself that effect the production of spray. It has the larger viscosity than other blends that cause unstable spray and droplets. Comparison between the maximum and minimum droplet sizes are also shown in this figure.

Figures 5 to 10 show that particle diameter is influenced by the properties of the fuel. Thus, the various biofuel blends gave the various particle diameters due to different fuel properties such as density, viscosity, and surface tension. The particle diameter is increased from pure diesel, followed by B5, B10, B15, B20 and finally pure RBDPO.

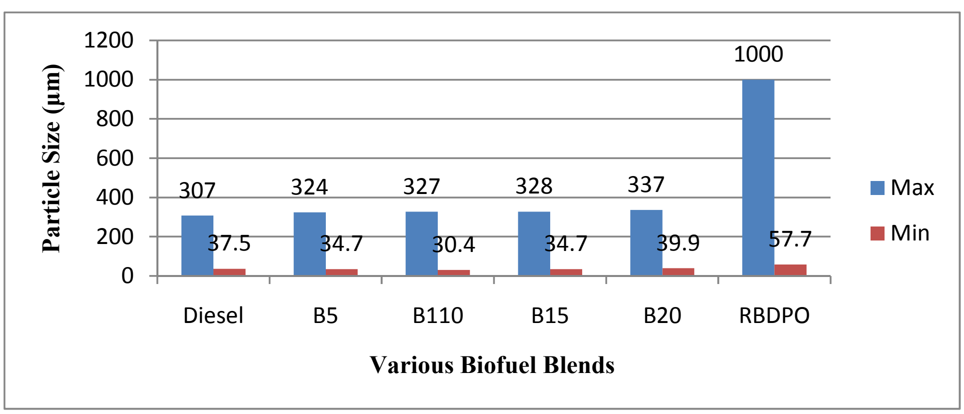

Figure 4: Particle size versus various different fuels

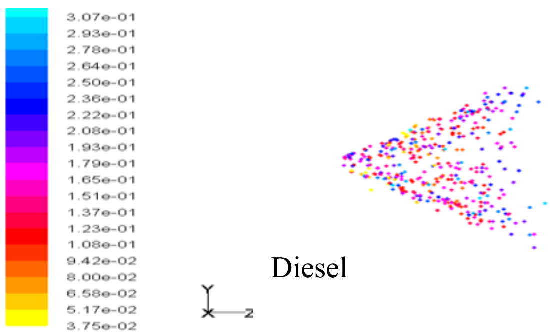

Figure 5: Particle diameter of Diesel

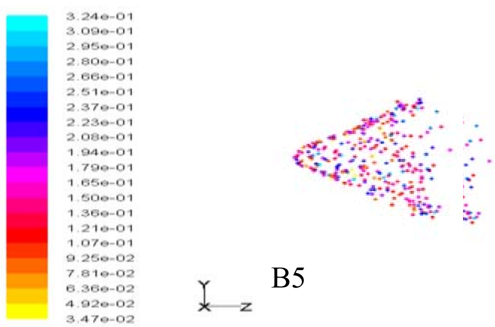

Figure 6: Particle diameter of B5

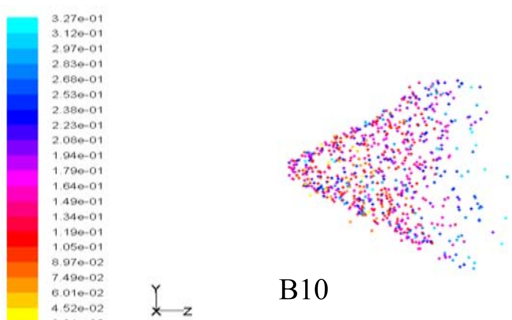

Figure 7: Particle diameter of B10

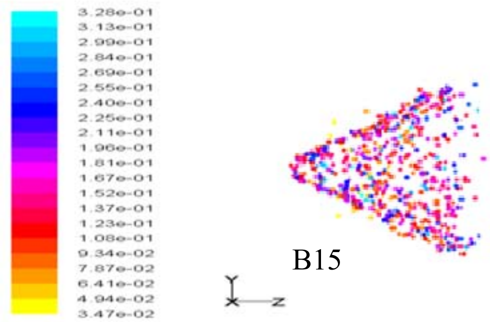

Figure 8: Particle diameter of B15

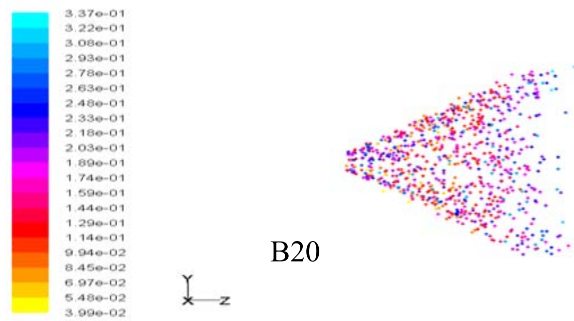

Figure 9: Particle diameter of B20

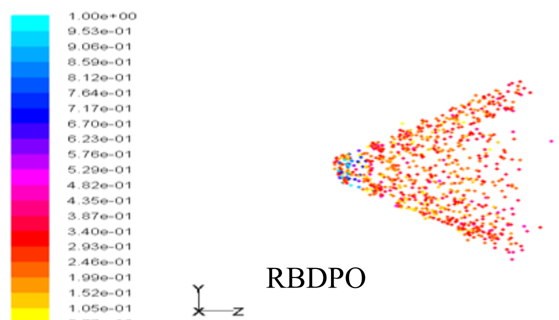

Figure 10: Particle diameter of RBDPO

Figure 11 shows that particle penetration is influenced by different biofuel blends. Comparison between the maximum lengths from the injector for various biofuel blends is also presented in this figure. Figures 12 to 17 show that most of the droplet particle has the biggest diameter located at the inner part of the spray while the smallest particle is located at the outer part of the droplet distribution. Therefore, the optimum combustion performance is obtained when the spray penetration is matched to the size and geometry of a particular combustion chamber (Lefebvre, 1978).

From Figure 18, the SMD is proportional to the percentage of RBDPO for both simulation and empirical methods (see also Tables 2 and 3). In CFD simulation, for the empirical method used the Benjamin equation,

$$SMD = 2.25\sigma^{0.25}\mu_L^{\ 0.25}\rho_A^{-0.25}\Delta P_L^{-0.5}m^{0.25} \quad (2)$$

It shows that SMD obtained from CFD simulation is twice the SMD from empirical method. Although both have different values, it can be seen clearly that both curves show similar trend. The empirical method is the verification for CFD simulation method. There are three main fluid properties that will affect the Sauter Mean Diameter of various biofuel blends, i.e. viscosity, density and surface tension and will be discussed in detail.

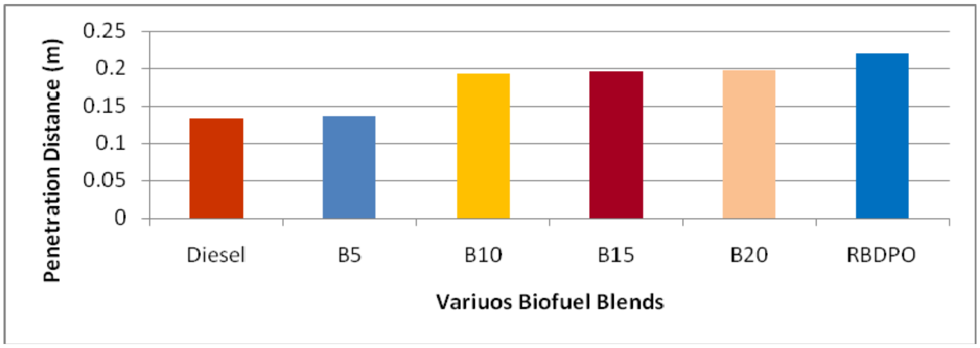

Figure 11: Penetration versus various biofuel blends

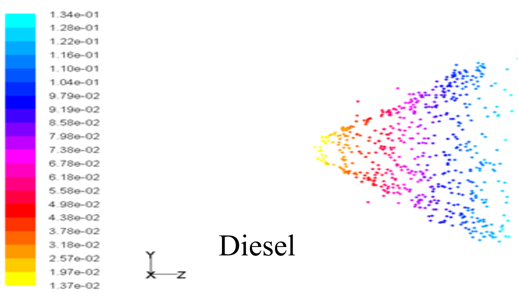

Figure 12: Penetration for Diesel

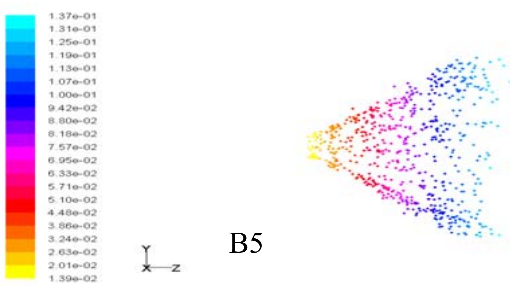

Figure 13: Penetration for B5

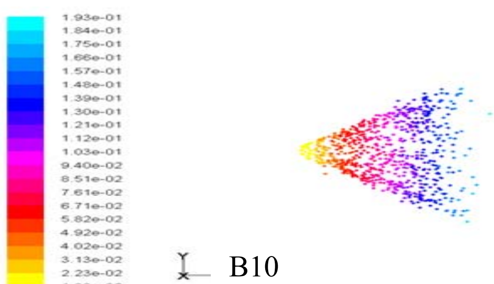

Figure 14: Penetration for B10

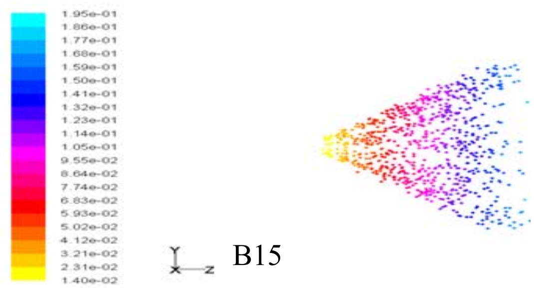

Figure 15: Penetration for B15

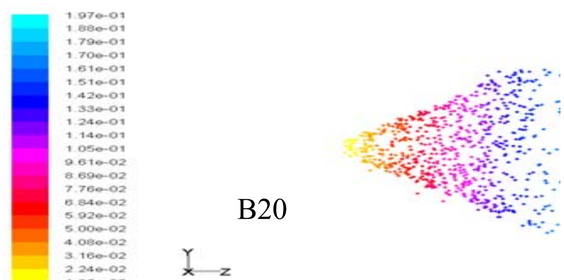

Figure 16: Penetration for B20

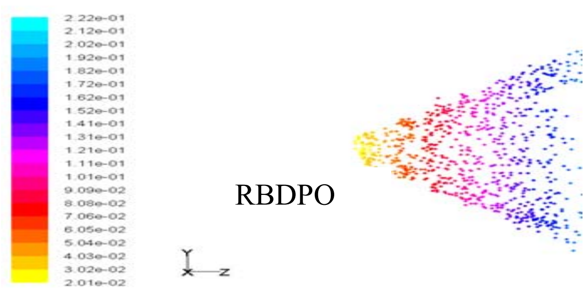

Figure 17: Penetration for RBDPO

From Figure 19, the viscosity presented in this graph was chosen based on various biofuel types, which are diesel, B5, B10, B15 and B20. The viscosity of diesel is 0.00324, followed by B10 that is 0.0041, and B20 that is 0.00504. The SMD that obtained from diesel is 73.42µm while B5 is 83.95 µm, B10 is 86.86µm, B15 is 89.89µm and B20 is 91.51µm. Through these data, a linear best fit line was plotted. From the plot, when the viscosity increased, the SMD also increased. From the Benjamin equation, when the viscosity increased, the SMD will also increase. In other words, Sauter Mean Diameter shows increasing trend from diesel, followed by B5, B10, B15 and B20.

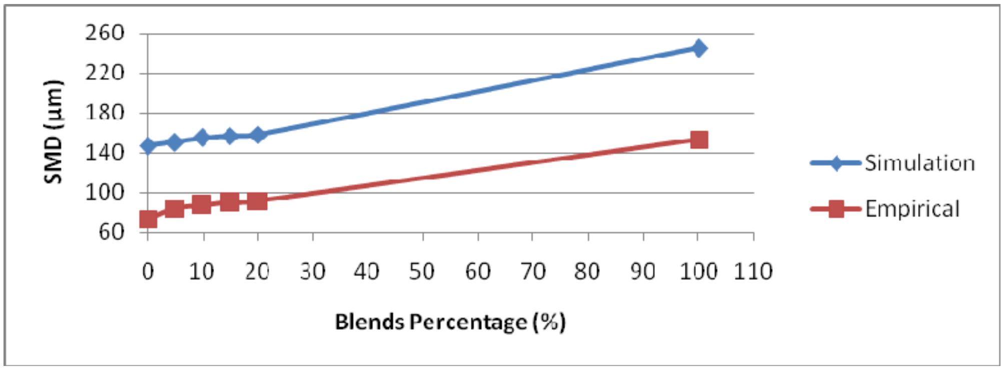

Figure 18: SMD versus percentage of RBDPO

Table 2: SMD by simulation method

Blends	SMD
Diesel	146.93µm
B5	150.5µm
B10	155.05µm
B15	156.89µm
B20	158.06µm
RBDPO	245.02µm

Table 3: SMD by empirical method

Blends	SMD
Diesel	73.42µm
B5	83.95µm
B10	86.86µm
B15	89.89µm
B20	91.51µm
RBDPO	153.39µm

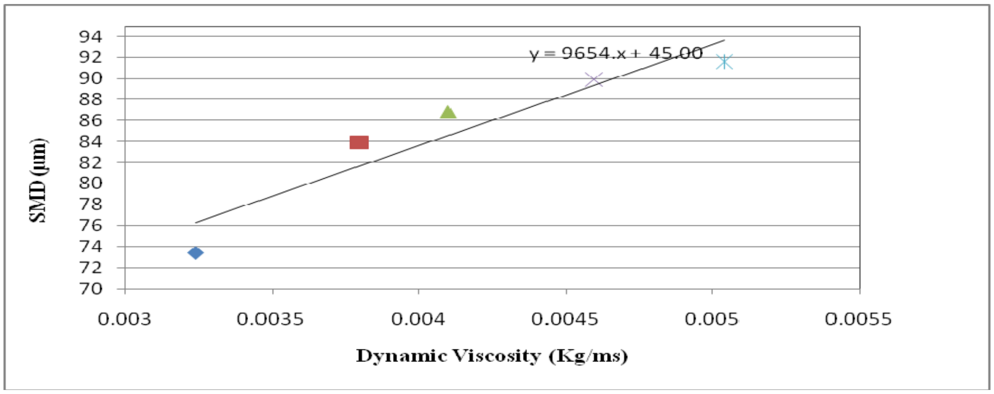

Figure 19: Graph of SMD versus viscosity

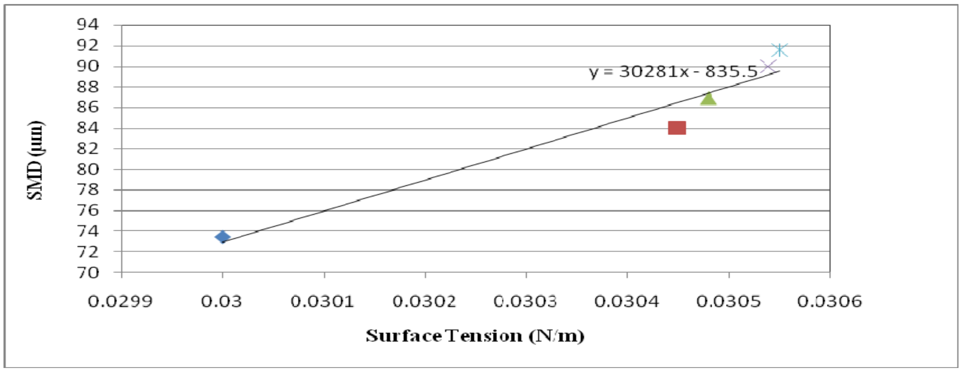

Figure 20: Graph of SMD versus surface tension

The surface tension in Figure 20 was chosen based on diesel, B5, B10, B15 and B20. The surface tension of diesel is 0.03 N/m, followed by B5 is 0.03045 N/m, B10 is 0.03048 N/m, B15 is 0.03054 N/m and B20 that is 0.3055N/m. A linear best fit line was plotted. Hence, the SMD is increased due to the increment of surface tension. Therefore, when surface tension increased, SMD will also increase. In other words, surface tension will affect the Sauter Mean Diameter of biofuel and SMD is increased from diesel, followed by B5, B10, B15 and B20.

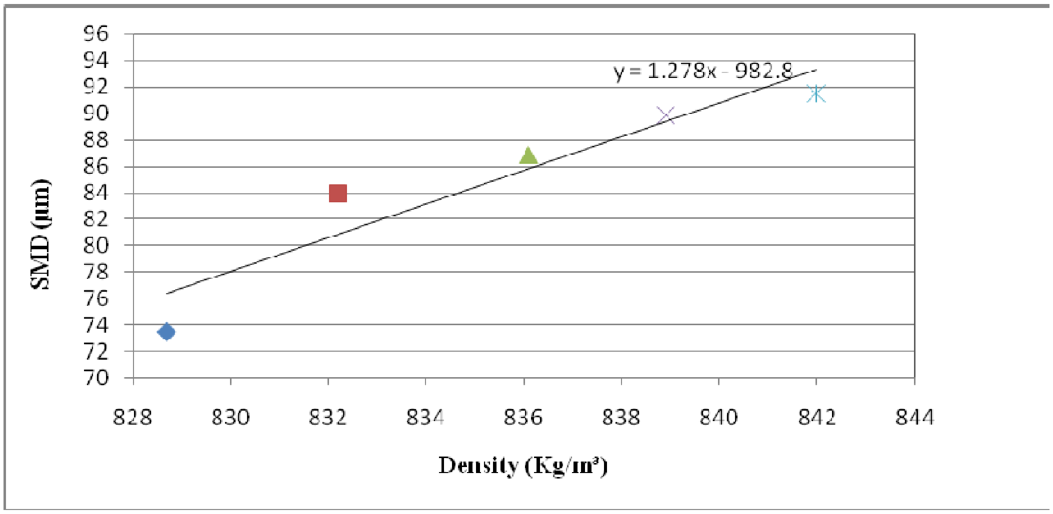

Figure 21: Graph of SMD versus density

The density in Figure 21 was chosen based on different biofuel blends, which consist of diesel, B5, B10, B15 and B20. The density of diesel is 828.7 kg/m^3, followed by B5 is 832.2 kg/m^3, B10 that is 836.1 kg/m^3, B15 is 838.9 kg/m^3 and B20 that is 842.0 kg/m^3. A linear best fit line was plotted. Thus, the SMD is increased when the density used is increased. When the density increased, atomization process will become slower and lead to the increased in SMD of droplet. In other words, density will affect the Sauter Mean Diameter of biofuel and SMD is increased from diesel, followed by B5, B10, B15 and B20.

It can be seen that viscosity, surface tension and density will affect the Sauter Mean Diameter of various biofuel blends. Those biofuel properties play an important role in affecting the spray characteristic of biofuel blends. Density has the highest influences in SMD of biofuel, followed by viscosity and surface tension.

4.0 CONCLUSION

It can be concluded that the spray characteristic can be obtained by using k-epsilon model. The k-epsilon model will be used to verify and validate the geometry of combustor model. The k-epsilon model was chosen in this simulation based on its advantages if compared to other CFD models. The fuel properties that were selected such as density, viscosity and surface tension in FLUENT simulation for various biofuel blends were tested in the chemical laboratory (UNIPEM).

The k-epsilon model has successfully predicted the spray characteristic of diesel, B5, B10, B15, B20 and RBDPO. Spray characteristic consists of Sauter Mean Diameter and penetration of droplet particle. The properties of various biofuel blends were taken into account where it will affect the spray characteristic.

The increased of percentage of RBDPO will increased the Sauter Mean Diameter and penetration of particle. Besides, when density increased, SMD will increase too. The effect is similar for surface tension and viscosity. SMD will increase when the surface tension and viscosity are increased. These results are similar to the findings of Allen and Watts (2000).

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