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Study of Droplet Size for Palm Bio-Fuel Blends

[1,2]M.S.A. Ishak, [2]Mohammad Nazri Mohd Jaafar and [2]C. Ze Dar

[1]School of Manufacturing Engineering, Universiti Malaysia Perlis, PO Box 77, Pejabat Pos Besar,01000 Kangar, Perlis, Malaysia.
[2]Department of Aeronautical Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

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ABSTRACT

The type of fuel atomizer chosen for this study is the pressure swirl atomizer. This type of atomizer can create a swirling motion imparted to the fuel, leading it under the action of centrifugal force and spreading the fuel in hollow cone after the fuel leaves the orifice. The reason for choosing this type of injector is because it was widely used in gas turbine and liquid propellant rocket. The fuel to be tested is the Refined Blenched Deodorized Palm Oil (RBDPO) based biofuel. The injector was simulated using CFD simulation software, Fluent to predict the behavior of an evaporating fuel spray and also the angle of spray. The Sauter Mean Diameter (SMD) and the spray cone angle are evaluated and compared with the empirical equation result. Besides that the SMD also measured with a laser scattering system to compare with the theoretically method result.

Keywords: Fuel injector; Pressure swirl atomizer; Computational Fluid Dynamics simulation; spray test

INTRODUCTION

All of the fuels employed in gas turbine must be atomized first before injected into the combustion zone. Atomization is a process which converts the liquid into multiplicity of small drops. This can be achieved by producing a high ratio surface to mass in liquid phase to maximize the evaporation rate. Besides, atomization can also be accomplished by injecting the high velocity liquid fuel into a relatively low velocity air or stream as used in pressure atomizer and rotary atomizer, which eject the liquid at high velocity from the periphery of a rotating cup or disc. Another method is to expose the relatively slow moving liquid to a high velocity airstream as used in twin-fluid, air assist, or airblast atomizer. The parameters that usually are used to measure the quality of spray include mean diameter, patternation, cone angle and dispersion. The mean diameter is used to calculate the evaporation rate and to compare the atomization qualities of various sprays. Generally the Sauter mean diameter (SMD) is one which is widely used. Form the definition the SMD is the diameter of the drop having the same volume/surface ratio as the entire spray [1,2].

When decreasing the length to diameter ratio of the final nozzle orifice, the mean droplet size also reduces. The reduction in mean droplet size will increase the length to diameter ratio of swirl chamber caused by elimination of flow striations due to finite number of swirl ports. Mean drop size will increase if the length to diameter ratio for swirl chamber is increase [3]. Meanwhile the mean drop size is reduced when the spray cone angle is increased. The variation of mean drop size and droplet distribution with axial distance in a spray generated by pressure swirl atomizer can be show in function of ambient air pressure and velocity, liquid injection pressure, and initial mean drop size and distribution [4,5]. In this analysis the spray charateristics can be determine and compare in simulation and experiment.

Methodology:

Design Consideration and Spray Prediction:

The following data is acquired after obtaining the properties (surface tension, density and viscosity), working condition, the discharging

Corresponding Author: M.S.A. Ishak, School of Manufacturing Engineering, Universiti Malaysia Perlis, PO Box 77, Pejabat Pos Besar, 01000 Kangar, Perlis, Malaysia.
Tel: 60-9885035; Fax: 60-9885034; E-mail: mshaiful@unimap.edu.my

ambient characteristics (ambient pressure and density) and liquid injection condition (refer Figure 1).

First, the mass flow rate is calculated using equation (1) [6]:

$$\eta = \frac{power\ output}{\dot{m}_L\ x\ cv} \quad (1)$$

Where *cv* is Calorific value for the fuel used and η is efficiency of turbine. Then the diameter is obtained from equation (2) [6].

$$\dot{m}_L = C_d \sqrt{2\rho_f \Delta P}\,\frac{\pi D_n^2}{4} \quad (2)$$

The ratio L_s/D_s should be reduced in order to minimize the wall friction loss. However, a limiting value is needed to achieve liquid flow stability and formation of a uniform sheet vortex. The ratio is higher than 0.5 and a typical value recommended for the proper design is 1.0.

The parameter L_o/D_o should also be reduced to minimize friction losses in the atomizer exit. Furthermore, the ratio L_p/D_p should be smaller than 1.3 because a short tangential inlet passage channel may generate a diffuse discharge leading to an unstable spray [7]. Nevertheless the range for ratio A_p/D_sD_o and D_s/D_o is recommended from 0.19 to 1.21 and 1.41-8.13 [6].

Finally the spray angle is calculated by equations (3) and (4) and the Sauter Mean Diameter (*SMD*) is calculated from equation (5).

$$\theta = 6\left(\frac{A_p}{D_o D_s}\right)^{-0.15}\left(\frac{\Delta P \rho L D_o^{\ 2}}{\mu L^2}\right)^{0.11} \quad (3)$$

$$\theta = 9.75\left(\frac{A_p}{D_o D_s}\right)^{-0.237}\left(\frac{\Delta P D_o^{\ 2} \rho L}{\mu L^2}\right)^{0.067} \quad (4)$$

$$SMD = 2.25\frac{(\sigma\mu\rho)^{0.25}}{\sqrt{P}}1.225^{0.25} \quad (5)$$

The final diameter that will be use is 1.5mm with a pressure of 8bar and mass flow rate of 0.006kg/s. The others parameter likes L_s/D_s, L_o/D_o, $A_p/(D_sD_o)$ and D_s/D_o is set to be 1.0, 1.1, 1.2 and 1.3 respectively, the biofuel properties which will be used are listed in Table 1.

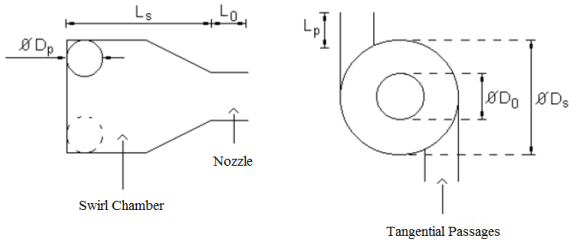


Fig. 1: Schematic diagram of pressure –swirl atomizer [9].

Table 1: Properties Biofuel (RBDPO Based).

Properties	diesel	B5	B10	B15	B20	RBDPO
Surface tension (mN/m)	30	30.5	30.67	30.3	30.5	34.83
Density (kg/m3)	828.7	832.2	836.1	838.9	842.0	901.2
Viscosity at 40 ^{0}C (cSt)	3.8677	4.5199	5.0717	5.5941	5.98153	39.0836
Viscosity at 100 ^{0}C (cSt)	1.5271	1.6838	1.8359	1.9855	2.1048	8.2299

Experimental Setup:

The method which will be used to measure the spray characteristic of the biofuel is using the Dual PDA laser scattering machine. The Dual PDA uses the concept of reflection and refraction of light theory based on Beam Gaussian effect and also the slit effect theory to operate. This machine uses argon-ion laser to produce 6 laser beam and the fiber PDA will receive the reflected laser beam after the beams have been reflected by the biofuel particle. When there is a particle pass through the intersection volume of the 6 laser beams then the fiber PDA will receive signal and send to the computer. Through the signal received, the axial velocity, radial velocity and the diameter of the specific particle will be known. Besides that, the 3D traverse system will also be used to improve the measurement in variable location of the spray. This system can help the investigators to get more understanding on the particle distribution by plotting the 3D histogram on the computer [8].

Results And Discussion

The following figures and tables are the simulations result of spray characteristics for diesel and biofuel blends using FLUENT software.

Figure 2 shows the half spay angle for the diesel, B2, B5 and also B10. The result of spray angle shows that when the fuel is changing from diesel, B2, B5 and B10, the angle will decrease. However the decreasing is very small that is about 1 to 2 degree and this is due to increase in density, viscosity and surface tension of fuel. The above phenomena are considered acceptable and normal. Thus it can be concluded that when the density,

viscosity and surface tension of the fuel increase it will cause decrease in spray angle. From the comparison of the spray angle between empirical equation and simulation, it shows a small different in the value with 1-2 degree. This small differ is considered very small and negligible. So it can be concluded both methods can be used to measure the spray angle effectively.

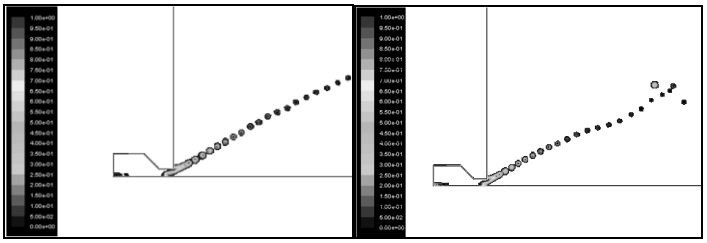
Figure 3a is the distribution of the SMD located around the combustor. From Table 3 of SMD obtained, the results show a hollow cone spray and the SMD obtained are decreasing in an acceptable amount that are in range of 99.90 μm to 120.12 μm. From the data it shows that when the pressure supply to the fuel increases, the SMD of the same fuel decreases. Meanwhile, the SMD shows an increasing value when the percentage of RBDPO added inside the diesel is increased. This is because the surface tension, density and surface tension of the biofuel increases when the percentage of RBDPO inside the diesel increases.

Table 2: Result of SMD and half spray angle from empirical equation.

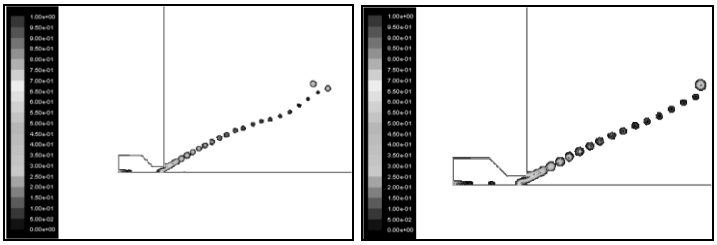
Fuel	SMD Le(μm)	Half Spray Angle $\theta_{Benjamin}$
Diesel	67.84	32.42
B2	69.94	31.97
B5	70.66	31.87
B10	74.18	31.13

Table 3 SMD of Biofuel and Diesel at Various Pressures (3D method)

Types of fuel	SMD at 7 bar (μm)	SMD at 8 bar (μm)	SMD at 9 bar (μm)
Diesel	100.25	100.20	99.90
B2	103.28	102.10	101.91
B5	107.60	104.93	104.47
B10	112.28	109.22	108.24
B15	116.22	113.80	111.30
B20	120.12	117..87	115.44



a) Diesel (32 degree) B2 (31 degree)



b) B5 (31 degree) B10 (30 degree)

Fig. 3: Half spray angle for different types of biofuel.

Table 4: SMD of Biofuel and Diesel at Various Pressures (2D method).

Types of fuel	SMD at 7 bar (μm)	SMD at 8 bar (μm)	SMD at 9 bar (μm)
Diesel	133.16	127.74	118.72
B2	137.92	130.28	120.62
B5	138.25	130.40	120.83
B10	138.77	131.46	123.13
B15	139.92	132.08	123.80
B20	140.35	133.65	124.84

Figure 3b is obtained from the 2D discrete phase model simulation. The figure shows the spray of diesel in hollow cone shape and the SMD obtained falls in range118-140μm. The figure shows the same phenomena as 3D model that is when pressure increase, the SMD of the same fuel show an increase in SMD meanwhile the SMD also show increase in value when the changing the fuel from diesel to B20. When changing the fuel from diesel to B20, the density, surface tension, and viscosity of the fuel are increasing.

The difference in data occur between the FLUENT data and the empirical equations data may due to FLUENT take in to consideration of effect of

diameter size of nozzle, temperature and others physical properties such as boiling point, thermal conductivity and the specific heat of the fuel meanwhile the empirical equation states that SMD of the fuel only depend on viscosity, density and surface tension. Tables 3 and 4 show that the SMD of biofuel increases when the percentages of RBDPO added into diesel increases. Furthermore it also shown that when pressure increase in the fuel supply, the SMD will reduce due to high energy to make the evaporation more effectively [8].

The experimental method started with measuring 25 point inside the spray volume. At every point the laser scattering machine will measure 100 sample of diameter. Then a mean diameter will be display in the BSA software for every point measured. After obtaining the mean diameter at all he point, a histogram will be plotted to estimate the most frequently appeared diameter that measured. The biofuel which has been used for the experimental testing are the B5 and B15 and the histogram is plotted in Figures 4 and Figure 5.

Figures 5 and 6 show the histograms of SMD for biofuel of B5 and B15. Respectively, from the observation, the SMD for B5 is in the range of 74-77 µm meanwhile for B15, the SMD is in range of 76-80 µm. The values of SMD for both biofuel blends are almost the same as empirical results.

Besides that, the SMD of B15 is larger than B5. This is reasonable and is due to the density, surface tension and viscosity of B15 is larger than B5. As the result of that, the SMD for denser fuel is larger.

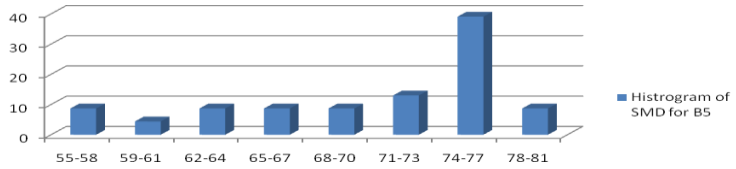


Fig. 4: Histogram of SMD for B5.

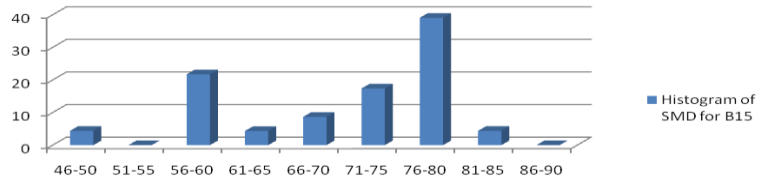


Fig. 5: Histogram of SMD for B15.

Conclusion:

The empirical and CFD results show almost the same result for the spray half angle which only differs by 1 degree. The small difference shows that the equation used to check half spray angle of the injector is reliable because it give the same results as the simulation. However, in case to find the Sauter Mean diameter of the spray, the mean diameter from simulation result was larger than the empirical equation result. The simulation shows that the mean diameter is always larger than the empirical equation and the difference is almost 1 times larger for 2D model. For the comparison of 2D model and 3D model in finding the SMD, it shows that the 2D model always give a result of 20µm larger than 3D. This occurs because of the 2D model is only simulated the spray on one plane meanwhile 3D model simulated the spray in multi planes. In the Dual PDA measurement, it shows the frequent mean diameter for the B5 and B15 are 74-77 µm and 76-80µm. Besides that the used of traverse system had also help to improve the spray measurement by allowing the user to measure the particle at the location that wanted. Besides that the BSA software can help the user to understand the particles distribution by plotting a histogram so that the distribution of mean diameter can be showed.

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Authors' Contribution:

M. S. Ishak and M. N. M. Jaafar developed the idea and had an important role in the result and material section. C. Ze Dar performed the numerical analysis using FLUENT package software.

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