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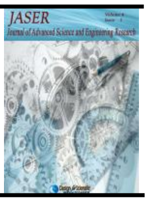

Investigation of Various Biodiesel Blend Spray Characteristics in Microturbine

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ABSTRACT

Due to the depletion of the crude oil and hazardous emission issues, biodiesel is the most suitable alternative fuel to replace fossil fuel. Application of biodiesel in power generation is still in the early stage and most of the research is focused on the transportation usage. This research aims to study the biodiesel fuel spray characteristic to gauge the technical feasibility of using biodiesel in a microturbine. Moreover, performance and emission characteristics of compression ignition engines depend strongly on inner nozzle and spray behavior. The same concept will be used for this research whereby it will be applied for power generation. Among the numerous alternative fuels, biodiesel can achieve high combustion efficiency and less emission because biodiesel has higher oxygen content and this completes the combustion process. Moreover, chemical fuel properties of biodiesel will affect the spray structure such as spray pattern, spary length, spray angle and sauter mean diameter (SMD). Composition of the chemical fuel properties depends on the blending ratio of diesel and biodiesel blend content, which produces different amount of density, viscosity and surface tension. Modelling of the atomizer will be presented using Computational Fluids Dynamics tools to present the analysis of SMD and spray pattern. Comparison will be made with respect to the experimental results carried out in the atomizer test rig. It can be said that the higher content of biodiesel gives a larger droplet size and longer spray length. However it produce smaller spray angle and spray width but with clearer vortex shape of spray pattern.

Keywords: Adsorption, Basic dye, Effective factors, ANOVA

1. Introduction

Depletion of crude oil and environmental concerns has triggered researchers to find alternative fuel to replace fossil fuel and reduce dependence on fossil fuel. The effect of global warming is largely felt due to the green house gas emission and power producing plants contribute a major involvement in this aspect. Replacing fossil fuel with renewable energy is one of the main solutions. Biodiesel is a renewable, biodegradable and oxygenous fuel with almost similar physical and chemical characteristic to diesel (Yuan et al., 2009). Biodiesel are ethylic or methyl esters of acids with long chain derived from vegetable oils and animal fats through a thermochemical process involving the transesterification process (Gerardo et al. 2011). In addition, biodiesel being an oxygenated fuel whereby it is environmentally cleaner than diesel with respect to unburnt hydrocarbon (UHC) and particulate matter (PM) emissions (Som et al. 2010). The success of biodiesel is proven as can be seen in its use as a secondary fuel for vehicle in Europe and followed by other developed countries. The reason for using biodiesel, is that it can increase engine performance and produces low emission compared with conventional diesel fuel [2,5,6,17]. Biodiesel can be obtained from various sources such as palm oil (Hashimoto et al., 2008) rapessed oil (Cavarzere et al., 2012a; Cavarzere et al., 2012b), soybean oil (Park et al., 2009a), vegetable oil (Prussi et al., 2012; Chiaramonti et al., 2013), waste cooking oil (Prafulla et al., 2010; Anh and Tan, 2008), oleaginous microorganisms (Xin et al., 2009) and sunflower seed oil (Cavarzere et al., 2012a; Cavarzere et al., 2012b). An important effect that has to be taken into consideration is the fuel spray atomizer whereby it is the contributing factor that will affect the efficiency and performance. Therefore, various biodiesel and diesel blend, are conducted experimentally in a fuel spray atomizer to study the spray angle, spray pattern, spray length and SMD. This will be compared with simulation results by modelling the geometry of spray atomizer and simulating using CFD software. Furthermore, various biodiesel blended fuel derived from waste cooking oil are produced through the method of Transesterification. ASTM standards are used to identify and verify physical and chemical properties such as viscosity, density, flash point, and cetane number of the biodiesel produced.

2. RESEARCH METHODOLOGY

2.1 Fuel Properties and Atomization Test Rig

Transesterification of palm oil was conducted to produce biodiesel fuel. Five sample test fuel ranging from B20, B50, B80, B100 and D100 were obtained. Furthermore, to ensure the quality of biodiesel produced meet the minimum requirement of international standards, all five types of the blended fuel were tested to meet the requirement of ASTM D2880, Standard Specification for Gas Turbine Fuel Oil and ASTM D6751, Specification for Biodiesel Fuel Blend Stock for Distillate. Table 1 shows the main fuel properties that will affect the atomization spray. The atomization test rig consists of control panel, test rig, digital camera, compressor, pressure tank, solenoid valve and spray gun. Figure 1 show the schematic diagram of the atomization test rig

Table 1: Chemical properties of biodiesel blend

Test	Methods	Diesel	B20	B50	B80	B100
Flash Point (°C)	ASTM D93	66	76	86	110	175
Water & Sediment (%vol)	ASTM D2709	_	0.005	0.02	0.04	_
Density (Kg/m^3)	ASTM D4052	842	852.9	860.6	869.2	8749
Kinematic Viscosity @ (mm^2/s)	ASTM D445	4.431	3.709	3.951	4.273	4.547
Sodium & Potassium (mg/kg)	EN 14538	_	<5	<5	<5	_
Carbon Residue(%wt)	ASTM D4530	_	0.01	0.01	0.01	0.02
Gross Calorific Value (MJ/kg)	ASTM D5865	_	44.172	42.732	41.034	_
Ultimate Analysis: Carbon Hydrogen Nitrogen (%wt)	ASTM D5291	_	84.4 13.1 <1	82.3 13.5 <1	78.1 12.4 <1	_

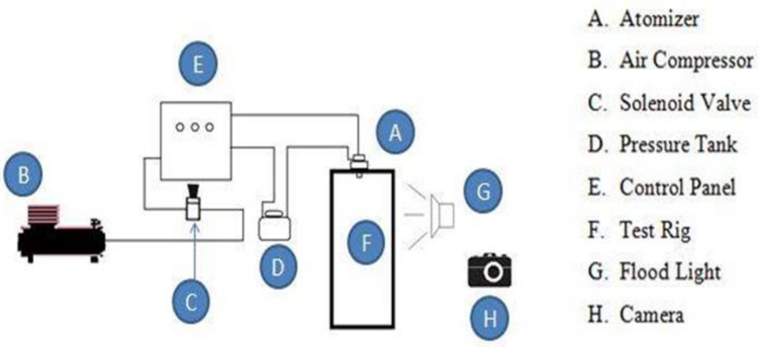

Figure 1: Schematic diagram of the test rig

2.2 Fuel atomizer

A fuel atomizer is used for the sole purpose of performing fuel atomization. Atomization is a process where liquid fuel is forced through a small opening or nozzle under high pressure. Atomization is the breakup of bulk liquid jets into small droplets using an atomizer (Ejim et al., 2007). This high pressure will force the liquid fuel and produce visible spray pattern that is needed for this research. There are four main inlets on the fuel atomizer mainly being cylinder air, liquid, fan air and atomizing air. All these inlets are responsible in producing the desired fuel spray pattern by changing any one of the inlet pressure. This will affect not only the dispersion spray pattern but also the droplet size. The connection for cylinder air, fan air and atomizing air comes directly from the control panel into the atomizer. On the other hand, the liquid inlet on the atomizer comes directly from the pressure tank that contains pressurized liquid fuel. Proper atomization is an important factor for the engine efficiency and emissions in order to have a complete combustion and enhances the mixing in a direct injection (DI) engine. Fuel spray atomization is important because it has close relationship to the pollutant emissions and also the efficiency of the engine (Zhu & Zhang, 2010; Park et al., 2006). There are various type of spray nozzle and different pattern of spray. The common spray pattern is hollow cone, full cone, flat spray and others. Thus, spray pattern depends on of the type of nozzle whereby each type of nozzle consists different shaped orifice. The SMD will be dependent on the nozzle type and will vary significantly from one type to another. Furthermore, there is several other factors that will affect the SMD, spray angle and spray pattern such as fuel properties. Density, viscosity and surface tension are major factors in the fuel properties that will give an impact in the atomization processes (Kippax et al., 2010). Nowadays, there are several type of nozzle had been used in industrial such as hollow cone nozzle, full cone nozzle, flat spray nozzle, hydraulic atomizing nozzle and two-fluid and air assisted nozzle.

3. Results And Discussion

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads- the template will do that for you.

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

3.1 Sauter Mean Diameter(SMD)

Sauter mean diameter is caused by aerodynamic force waves on the liquid surface and consequently produce unstable ligaments that eventually disintegerate into droplets on any increase in the relative velocity (Semião et al., 1996). It is the diameter of a sphere that has the same volume/surface area ratio as a particle of interest. Therefore, the specific equipment that can capture or measure the size of the sauter mean diameter accurately is the phase doppler particle anylzer (PDPA) system (Chang et al., 2002). Furthermore, other several factors that will affect the SMD are chemical properties, pressure, nozzle design, operating condition and ambient pressure. Critical properties like density, viscosity and surface tension are the chemical properties that will affect the droplet size. The SMD value is calculated using equation 1 (Ejim et al., 2007).

$$SMD = 2.25\, \sigma^{0.25}\, \mu_L^{0.25}\, m_L^{0.25}\, \Delta P_L^{-0.5}\, \rho_A^{-0.25} \qquad (1)$$

Where;
σ = fuel surface tension (N/m)
μ_L = fuel viscosity (m^2 /s)
m_L = fuel mass flow rate
ρ_A = air density
ΔP_L = liquid fuel injection pressure differential

Figure 2 shows SMD for all the five types of sample fuel. From that figure, it can be seen that B100 has the largest SMD, followed by B80, B50, B20 and D100

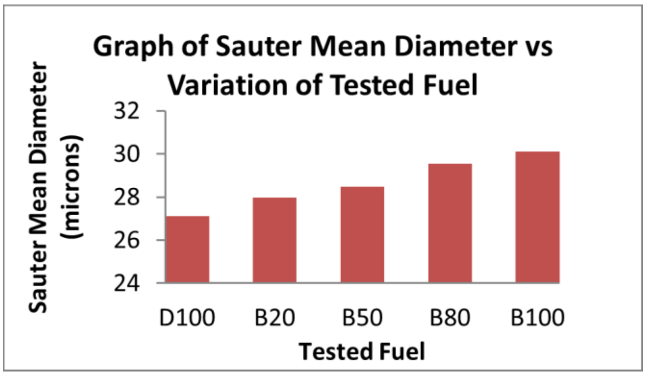

Figure 2: Result of Sauter Mean Diamater (SMD) for various fuel blends

This shows the relation between the chemical properties and spray atomizer because density can cause a fluid to resist acceleration. Meanwhile, viscosity causes the fluids to resist agitation, tending to prevent its breakup and leading to a larger average droplet size. Therefore, the higher density and viscosity the larger SMD of fuel. In addition, higher injection pressure in the spray system will generate higher actuation velocity of the fuel particles and produce smaller droplet size from the nozzle orifice (Kippax et al., 2010). Furthermore, higher injection pressure leads to an increase in the ambient gas density and aerodynamics interactions and so the breakup time occur earlier and thus decreasing the SMD of the fuel. Thus the injection pressure also affects the spray atomizer and all tested fuel resulted smaller SMD when higher injection pressure is applied during atomization process.

3.2 Spray Cone Angle, Spray Tip Penetration and SprayPattern

Spray cone angle, spray tip penetration and spray pattern are important atomization characteristics that have to be determined through this research for atomization analysis. The spray pattern was captured using DSLR camera and the analysis of the spray cone angle is determined. Spray cone angle is defined as angle formed by the cone of liquid leaving a nozzle orifice where two straight lines wrapped with the maximum outer side of the spray (Park et al., 2009). Chemical properties such as density, viscosity and surface tension will affect spray angle, then different blend gives different values of chemical properties. Table 1 shows biodiesel contains the highest value of density and viscosity. Hence, spray angle will decrease irregularly as the biodiesel fraction increase but inversely with surface tension (Zhu & Zhang, 2010). When surface tension is low, spray droplet are prone to quicker break up and wider dispersion and cause a relatively larger spray droplet [Park et al., 2009b; Park et al., 2009a). It is proven as shown in Figure 3 whereby spray angle of B100 is

30.24º and B20 is 38.68º. Hence B100 is smaller than B20. As the blending ratio of biodiesel increases, the spray cone angle decreases. This can be due to the higher density of biodiesel compared to diesel. Another physical characteristic that affects spray cone angle is the viscosity of the liquid fuel (David et al., 2012). At a lower ambient pressure compared to atomization pressure, the spray cone angle produced is also smaller (Yuan et al., 2009)

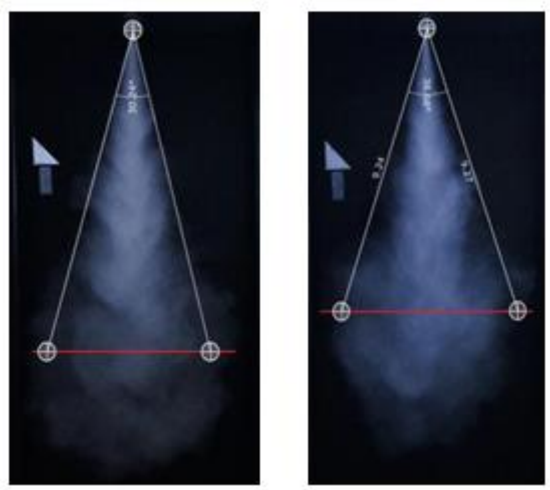

Figure 3: Spray angle of B100 (left) and B20 (right) at 0.4MPa.

Furthermore, higher injection pressure will increase spray angle during atomization process (Suryawanshi and Desphande, 2010). Increase in injection pressure will increase the flow rate through the nozzle orifice which will then increase the SMD of the fuel and facilitate evaporation. Thus, this will result in a larger spray angle (larger dispersion size) and a signification increase of spray coverage. Meanwhile, spray tip penetration (spray width and spray length) is another important factor that will be affected when tested with all five samples of fuel. Figure 4 shows the sample picture of spray tip penetration whereby B100 produce the longer spray penetration compared with B20 thus, fuel properties are also affecting the spray tip penetration. The higher content of biodiesel the longer spray tip penetration. The spray tip penetration is defined by the maximum distance from the nozzle tip reached by the injected spray (Park et al., 2009a). Spray tip penetration can also be measured by selecting a threshold value for intensity and determining a spray boundary (Wang et al., 2010). There are three main parameters in spray tip measurements which are spray length, spray width and spray pattern. Spray tip penetration is significant atomization characteristic which is used to determine the size or area of the atomization. Moreover, spray length is also defined as the measurement of travel distance of the liquid fuel when it initiates the first spray from the nozzle orifice, whereas spray width is the atomization parameter investigating area of dispersion of the spray (Tan & Zulhairi, 2012). Since the spray is dispersed to the surrounding, factors that can affect the spray tip penetration include the surrounding air velocity and also ambient pressure. For instance, fast movement of air surrounding the dispersion of spray will cause movement of spray penetration and unable to reach its maximum tip penetration. The same goes to ambient pressure where higher surrounding pressure will cause the spray leaving the nozzle to disperse in a shorter spray tip penetration. With increment in pressure of air, this will also increase density of air and affects the spray tip penetration as well

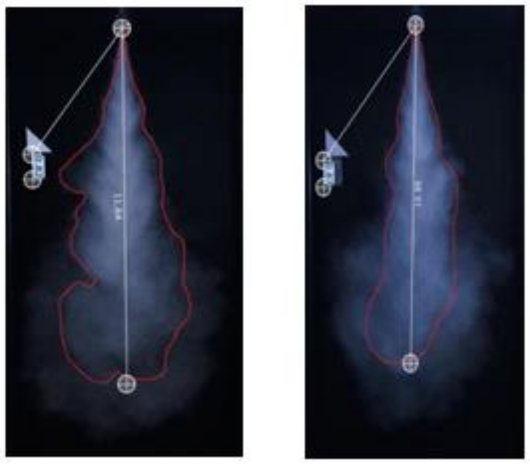

Figure 4: Spray tip penetration of B100 (left) and B20 (right) at 0.4MPa.

Furthermore, spray length and spray width are affected when higher content of biodiesel in each fuel exist because it will produce longest spray length. Meanwhile, spray width is defined as the maximum radial distance of the bottom view (Park et al,., 2009b). Quality of the atomization can be increased by increasing the surface area, this usually happens when higher viscosity of fuel develops a longer potential core and larger spray area. Otherwise, higher injection pressure will produce larger spray width (Wang et al., 2010) but higher fraction of biodiesel will produce smaller spray width. As time of atomization elapsed further, the spray width was also shown to be larger. Spray width is closely related with spray cone angle as larger spray cone angle will produce larger spray width. The same results were seen in experimental test whereby B100 shows the smallest spray width compared with B80 which larger spray width as shown in Figure 5.

Spray pattern is used to describe and characteristic types and quality of spray such as spray shape, colour intensity of spray and others. It is explained more clearly (Park et al. 2009a), that the vortex shape of biodiesel fuel with high viscosity is clearer than diesel fuel because the breakup frequency of biodiesel fuel is low. Otherwise, higher injection pressure will give better quality of spray due to mass flow rate increase and the increase of the diameter of fuel core will cause a smaller droplet within the upper canopy near to the nozzle orifice. In addition, fuel properties is the most important factor that will affect the spray pattern whereby higher ratio of the B100 (increase of viscosity and density) will results in a larger droplet size and will cause clearer spray pattern compared to diesel. Furthermore, ambient pressure play a role as an external pressure that affect the spray characteristic because high ambient temperature tends to form a more volatile fuel (lower viscosity, specific gravity and surface tension). It will decrease SMD and spray length of fuel at constant atomization viscosity and density of the fuel can affect the initial spray velocity. Therefore, internal factor such as fuel properties, biodiesel blend and others, and external factor such as ambient pressure ambient pressure and others have to be taken into consideration.

Figure 5: Spray width of B100 (left) and B80 (right).

3.3 CFD Simulation

CFD Fluent is a powerful tool to simulate of different type of geometry and situation. In advance, setting of simulation is the most important part that have to be focused to obtain good results. Experiment result will be compared with simulation results in terms of spray angle and spray pattern for all five types of fuel. In addition, experiment results are mainly photographs of the spray angle and spray pattern but in CFD simulation, the results of SMD, spray angle and spray pattern are measured directly from simulation.

The CFD model of the spray region created will only be 1/12 of the spray region. This means on 30 degree of the spray region will be created. The reason behind partial creation of the spray region as the CFD model is because the spray region option uses the periodicity function in Fluent software to stitch the CFD model of 30 degree spray region to be 360 degree full CFD model spray region. The construction of the CFD model in Gambit software is to create the spray region CFD model and insert meshes to the CFD model. Geometry of the spray was modelled whereas boundary condition and meshing was conducted in Gambit

Meanwhile, Gambit file will be exported to Fluent for simulation and injection model used in Fluent is the surface injection and the breakup model used is k-Epsilon model. The computations were limited to only the spray nozzle to reduce converge time. All the five types of fuel were simulated in Fluent and SMD obtained from the summary of simulation. Results show diesel fuel as the smallest value of SMD compared with the other five types of fuel. Meanwhile, percentage error is quite high due some differences in the experiment and simulation tools. Firstly, the process of transesterification was conducted with low quality raw material. This attributes to a poor quality of the fuel chemical properties. Secondly, the geometry modelling was done in Gambit based on assumptions of the nozzle diameter inlet. These reasons could attribute to the higher percentage differences between the experimental and simulation results. Another comparison that had been made is spray angle and it is obtained directly from CFD as shown in Figure 6. Moreover, the results shown does not differ much and pattern of spray still maintain similar to the experiment result whereby B100 is the smallest spray angle and diesel is the largest spray angle. Spay pattern had been compare with CFD simulation and experiment testing. It shows similar pattern for both results. Thus, spray angle can be seen from spray pattern which shows that it is smaller from DF100, B20, B50, B80 and B100. All five types of fuel compared with CFD simulation and experiment testing are shown in Figure 7

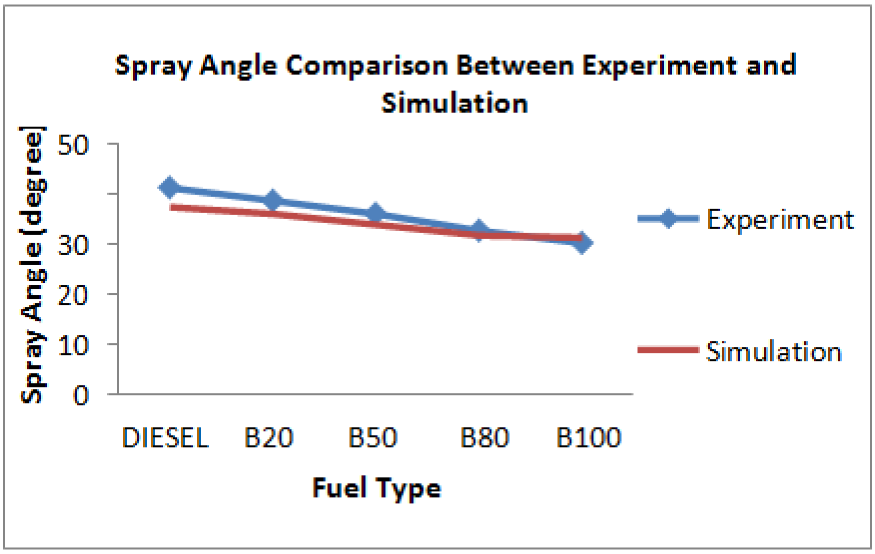

Figure 6: Comparison between the experiment result and CFD simulation result

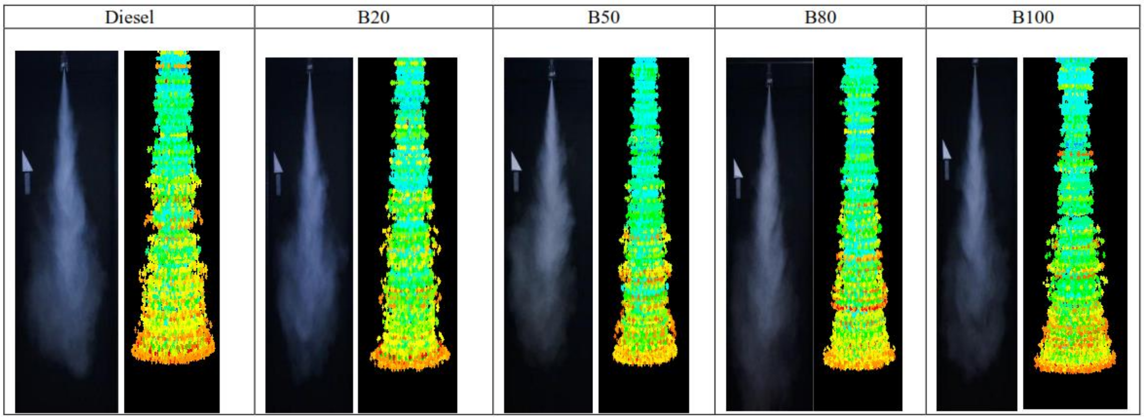

Figure 7: Spray pattern comparison between experiment and simulation

4. Conclusion

There are three parameter that had been determined from experimental and CFD simulation analysis which are spray angle, spray width and sauter mean diameter (SMD). Each parameter affects the various blend of fuel, injection pressure and others. High density, high viscosity and surface tension occurs when higher ratio of biodiesel is blended whereby this will result in a larger SMD and longer spray length but smaller spray angle and spray width with clearer vortex shape of pattern. SMD obtained through numerical computation of SMD formula are based on chemical fuel properties. Another factor that will result in larger spray angle and spray width is higher injection pressure because it tends to break up fuel particle into smaller size. The most optimum fuel for use in mocroturbine is B20 whereby it contains the suitable chemical fuel properties that does not contain viscosity that is too high until it affects the engine performance and B20 has a good combustion process completion due to its effective atomization characteristics, thus is suggested that this blend is to be used for microturbine.

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