Study on Atomization Characteristics for Power Generation Application

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Abstract: The world is dependent on two common basic needs which is electricity and water supply. Thus, power generation is the pulse of a country’s economy. However, most of today’s power is generated from fossil fuel which is non-sustainable. This research aims to study the feasibility of biodiesel to substitute diesel fuel for gas turbine application. The objective is to investigate the atomization characteristics using various blend of biodiesel derived from transesterification of palm oil. There are five types of fuels tested which are pure Diesel, B20, B50, B80 and B100 which were experimentally tested in a spray atomizer to evaluate the relationship of the of the fuel blend ratio with atomization characteristics such as spray cone angle, spray tip penetration and Sauter Mean Diameter. Besides that, fuel chemical properties testing were conducted to ensure the fuel chemical properties for tested fuel meet the standard requirements for gas turbine fuel oil. Result shows that the higher blend of biodiesel will give larger SMD, longer spray tip penetration, and a smaller spray cone angle. The SMD was calculated based on a general equation. Meanwhile, spray angle and spray tip was obtained from photos captured and anlayzed using software.

1. Introduction
Power generation depend on fossil fuel to generate electricity from coal, natural gas, diesel and other sources. There are various types of turbine technology used in power generation. Diesel is typically used as a secondary backup fuel for gas turbine as its harmful emission can affect the environment. Thus this study proposes to solve this problem by substituting diesel with biodiesel in a gas turbine. Moreover, biodiesel was successfully used in diesel engine and proved that it can reduce the environmental pollution such as unburnt hydrocarbon (UHC) and particulate matter (PM) emissions [1,3]. Biodiesel influences the performance and emission of the diesel engine. Hence the various blends of biodiesel and diesel were tested in experimental test rig. Biodiesel gives a good impact in environment and performance of the diesel engine [4,5]. In addition, biodiesel is a renewable and sustainbale fuel that is able to handle the depleting of fossil fuel because biodiesel can be derived from various types of sources for the production of biodiesel such as waste cooking oil, vegetable oil, sunflower seed oil and animal fats. The production of biodiesel involves the transesterification process [2]. Palm oil is the most suitable source to generate biodiesel because it has a higher yield and it is one of the most economical oil compared to other vegetable oils. Moreover, palm oil is local resource in Malaysia, so the cost will be reduced and the use of palm oil can boost the economic trasformations of the country. Besides that, palm oil can help to absorb carbon dioxide to reduce greenhouse gas. Therefore, the investigation of atomization characteristic is the main objective of this research because it will affect the performance of gas turbine. The feasibility of using biodiesel in power generation will be evaluated and discussed through experimental investigations in a fuel spray test rig. Spray angle, spray pattern and Sauter Mean Diameter (SMD) are some of the atomization characteristics that will be studied for various types of fuel blends. Five types of fuel will be tested which are diesel, B20, B50, B80 and B100.
2. Research Methodology

Palm oil was used as the raw material to process the biodiesel. Biodiesel was generated from transesterification processes to produce B100 as a pure biodiesel. The subsequent fuel blends were mixed with diesel to generate B20, B50 and B80. Besides that, quality of the fuel will be tested to ensure the fuel meet the minimum requirement of the ASTM standards. The chemical properties of the fuel blends were tested as shown on Table 1. Besides that, the fuel chemical properties will affect the atomization spray because different blends of biodiesel and diesel fuel will contain different amount of fuel chemical properties. Meanwhile, the system of the experimental test rig consists of the control panel, experimental test rig, digital camera, air compressor, pressure tank, solenoid valve and spray gun atomizer. Figure 1 shows the schematic diagram of the atomization test rig. The atomizer will be placed on the top of the experimental test rig to spray the fuel droplets into the rig. Biodiesel fuel is filled inside the pressure tank and the air compressor compresses the air to inject the fuel through the spray gun atomizer. A digital camera is placed in front of the test rig to obtain photos of the fuel droplets and spray patterns. The injector pressure can be adjusted from control panel within the range of 0-5 bars. The experimental test rig is operated by pushing the switch button and then capturing the atomizer spray from the camera. Photos of the spray will be analysed using software to determine the atomization characteristic such as spray angle, spray width and spray length.

### Table 1: Important fuel characteristics of Biodiesel and its blend with Diesel.

| Fuel Blend | Mixture Viscosity \(\text{m}^2/\text{s}\) @ 40Celsius | Density \((\text{kg/m}^3)\) |
|------------|---------------------------------|-----------------|
| Diesel     | \(3.88 \times 10^{-6}\)           | 842             |
| B20        | \(3.71 \times 10^{-6}\)           | 852.9           |
| B50        | \(3.95 \times 10^{-6}\)           | 860.6           |
| B80        | \(4.27 \times 10^{-6}\)           | 869.2           |
| B100       | \(4.55 \times 10^{-6}\)           | 874.9           |

3. Results and Discussion

3.1 Sauter Mean Diameter (SMD)

Atomization characteristic consist of spray angle, spray length and Sauter Mean Diameter in which these are the parameters that will affect the performance and emission of the system. Besides that, to ensure the quality of the spray, the variable that has to be taken into consideration is the nozzle type, pressure and fuel properties. Atomization is the process of generating drop or also known as SMD. It begins by forcing liquid fluid through a nozzle or can be explained by aerodynamic force waves on the liquid surface and consequently produces unstable ligaments that eventually disintegrate into droplets on any increase in the relative velocity [6]. Moreover, process of atomization begins with the formation and growth of disturbance waves in the liquid followed by formation of liquid sheet into ligament and fragmentation. Final process is formation of droplets by the further breakup of fragments and it becomes droplets. Phase doppler particle analyser (PDPA) system [7] is one of the most accurate measuring device to measure the SMD. It operates using laser as a detector and measures the droplet size when it hits the laser beam. Due to the complexity of the research, other alternative option is taken to measure the SMD using equation that has to determine the fuel properties such as density, viscosity and surface tension "(1)"[4].
\[ \text{SMD} = 2.25 \sigma^{0.25} \mu_L^{0.25} m_L^{0.25} \Delta P_L^{-0.5} \rho_A^{0.25} \] (1)

where:
- \( \sigma \) = surface tension
- \( \mu_L \) = mixture viscosity
- \( m_L \) = fuel mass flow rate
- \( \rho_A \) = air density
- \( \Delta P_L \) = liquid fuel injection pressure differential

Figure 2 shows SMD for all the five types of sample fuels. From that figure, it can be seen that B100 has the largest SMD, followed by B80, B50, B20 and D100. It can be seen the trend of the graph is increasing. In addition, this happens because of the fuel chemical properties also affect the atomization characteristics and the higher blend of biodiesel the higher content of density and viscosity. The reason is density can cause a fluid to resist acceleration and viscosity cause the fluids to resist agitation that tending to prevent breakup and leading to larger average droplet size. Thus, the higher content of biodiesel fuels the larger SMD. Another variable that can affect the atomization characteristics is injection pressure whereby higher injection pressure will lead to smaller SMD during the conduct of the experimental testing. On the other hand, injection pressure can be explained through the generation of actuation velocity of the fuel particles which produces smaller droplet size [8].

3.2 Spray Cone Angle, Spray Tip Penetration and Spray Pattern

Basically, this research is to obtain the atomization characteristic that consists of spray cone angle, spray tip penetration and spray pattern. Previous studies proved that atomization characteristics has an impact on the performance and emission of the diesel engine. Thus the same concept is used for gas turbine and in the early stage of the research this atomization characteristic will be investigated for gas turbine. The atomizer spray is captured using DSLR camera for all five types of fuels. Furthermore, a photofit software is used to analyze the atomization characteristics such as spray cone angle and spray tip penetration. Spray cone angle is the angle formed by the cone of liquid leaving a nozzle orifice where two straight lines wrapped with the maximum outer side of the spray [10]. Results show that spray angle is also affected from the fuel chemical properties and injection pressure whereby spray angle decreased when biodiesel blend increase due to the fraction increase but inversely with surface tension because if the surface tension is low, spray droplet are prone to quicker break up and wider dispersion and cause a relatively larger spray droplet [10]. Besides that, higher injection pressure will increase spray angle because there are changes in the flow rate through the nozzle orifice. Hence, SMD will increase together with the spray angle and spray coverage. Spray tip penetration that consist of spray width and spray length were also analyzed for all five types of fuels. Spray tip penetration is to determine the size or area of the atomization whereas the length of the spray will be analyzed using the software imposed on the photo. Spray length is defined as the measurement of travel distance of the liquid fuel when it initiate the first spray from the nozzle orifice and spray width is the atomization parameter investigate area of dispersion of the spray [9]. Spray length will become longer when content of the biodiesel blend increase.
4. Conclusion
The atomization characteristics parameters were successfully obtained from the experiment testing. Spray angle, spray tip penetration and spray pattern was determined using software that analyses directly through photographic views captured by DSLR camera. Spotlight is used to get clearer and better image quality of the spray. Meanwhile, sauter mean diameter (SMD) was obtained from equation 1. It consists of fuel chemical properties details such as density, viscosity and surface tension which are required in the equation to enhance the accuracy of the result. There are various factor that effect atomization characteristic such as biodiesel and diesel blend ratio, injection pressure and environmental factor. The higher content of biodiesel blend resulted in larger SMD and longer spray length but spray angle shows a different result whereby it resulted in smaller spray angle. On the other hand, spray angle and spray width become larger when there is an increase in the injection pressure because it tends to break up fuels particle into smaller size. The suggested optimum biodiesel blend is B20 for atomization characteristics. Besides that this blend also have a good impact on the performance and emission. This research could be enhanced in the future by conducting the experiment during different ambient temperatures due to the rapid changes in local weather climate.

![Figure 3: Example of atomization characteristic for B100 (left) and Diesel (right)](image)

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