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Effect of Non-Edible Biodiesel Physical and Chemical Properties as Microturbine Fuel

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Abstract

The world is facing critical energy concern, in view of depleting fossil fuel reserves and increasing environment pollution. Biodiesel can potentially substitute fossil fuel, and is produced through the transesterification of vegetable oils. This paper will emphasize on the transition from first generation derived from waste cooking oil, to second generation biodiesel derived from calophyllum inophyllum, which is a non-edible plant. The objective of this paper is to optimize the performance of biodiesel blends with diesel in a 30 kW microturbine. The characterization of chemical fuel properties of distillate and biodiesel blends will be conducted to determine if it meets international standards for power generation. Temperature profiles, pressure, and flame imaging will be closely monitored to detect possible problems in operability of the combustor caused by the differences in fuel characteristics. The findings may provide useful information towards optimization of microturbine performance, considering the wide range of biodiesel feedstock that exist. The paper outcome will show the potential of non-edible biodiesel blends to be used as alternative fuel in microturbines for power generation.

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Keywords: "Biodiesel, Microturbine, physicochemical, Calophyllum Inophyllum"

1. Introduction

The dependence on fossil fuel for energy has caused major effects of global warming, particularly due to the greenhouse gas emission from power producing plants, which is a major source of fossil fuel consumption. There is a need to find a renewable and sustainable energy. Among many renewable energy sources, biodiesel is regarded as the most promising fuel because of its sustainability and availability of raw materials worldwide. However, the current biodiesel produced from edible plants, have become a controversial problem, where the food

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chain is compromised. Therefore, research is focused on the non-edible plants, particularly calophyllum inophyllum which is known to have a high yield. There is potential for biodiesel derived from the inedible plant of calophyllum inophyllum to be blended with diesel and used in power generation, particularly for microturbine. This application of biodiesel is a new research area that have not been previously explored. Biodiesel is derived from renewable sources such as plants; therefore the emission from the combustion of biodiesel blends will be able to produce less greenhouse gas emissions, particularly CO_2 gas. The combustion efficiency of the microturbine could be increased, as both these fuels are oxygenated fuels, in which they are able to aid the completion of combustion in the microturbine system [1]. Blending biodiesel and diesel could widen their field of applications as an alternative green fuel. A blend could allow for mixtures to be created with improved properties to enable matching of the blend to the requirements of the application, such as desired viscosity of a target minimum heating value [2]. The main advantages of these liquid biofuels when compared to raw (solid) biomass are its higher energy density and availability on demand, which makes it easier for storage and transportation.

Microturbine systems have many claimed advantages over traditional reciprocating engine generators, such as higher power-to-weight ratio, low emissions, and less moving parts. There is a need to undertake studies on the technical feasibility of calophyllum inophyllum biodiesel blends for microturbine power generation. Various fuel samples will be tested experimentally in a 30 kW microturbine to study the combustion characteristics such as temperature profiles, efficiency and emissions.

Nomenclature

ASTM	American Society of Testing Methods
HI	heat input
LHV	lower heating value
SH	sensible heat
W	work

2. Research Methodology

There is potential for biodiesel to be blended and used in power generation, particularly for microturbine. In order to mitigate these problems, creating blends of biodiesel with diesel could be a viable short-term alternative to utilize an important fraction of these fuels in microturbine. Biodiesel is a renewable fuel derived from vegetable oils and animal fats through a process called transesterification. However, biodiesel produced from edible oils raised concerns of feedstock competing with food supply, therefore, non-edible oils such as calophyllum innophyllum becomes a possible source. Blending biodiesel with diesel could widen their field of applications as an alternative green fuel. A blend could allow for mixtures to be created with improved properties to enable matching of the blend to the requirements of the application, such as desired viscosity of a target minimum heating value. The main advantages of these liquid biofuels when compared to raw (solid) biomass are its higher energy density and availability on demand, which makes it easier for storage and transportation. Although the most successful use of liquid biofuels has been proven in the transport sector, recently there has also been a growing interest in the industrial sector.

A potential market for this type of fuels is related to microturbine, which are becoming more popular due to characteristics such as small size, fuel flexibility, low maintenance costs and low emissions. Figure 1 shows the microturbine schematic diagram. A pump is placed on the fuel tank to channel the fuel into the combustion chamber. There is a mass flow meter attached to the fuel tanks to obtain data for the mass flow rate. The real-time data are available for the fuel flow, the combustion efficiency, the temperatures, the pressures, the high heating value or the calorific value, the combustion efficiency, the generated power output, the speed and the torque. These parameters are logged in via the data acquisition system. Microturbines are compact electricity generators with rated capacities in the 25–300 kW range and have become widespread in distributed power and combined heat and power (CHP) applications. Microturbine systems have many claimed advantages over traditional reciprocating engine generators, such as higher power-to-weight ratio, low emissions, and less moving parts. Research have shown that thermal efficiency and the combustion efficiency showed the peak values at 20% biodiesel blend with distillate, despite biodiesel having lower calorific value and higher fuel consumption [3]. Meanwhile, other researchers have reported that no apparent deterioration was observed in the use of biodiesel blends in a stationary diesel engine [4]. However, the injectors were found to have heavy carbon deposition and noticeably reduced opening pressure, which may lead to deteriorated engine performance and exhaust emissions in extended operation [5]. Thus, this paper intends to study the technical feasibility of biodiesel blends in microturbine application.

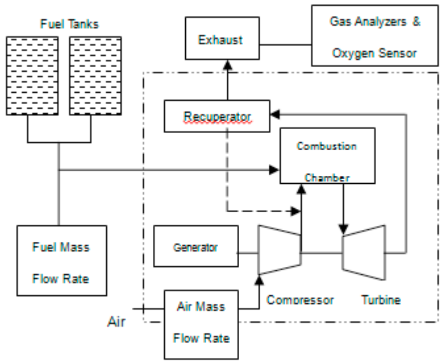

Fig. 1. Schematic diagram of the microturbine system.

Gas turbines are established in power generation with application in on-site generation, distributed power systems, oil and gas operations, and industrial processes. The possibilities of added arrangements such as steam cycles for combined cycle power plants, heat recovery boilers for combined heat and power systems have made gas turbines indispensable for large scale power generation, district heating and mechanical drive applications. Apart from the simple cycle, gas turbines could employ advanced cycles such as recuperated, reheat and intercooled cycles as well as utilise steam or water injection to improve work output, cycle efficiency and performance or drive emissions to reliable technical limits. These engines can be applied for peak, base or intermediate loads, especially when operating as multiple units [6]. Their advantages over reciprocating engines include: large amount of useful work from a relatively small size and weight engine, Capability for fuel flexibility (gas and distillate oil), compact size, relatively low capital and maintenance cost and fast starting and loading

3. Results and Discussion

The thermal efficiency is important to determine the performance outcome of the fuel on the microturbine test. Equation 1 and Equation 2 below are used to assess the thermal efficiency of the fuel used in the microturbine performance test [7].

$$\eta = \frac{W_{net}}{HI} \qquad (1) \qquad\qquad HI = Q_l \rho_l (LHV_p) + SH_p \qquad (2)$$

Where W_{net} = generator power
HI = Heat Input which is calculated using Equation (2).
Q_l = volumetric flow
ρ_l = density of the liquid fuel at operating temperature
LHV_p = lower heating value at constant pressure
SH_p = sensible heat at constant pressure

3.1. Chemical Properties Evaluation

Biodiesel fuel has its own standard to ensure the biodiesel product quality meet the certain standard that had to be followed such as American standard ASTM D6751 (American Society for Testing and Materials) and the Europe Standard, EN 14214. This standard describes the minimum requirement of biodiesel properties that can be applied to diesel engines. Biodiesel fuel will not have the same biodiesel properties values because it was not generated from the same feedstock due to every feedstock having different chemical composition that can influence the fuel properties. In addition, biodiesel fuel is really convenient to be brought forth from various feedstock. The properties of biodiesel are the chief factors that can influence the atomization characteristics of the biodiesel [8]. The atomization characteristics can be tempted by the density, surface tension, viscosity of the biodiesel and also there are few more significant attributes as expressed under:

- ***Cloud Point -*** The temperature at which oil starts to solidify is known as the cloud point. While operating an engine at temperatures below the oil cloud point, heating will be necessary in order to avoid waxing of the fuel.
- ***Pour Point -*** Pour point refers to the temperature at which the oil in solid form starts to melt or pour indicates the lowest temperature at which a fuel can be stored and still be capable of flowing under gravitational forces especially in the four season country.
- ***Flash Point -*** The flash point temperature of diesel fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source, whereas biodiesel fuel have a higher flash point than diesel fuel due to the reflection of the boiling points caused by the individual components. The purpose of having the flash point value is to indicate the maximum temperature at which a fuel oil can be stored and handled without serious fire hazard for safety purposes.
- ***Calorific Value -*** Calorific value is the amount of heating energy released by the combustion of a unit value of fuels.
- ***Cetane number -*** Cetane number is a relative measure of the interval between the beginning of injection and auto ignition of the fuel. Cetane number can be seen as the indicator of the fuel quality and combustion quality because the higher the cetane number the greater it is combustibility and higher cetane number also resulted the shorter ignition delay time. Su Han Park et al. [9] stated that exhaust emission shows an improvement of lower emission when the cetane number is high compared with diesel fuel showing the investigation of biodiesel fuel having a high cetane number due to the oxygen content in the biodiesel is greater than diesel fuel. This will cause the fuel to combust easily in the engine, especially in the diesel compression engine.
- ***Viscosity -*** Viscosity can be classified into dynamic and kinematic viscosity. The dynamic viscosity refers to the resistance of the fuel to move over another fluid or surface and the kinematic viscosity refers to the ratio of viscous forces to inertia. The dynamic viscosity is most applicable to liquid fuels performance because it determines the ability of a fuel to meet pumping requirement while kinematic viscosity determines the bulk conditions. Biodiesels are more viscous than conventional diesel fuels, although some biodiesel fuels are in close range with diesel fuels as shown in Table 1. Viscosity directly affects fuel flow rates, spray characteristics and atomizing properties of a fuel [10]. A highly viscous fuel reduces evaporation rate, induces poor fuel atomization, and also increases the specific fuel consumption of a fuel pump.

Table 1: Liquid Fuel Properties and Specifications

Fuel Properties	ASTMD2880	ASTMD6751	Typical Biodiesel
Density (kg/cm^3)	876	880	837-930
Kinematic Viscosity at 40°C (cSt)	1.3[5] – 2.4[6]	1.9-6.0	2.61-5.9
Calorific Value (MJ/kg)	42-46	-	33-42.73
Flash Point (°C)	38	100-170[7]	69-259
Water and Sediment (vol %)	0.05	0.05	<0.005-0.05
Sulphur (m/m %)	0.05	0.05	<0.005-0.02
Lubricity (HFRR, μm	-	-	135-280

Physical properties and chemical elements that are required for controlling the perfect combustion are such as Ash Content, Carbon Residue, Density, Flash Point, Gross Calorific Value, Viscosity, Sulfur Content, Pour Point, Sodium, Potassium, Vanadium and Water by Distillation. The parameter must be within the limit of operating. The efficiency of a combustion process may found from the chemical analysis of the combustion process or exhaust test and the power delivered [11]. The properties and specification of the biodiesel and diesel blend can affect the performances of the gas turbine. An intense analysis of the significant physical properties of the biodiesel and diesel blends needs to be understood and controlled in order not to deteriorate or damage the gas turbine. The fuel properties specified include both those which could affect turbine operation and those additional properties related to fuel storage and handling [12]. Another important is that the biodiesel and diesel blends produce is fulfilling the local safety and environmental codes.

Both the physical properties and chemical properties are important aspects in determining the characteristics of fuels. Table 2 shows the critical fuel properties for the first generation biodiesel derived from waste cooking oil. The second generation biodiesel fuel chemical properties are undergoing characterization of the fuel to determine its properties.

Table 2: Chemical fuel properties of distillate, B20, B15, B10, and B5.

Properties	Standards	BD20	BD15	BD10	BD 5	Distillate
Water & Sediment (%vol)	ASTM D 1796	0.0700	0.0525	0.0350	0.0175	-
Viscosity (mm^2/sec)	ASTM D 445	4.712	4.709	4.706	4.703	4.700
Calorific Value (kJ/kg)	ASTM D 3286-96	43,480	43,810	44,140	44,470	44,800
Sulfur Content (%wt)	ASTM D 4294	0.112	0.119	0.126	0.133	0.140
Carbon (%wt)	ASTM D5291	83.30	83.88	84.40	84.90	85.38
Hydrogen (%wt)	ASTM D5291	13.16	13.20	13.21	13.25	13.27
Oxygen (%wt)	ASTM D5291	3.42	2.80	2.26	1.72	1.21
Nitrogen (%wt)	ASTM D5291	0.12	0.12	0.13	0.13	0.14
Ash Content (%wt)	ASTM D482	0.017	0.018	0.019	0.02	0.021
Sodium (mg/kg)	ICP-OES	0.624	0.613	0.602	0.591	0.58

3.2. Spray Atomization Test

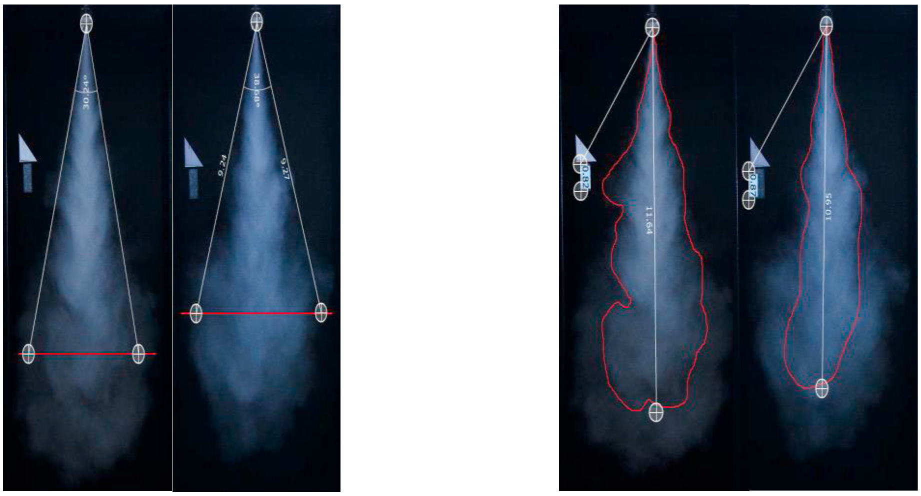

Fig. 2 (a) Spray angle of B100 (left) and distillate (right) at 0.4MPa. (b) Spray tip penetration of B100 (left) and distillate (right) at 0.4MPa.

Fig. 2 (a) shows the spray angle of B100 and distillate while Fig. 2 (b) shows the spray tip penetration at 0.4MPa. Spray angle for biodiesel is smaller, whereas the spray length is longer. This is because biodiesel has higher viscosity thus, resisting breakup of the molecules. A smaller spray angle is favourable in the smaller combustion chamber of a microturbine to avoid back flame burning. The thermal efficiency versus the load obtained by Equation 1 lies within the range of 18-24 %. It can be noted that the thermal efficiency of biodiesel blends surpasses that of pure distillate. This is because biodiesel is an oxygenated fuel, having more oxygen content in the fuel compared to distillate, thus aiding to complete the combustion process. The elemental analysis showed in Table 1, observes the oxygen content of B20, which is approximately three times more than distillate. Therefore, this shows that biodiesel, which has a lower calorific value compared to distillate, may not necessarily have a negative consequence on the performance of the microturbine. The thermal efficiencies of a B20 were slightly higher compared to normal distillate, thought to be a result of the oxygenation of the fuel. This claim has agreed with the findings by other researcher [13]. Interestingly, this means that B20, having the lower heating value compared to distillate, was able to sustain better thermal efficiency. Although it is merely 3 % difference between the two numbers, it is sufficient to cause an increase in the net combustion efficiency for biodiesel blended fuel, compensating the lower heat of combustion due to the non-hydrocarbon features of biodiesel. The differences would be most noticed at low rpm and high engine load when the engine would most benefit from more oxygen.

4. Conclusion

The physical and chemical fuel properties of biodiesel have a linear correlation with percentage of biodiesel blends with diesel/distillate. A full properties test was conducted for five types of biodiesel and diesel blends, namely B5, B10, B15 and B20 for the microturbine performance and emission test. Although moisture content for neat biodiesel is higher compared to standard specifications, it can be reduced by a heating process. High moisture content contributes to a high value of density which will generally improve atomization injection properties. This paper has proven that microturbine is able to operate on biodiesel derived from non-edible feedstocks. Thermal efficiency increase as percentage of biodiesel in the blend increased despite biodiesel having low calorific value and a slightly higher fuel consumption. The finding from this study shows promising potential for the application of biodiesel as substitute for microturbine liquid fuel, which is to achieve an increase in efficiency.

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