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## Evaluation of diesel engine performance with high blended diesel-biodiesel fuel from waste cooking oil

To cite this article: Obed M. Ali 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **518** 032054

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# Evaluation of diesel engine performance with high blended diesel-biodiesel fuel from waste cooking oil

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**Abstract.** The production of fossil fuel reaches its peak during the current decade. Unfortunately, the reserves of this fuel are depleting with time and limited to certain regions of the world which alarm for a series energy crisis in the future. Furthermore, the world starts to face the problem of global warming which increases rapidly and needs to be controlled. Waste cooking oil is one of the domestic available sources is the waste cooking oil. This source can represent a viable source in different countries which is free of cost. In this study, investigation of using a high blend of waste cooking oil biodiesel-diesel fuel is conducted in term of fuel property and engine performance. The results reveal that diesel fuel has the lower viscosity which is lower than that of WCOB by about 34%. However, this difference is converged with blended fuel B30 to about 9%. Furthermore, diesel fuel has higher heating value than WCOB by about 18%. However, this difference is converged with blended fuel B30 to about 4%. The maximum engine brake thermal efficiency observed with blended fuel B30 over the whole engine speed compared to mineral diesel and pure biodiesel. Accordingly, it can be suggested as a high blended fuel for diesel engine.

**Keyword:** Biodiesel; Blending; Cooking oil; Fossil fuel; Diesel engine.

## 1. Introduction

Fossil fuel represents the main source of conventional energy nowaday. The consumption of these fuels is increasing rapidly with time since the industrial revolution in the 18<sup>th</sup> century as a result of the industry development in addition to the continuous increase of the world population. Due to the availability of fossil fuel at relatively low prices compared to other energy sources, it has been introduced in most of the current industrial applications which limited the investigation for alternative energy sources [1,2]. The production of fossil fuel reaches its peak during the current decade. Unfortunately, the reserves of this fuel are depleting with time and limited to certain regions of the world which alarm for a series energy crisis in the future. Furthermore, the world starts to face the problem of global warming which increasing rapidly and needs to be controlled. Environmental pollution is mainly due to the utilization of fossil fuel according to the environmental agency report. The emissions from the transportation and industry sectors are the main contributors to this pollution [3,4].

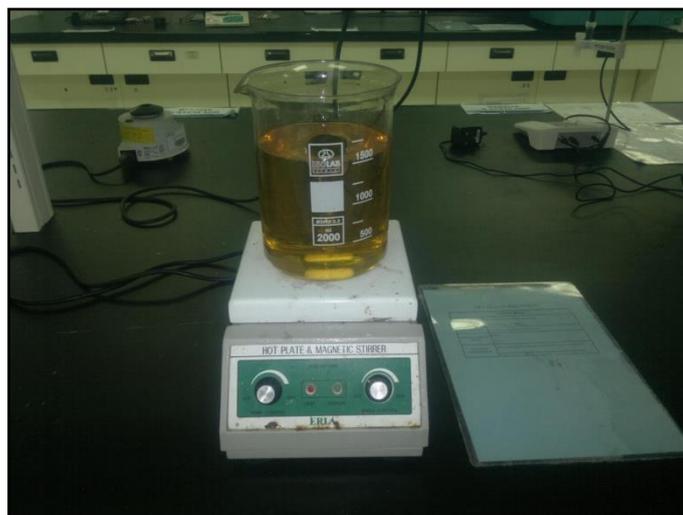
Many countries start to search for alternative energy sources and put the roles to control environmental pollution through the utilization of renewable clean energy sources. Though the variation of suggested renewable energy sources; their utilization still limited to certain applications. These sources represent a small share of the world energy consumption and sometimes need for high-cost technology for conversion and utilization. Transportation and industry sectors consume the main



share of world energy; these sectors developed rapidly with time which means more energy needed in the future [5]. Internal combustion engines are mainly used in these sectors due to their high efficiency and durability [6]. The current existing internal combustion engine designed to operate with a liquid which makes the utilization of conventional renewable source limited. Therefore, it is essential to search for a suitable alternative that can operate the engine without major modification. Biodiesel fuel is the most promising alternative for diesel fuel due to their similar characteristics. This type of fuel can be used as a blended fuel with mineral diesel at any percentage [7]. It is produced from different animal's fats and plants which can be considered as a renewable source of energy. However, many of these sources can affect food security, especially in the developing country. Therefore, the current studies focused on the production of biodiesel from waste products. This will provide a cheap source of biodiesel, in addition, to reduce environmental pollution by this waste. One of the domestic available sources is the waste cooking oil. This source can represent a viable source in different countries which is free of cost. Biodiesel fuel from waste cooking oil can be produced via transesterification process according to ASTM fuel standard specifications. However, this type of biodiesel approved commercially for operating diesel engine up to 20% due to their property variation [8], [9]. This study aims to use waste cooking oil with mineral diesel at a high blending ratio of 30% (B30) and assess the engine performance. Fuel test was conducted to evaluate property variation with increasing blend ratio. These results were essential to understand the behavior of engine performance trend of change and indicate the suitable blend for operating the engine.

## 2. Materials and methods

Waste cooking oil was collecting from the local restaurants and biodiesel produced in the chemical lab. Blended biodiesel diesel fuel samples prepared as B30 (30% WCOB and 70% diesel) using magnetic stirrer shown in Figure 1. The fuel blend mixture stirred for about 20 minutes to ensure homogenous fuel blend. Fuel property test was conducted according to ASTM standard procedures methods listed in Table 1. Kinematic viscosity, density and calorific value have been tested for biodiesel blends and pure biodiesel in addition to mineral diesel. Engine test is conducted using four-stroke single cylinder diesel engine Yanmar TF120 with water cooling system. The engine is naturally aspirated with direct injection system. Hydraulic dynamometer is coupled to the engine which controlled by valve controller to adjusting the engine load. The tests were conducted at variable increasing engine speed and constant half engine load. Engine test was started with pure diesel for about 5 minutes then changed to the desired blend. The data collected after a suitable time of engine operation to reach stable engine operation and ensure accurate results.



**Figure 1.** Magnetic stirrer.

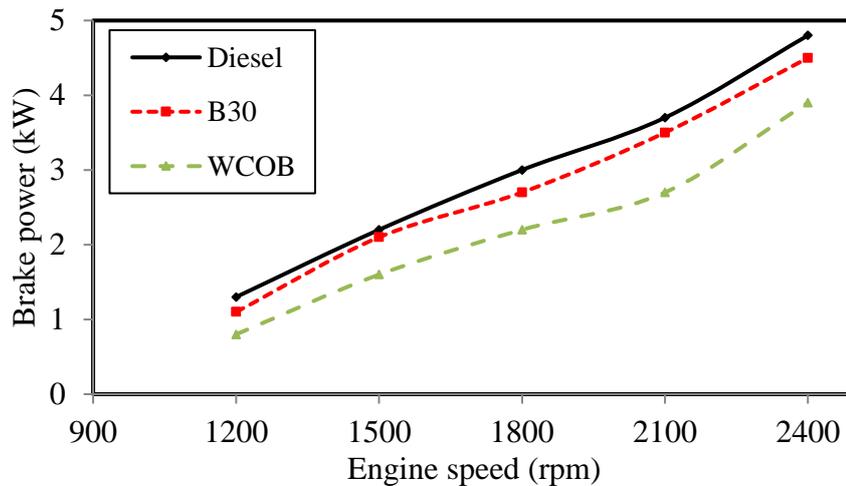
### 3. Results and discussion

Fuel properties can directly influence the engine performance as it has been designed to operate with mineral diesel as a standard fuel [10], [11]. The kinematic viscosity of fuel can influence the formation of the injected fuel spray and the size of fuel droplets [12], [13]. Spray formation is one of the most important design parameters that adjusted to obtain small fuel spray droplets with suitable spray penetration inside the combustion chamber for efficient fuel combustion process [14], [13], [14], [15], [16]. Higher fuel density can affect directly the fuel handling by the fuel injection system. Furthermore, the fuel injection system injects the fuel based on volume which means that the fuel density will influence the BSFC when using alternative fuel [17], [18]. Table 1 presents the results for the property measurement of the investigated fuel samples. The results show that diesel fuel has the lower viscosity which is lower than that of WCOB by about 34%. However, this difference is converged with blended fuel B30 to about 9% due to the effect of blending. A slight increase in density is obtained for WCOB compared to mineral diesel with comparable density for blend fuel B30 and Mineral diesel. Significant variation in heating value obtained among tested fuel with higher heating value for mineral diesel. The results show that diesel fuel has higher heating value than WCOB by about 18%. However, this difference is converged with blended fuel B30 to about 4% due to the effect of blending.

**Table 1.** Fuel property results.

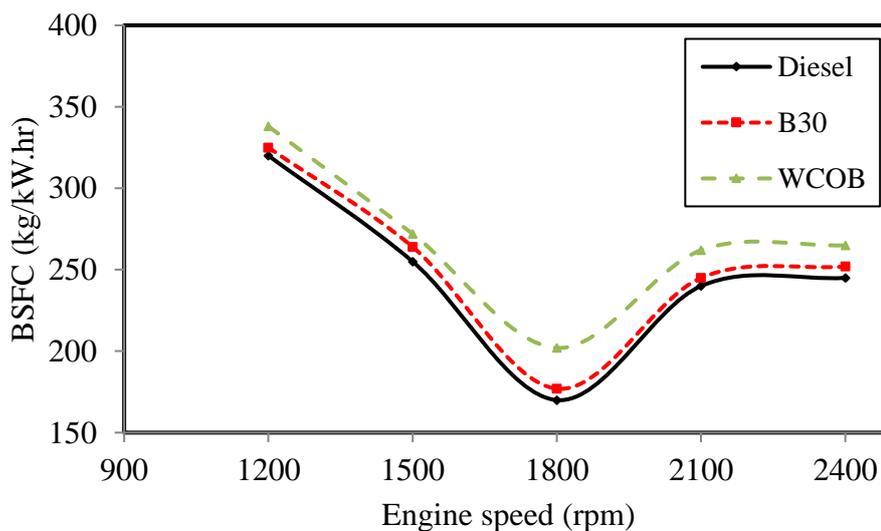
Property	Diesel	WCOB	B30	Measuring standard
Kinematic viscosity @ 40 °C (mm <sup>2</sup> /sec)	3.8	5.8	4.4	ASTM D445
Density @ 15 °C (kg/m <sup>3</sup> )	835	850	839	ASTM D1298
Heating value (Mg/kg)	45.2	38.3	43.5	-----

Engine test is an important indicator to evaluate the fuel quality and suitability to operate the diesel engine at wide range of operating conditions. In this study, engine test was conducted at increasing engine speed from 900 rpm to 2400 rpm at constant increment of 300 rpm and constant half load conditions. Mineral diesel fuel has been adopted as a threshold for comparison to achieve accurate results with the other fuel samples. Engine test data has been collected after a suitable time from engine starting to ensure steady operation and accurate results. Engine brake power represents the net output power from the engine and calculated based on the measured torque at certain engine speed. Figure 2 shows the trend of change of engine brake power with increasing engine speed for different fuel samples. In general, similar trends of change in brake power is observed for all tested fuel samples with increasing engine speed. However, there are noticeable differences in the measured brake power among the tested fuel at the same engine speed. The maximum brake power obtained with mineral diesel fuel over the whole engine speed, followed by blended fuel B30. On the other hand, the minimum brake power obtained with pure biodiesel fuel over the whole engine speed. A reduction of brake power at 1800 rpm by about 10% and 27% obtained with B30 and WCOB respectively compared to diesel fuel. This reduction in brake power can be attributed to the lower heating value of WCOB compared to mineral diesel [19], [20]. However, this reduction is less than the reduction in heating value for B30 and WCOB as shown in table results which mean more efficient fuel combustion due to the presence of oxygen in biodiesel fuel [21], [22].



**Figure 2.** Variation of brake power.

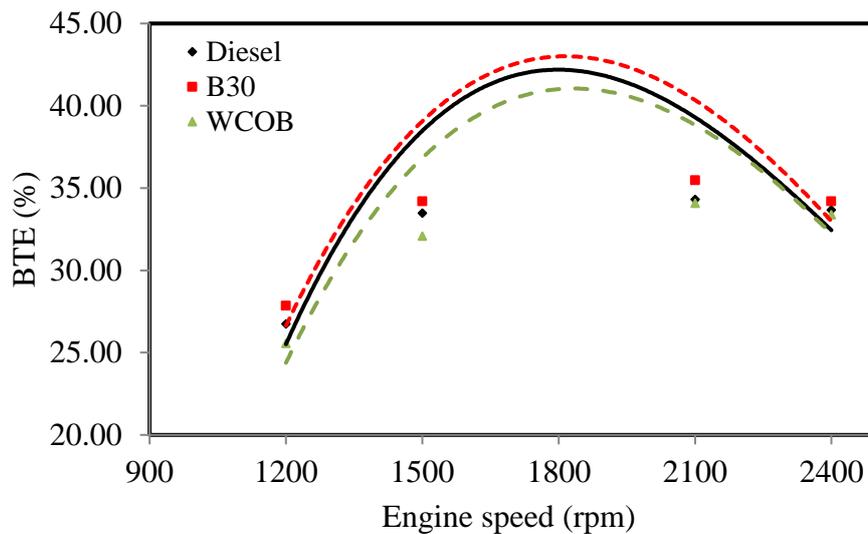
Engine brake specific fuel consumption (BSFC) represents the mass of fuel consumed by the engine and calculated based on the fuel flowrate for a certain time and predicted brake power at certain engine speed. As the fuel injection system injects the fuel based on volume, the fuel density will influence the calculated BSFC when using alternative fuel. Figure 3 shows the trend of change of engine BSFC with increasing engine speed for different fuel samples. Similar trends of change are observed for all tested fuel samples with increasing engine speed. However, there are noticeable differences in the BSFC among the tested fuel at the same engine speed. The minimum fuel consumption obtained with mineral diesel fuel over the whole engine speed followed by blended fuel B30. On the other hand, the maximum value obtained with pure biodiesel fuel over the whole engine speed. An increase of BSFC at 1800 rpm by about 4% and 18% observed with B30 and WCOB respectively compared to diesel fuel. This increase can be attributed to the higher density and lower heating value of WCOB compared to mineral diesel, which required more fuel consumption to produce the same engine brake power [22], [23].



**Figure 3.** Variation of brake specific fuel consumption.

Engine brake thermal efficiency (BTE) can be considered as a measure of fuel conversion efficiency. It is calculated based on the fuel consumed for a certain time and predicted brake power at certain engine speed in addition to the heating value of the tested fuel. Figure 4 shows the trend of change of

engine BTE with increasing engine speed for different fuel samples. Same trends of change are observed for all tested fuel samples with increasing engine speed. However, there are noticeable differences in the BTE among the tested fuel, especially at low and high engine speeds. The maximum BTE observed with blended fuel B30 over the whole engine speed followed by mineral diesel. On the other hand, the minimum BTE obtained with pure biodiesel fuel over the whole engine speed. This behaviour may attribute to two conflicted parameters which are the fuel heating value and the oxygen content [1]. For diesel fuel, the high heating value is the dominant parameter while oxygen content in the WCOB. The conflicted effect of these parameters results in improving the BTE with blended fuel B30 compared to mineral diesel and WCOB due to the improvement in fuel combustion process. This improvement results from the oxygen content of blended fuel that overcomes the reduction in heating value [24], [25].



**Figure 4.** Variation of brake thermal efficiency.

#### 4. Conclusion

In this study waste cooking oil biodiesel has been used with mineral diesel at high blending ratio of 30% (B30) to operate diesel engine and assess the performance. Fuel test was conducted to evaluate property variation with increasing blend ratio. Engine test was conducted at increasing engine speed from 900 rpm to 2400 rpm at a constant increment of 300 rpm and constant half load conditions. Mineral diesel fuel has been adopted as a threshold for comparison to achieve accurate results with the other fuel samples. The results show a noticeable variation in fuel property with blending. The variation in fuel viscosity among diesel and pure biodiesel is converged with blended fuel B30 from 34% to about 9% with comparable density for blend fuel B30 and Mineral diesel. A similar trend of converging for the heating value obtained with blended fuel B30 from about 18% to about 4%. The maximum brake power obtained with mineral diesel fuel over the whole engine speed followed by blended fuel B30. However, this reduction is less than the reduction in heating value of B30 which means more efficient fuel combustion due to the presence of oxygen in biodiesel fuel. Slight differences in the BSFC between B30 and mineral diesel fuel at the same engine speed with minimum fuel consumption obtained for mineral diesel. However, the maximum BTE observed with blended fuel B30 through the whole engine speed over mineral diesel.

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