The performance and emissions of diesel engines with biodiesel of sunan pecan seed and diesel oil blends

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Abstract. An observation was performed to evaluate the performance of direct injection stationary diesel engine which used a blends of biodiesel of Sunan pecan seed. The experiments were done with diesel oil, B5, B10, B15 and B20 in the engine speed variety. Results showed that the values of torque, power and thermal efficiency tend to decrease when the engine is using B5, B10, B15 and B20 , compared to diesel oil. It also shown that the specific fuel consumption is increased when using B5, B10, B15 and B20. From the results of experiments and calculations, the maximum power of 3.08 kW, minimum specific fuel consumption of 189.93 g/kWh and maximum thermal efficiency of 45.53% when engine using diesel oil. However, exhaust gases were measured include opacity, carbon monoxide and hydrocarbon when the engine using biodiesel B5, B10, B15 and B20 decreased.
Keywords: performance, emissions, sunan pecan seed

1. Introduction
Nearly 26-27% of energy consumption met by fossil fuels in the transport sector should be replaced in 2050 [1], [2]. The increasing energy demand and environmental deterioration are two major factors which drive the investigation on alternative fuels to replaced the conventional fuels for internal combustion engines. One of these alternative fuels is biofuels in the form of alcohol or biodiesel which are recommended as an alternative fuel for internal combustion engines [3], [4], [5]. Biodiesel is an alternative expectant fuel because it is renewable, biodegradable, non-toxic and environmentally friendly [6], [7]. Biodiesel can be used in its pure form or also as a blend form. It can also be used as a diesel fuel additive to improve its properties. Biodiesel has been widely used in diesel engines mainly because the raw materials can be obtained from a wide variety of oils such as plants, animals, and waste oil [8], [9], [10]. As noted, the fuel type is also affecting the performance of the diesel engine. One of the biodiesel raw material is sunan pecan seed . The populations of Sunan pecan seed are widely available in Indonesia, particularly in the area of Garut, Majalengka, West Java, Central Java, East Java, East Tenggara Nusa, West Tenggara Nusa, Riau, Jambi, Bangka, and East Kalimantan [11]. Currently, biodiesel of Sunan pecan seed was rarely used as an alternative fuel in diesel engines. Exceedingly, Sunan pecan seed biodiesel was potentially be used because they are not consumed by humans, therefore do not interfere with food needs. This experimental study aims to determine the performance of single-cylinder engines diesel which use Sunan pecan seed-diesel oil.
The parameters studied for engine performance were included of power, specific fuel consumption, thermal efficiency, effective mean pressure and exhaust gases produced.

2. Methods

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2.1. Parameter of Internal Combustion Engine

The performance of the internal combustion engine is specifically indicated by the value of the parameters of the engine. Some of these parameters can be described as follows [12]:

2.1.1. Power. The power is influenced by engine speed and torque that produced by the engine. In most cases, in the internal combustion engine, it is known two type of power that consist of shaft power and power indicator. As practice, it uses only the shaft power. The shaft power or effective power is the power that produced by an engine on the output shaft or it commonly known as brake horse power which is calculated by the equation:

$$\dot{W} = \frac{2\pi . \, N . \, \tau}{60000} \qquad \text{kW} \qquad (1)$$

where N is engine speed (rpm) and τ is engine torque (Nm).

2.1.2. Specific Fuel Consumption. The specific fuel consumption is the amount of fuel that should consumed per unit of power which produced per hour of operation. Indirectly, the specific fuel consumption is an indication of the engine efficiency to generating power from fuel combustion. The value of specific fuel consumption can be defined as follows:

$$\text{Sfc} = \frac{\dot{m}_f}{\dot{W}} . \, 3600000 \qquad \text{gr/kWh} \qquad (2)$$

where $\dot{m}_f$ is mass flow rate of fuel (kg/s).

2.1.3. Thermal Efficiency. The thermal efficiency of an internal combustion engine constituted the ratio between the output energy and the chemical energy of fuel, that can be stated as:

$$\eta_t = \frac{\dot{W}}{\dot{m}_f . \, Q_{HV} . \, \eta_c} \qquad (3)$$

where Q_{HV} is calorivic value (kJ/kg) and η_c is combustion efficiency 0,97.

2.1.4. Mean Effective Pressure. Mean effective pressure is a good parameter to compare engines for design or output because it is independent of engine size and/or speed. The value of mean effective pressure can be defined by using equation:

$$\text{mep} = \left(\frac{4 \, \pi \, \tau}{V_d} \right) \text{x} \, 1000 \qquad \text{kPa} \qquad (4)$$

where V_d is displacement volume (cm^3).

2.2. Material

The experiments were using a blends of diesel oil, the biodiesel of Sunan pecan seed with the composition of, B5 (diesel that contained 5 vol.% of biodiesel), B10 (diesel with 10 %vol.), B15 (15 vol.% of biodiesel) and B20 (contained 20% vol). The blended fuel is limited to B20 because higher biodiesel are not in common use.

2.3. Main Equipments

The main equipments used in this study consisted of:
1. Single cylinder stationary diesel engine
2. Calorimeter bomb to determine the calorific value of the fuel
3. Automotive emission analyzer to determine the composition of exhaust emissions

Figure 1. Single cylinder stationary diesel engine

Tabel 1. Engine specifications [13]

Type	ROBIN - FUJI DY23D
Valve position	Overhead
Valve rocker clearance	0,10 mm
Cylinder volume	230 cm^3
Bore	70 mm
Stroke	60 mm
Compression ratio	21
Number of cylinder	1
Maximum power	4.2 kW / 3750 rpm
Maximum torque	11.2 Nm / 3500 rpm
Injection time	23^0 BTDC

2.4. Scheme of Experimental
Figure 2 shows the scheme of experimental. The ROBIN FUJI DY23D engine that used in this research is the type of a four stroke one cylinder direct injection stationary diesel engine which specifications are summarized in Table 1. All experimental data were taken after the engine was properly warmed up 15 minutes   after starting. An automotive emission analyzer HG-510 with accuracy of ±5% were used to measure the exhaust gases which placed on the exhaust gas manifold. For each fuel, different emission data were taken over three repetitions. The testing was under the constant engine loads of 4 kg at the engine speed variety from 1000 rpm, 1300 rpm, 1600 rpm, 1900 rpm, 2200 rpm, 2500 rpm and 2800 rpm. Loads were supplied by an eddy current dynamometer. Maximum torque 11.2 Nm at speed of 3500 rpm and maximum power 4.2 kW at 3750 rpm. The Accuracy of torque measurement is about ±0.17 Nm, and the acccuracy of rotation controlling ±10 rpm. The engine was started by using diesel fuel, where as it was warmed up, should switched to the

biodiesel, the diesel blends (B5, B10, B15 and B20). After switching fuel from one type to another, engine was running about 10 minutes to get stable condition with the new fuel before the measurements were taken. When the load decreased, the engine rpm tends to increase, therefore the amount of fuel supply reduced by adjusting the fuel control screw to maintained the engine speed. Engine torque and fuel consumption were measured to calculate the power, specific fuel consumption and thermal efficiency of the engine. A 8 ml burette and a timer are used to measure the fuel consumption. The accuracy of the burette about ±0.1 ml and the timer about ±0.01 s.
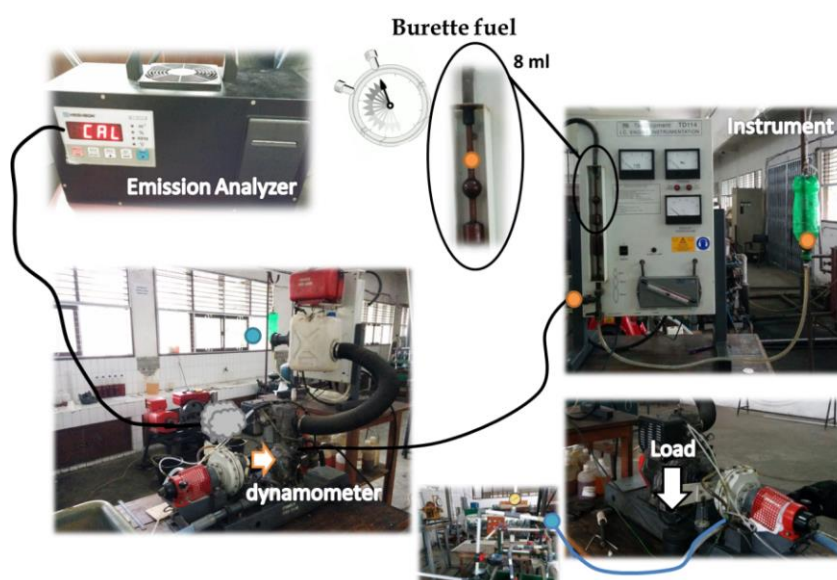

Figure 2. Scheme of experimental

3. Results and Discussions

3.1. The Calorivic Value of Fuels

The calorivic value of fuel was examined by using a bomb calorimeter apparatus with the accuracy of ±5%. To get the calorific value of diesel oil, B5, B10, B15 and B20, were the experiments carried out which each fuel as many as five sample. Then the average results of the five samples were to obtain the calorific value of the fuel. The Observation results obtained that the highest calorific value is in diesel oil that reached about 43142 kJ/kg and the lowest is B20 about 36819 kJ/kg. The calorific value of fuel shows the energy that generated during the combustion process of fuel per unit mass which is influenced by the composition of the fuel constituent. The higher the concentration of biodiesel in the blends, will decreased the calorific value of the fuel. Table 2 shows the calorivic value of fuels which obtained by using a calorimeter bomb.

Table 2. The calorivic value of fuels

Fuel	Calorivic Value (kJ/kg)
Diesel oil	43142
B5	41231
B10	40201
B15	39025
B20	36819

3.2. The Performance of Diesel Engine

3.2.1. Power. The experimental data in figure 3 shows that the maximum power occurs in 3.08 kW when the engine is using diesel oil at speed of 2800 rpm. The minimum engine power obtained 0.74 kW when engine using B20 at the speed of 1000 rpm.
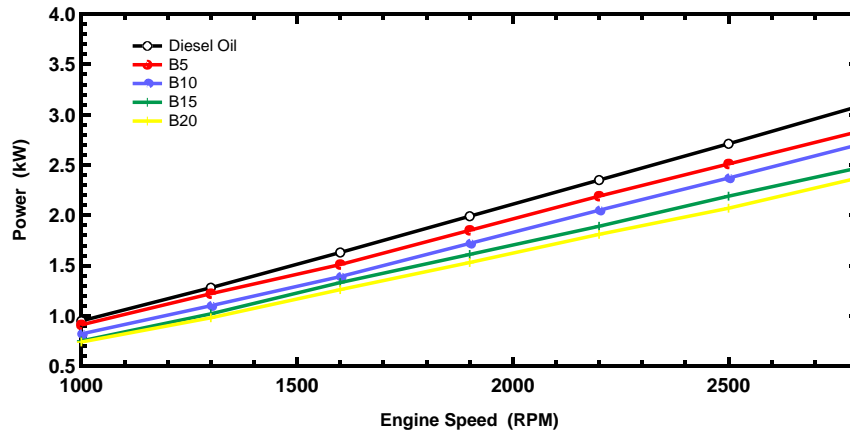

Figure 3. The engine power during experiments

The most influential of the power that generated by the engine shaft is torque. When the engine torque more greater, the engine power generated is also getting bigger and vice versa. This is due to the changing of engine power which is equally linier with engine torque. Another factor that allows the reduction in engine power is when the engine using B5, B10, B15 and B20 due to less precise injection timing settings, this is appropriated to the cetane number of the biodiesel. The cetane number of Sunan pecan seed is higher than diesel oil so that the required ignition delay is shorter than using diesel oil. Therefore, it is necessary to advance the injection timing in order to obtain the optimum power. As noted, during the experiments, no modification to the diesel engine used.

3.2.2. Specific Fuel Consumption. The experimental results in figure 4 shows that when the diesel engine using B20 at the speed of 1000 rpm , the maximum specific fuel consumption is obtained 439.26 g/kWh. The minimum value of specific fuel consumption when the engine using diesel oil at speed of 2800 rpm is obtained to 189.93 g/kWh. The average of specific fuel consumption during experiments is 284.38 g/kWh.
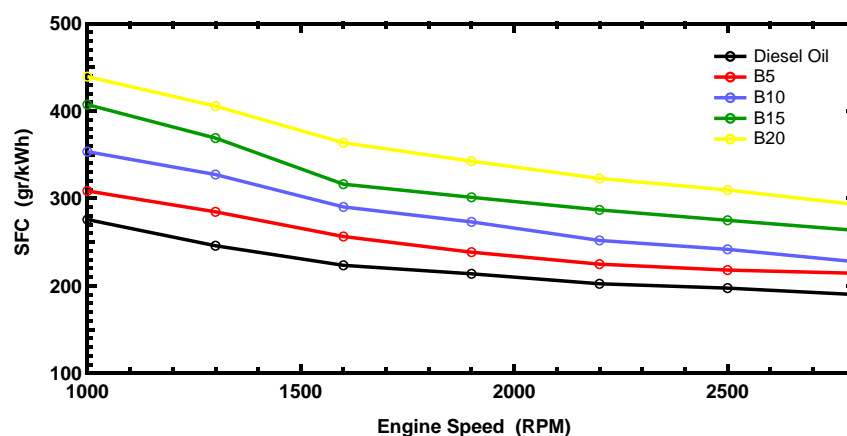

Figure 4. Specific fuel consumption during experiments

In general, the specific fuel consumption when the diesel engine using B5, B10, B15 and B20 increased. The calorific value of B5, B10, B15 and B20 were lower compared to the diesel oil because the presence of oxygen in biodiesel which result the air fuel ratio becomes a lean mixture. These conditions make the fuel becomes more needed than when using diesel oil. Higher specific fuel consumption Sunan pecan seed- can be attributed to the lower the heating values of these blends compared to diesel oil.

3.2.3. Thermal Efficiency. Figure 5 shows the value of maximum thermal efficiency 45.53% was reached by using diesel oil at the speed of 2800 rpm.
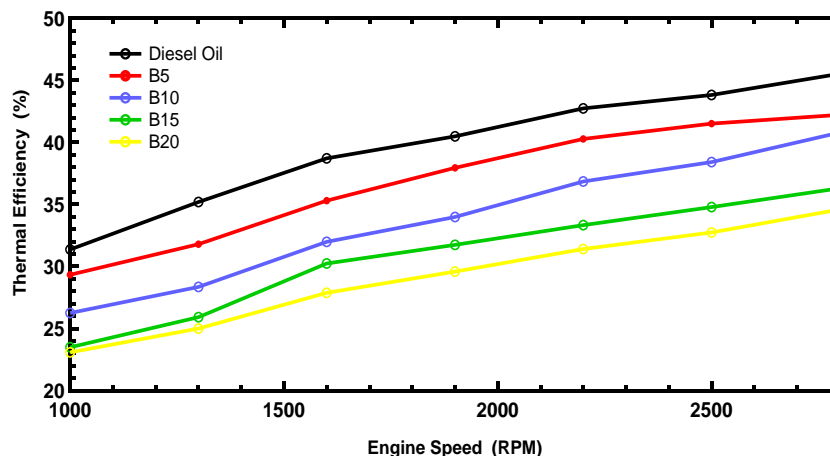

Figure 5. The thermal efficiency of engine during experiments

The value of minimum thermal efficiency is 23.07% by using B20 at speed of 1000 rpm. The average value of thermal efficiency resulting from the experiments conducted 34.08%. The decreasing of the thermal efficiency when the diesel engine is using blends fuel is about 9% - 35%. The average decreasing of the thermal efficiency occurs when the engine using blends fuel is 26.21%.
As noted, that the thermal efficiency of the internal combustion engine are influenced by several parameters such as engine power, specific fuel consumption and the calorific value of the fuel that be used. The three parameters simultaneously affect the achievement of the engine thermal efficiency.

3.2.4. Mean Effective Pressure. The experimental data shown the maximum mean effective pressure (mep) is 571.97 kPa which occur when the speed constantly 2800 rpm using diesel oil as shown in Figure 6. The minimum mean effective pressure is obtained 382.11 kPa by using B20 on the speed of 1000 rpm. As noted that the maximum mean effective pressure of good engine designs is well established, and is essentially constant over a wide range of engine sizes. The actual mean effective pressure is a particular engine develops that can be compared with this norm and the effectiveness with which the engine's displaced volume can be assessed. For design calculations, the engine displacement required to provide a given torque or power at a specified speed that can be estimated by assuming the appropriate values for mean effective pressure for that particular application [14].
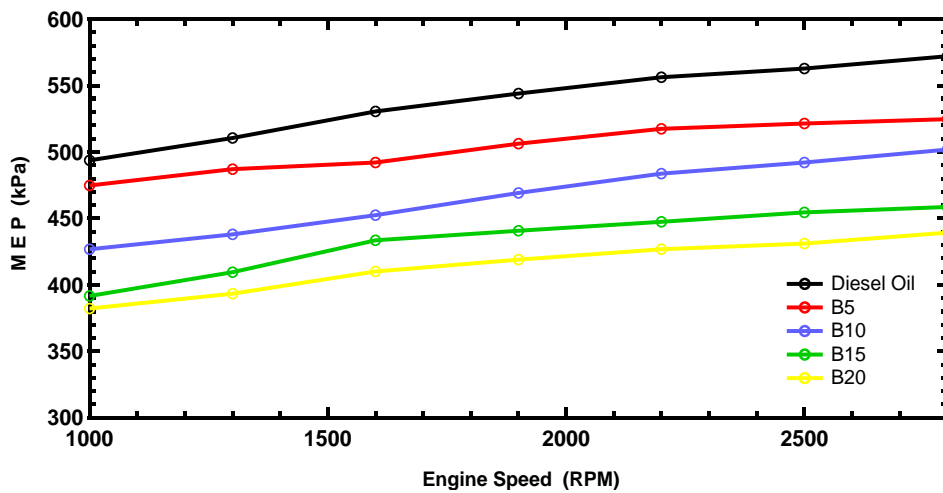
Figure 6. The mean effective pressure of engine during experiments

3.2.5. Emissions Measurement. In this study, the emissions studied were opacity, hydrocarbons (HC) and carbon monoxide (CO) by using automotive gas analyzer. The data measurement of exhaust gases can be seen in Table 3.

Table 3. The measurement result of exhaust gases

Load (kg)	Fuel	Opacity (%)	CO (%)	HC (ppm)
	Diesel oil	18.018	0.058	29.728
	B5	15.799	0.048	26.855
4	B10	15.078	0.048	21.878
	B15	14.448	0.038	19.264
	B20	13.818	0.038	16.909

Based on the results of the experiments when the engine is using B5, B10, B15 and B20, it were obtained the reduction in exhaust gases of carbon monoxide in the ranges of 13% - 27% for variations of speed. The exhaust gases of CO is caused by lack of oxygen produced, therefore the combustion process is not perfect because a lot of the carbon atoms are not getting enough oxygen to form carbon monoxide gas. The otherwise, this condition would make carbon dioxide emissions have increased. It has argued that biodiesel has an excess of oxygen atoms so that biodiesel is an oxygenate fuel that have the ability to bind a molecule of carbon monoxide to be the carbon dioxide. The reduction in exhaust gases of hydrocarbon ranges about 10% - 44% for all engine speed variation. The presence of hydrocarbon emissions is caused by unperfect of the combustion process. The fuels of B5, B10, B15 and B20 which have the OH bond in the molecular arrangement makes the combustion process of fuel in the combustion chamber is better so that the exhaust gases produced is becoming more environmentally friendly than diesel oil.

4. Conclusions
The performance and emission of a single cylinder direct injection CI engine fuelled with Sunan pecan seed and its blends have been observed and analyzed comparing to the base line of diesel oil. Experimental result analysis has shown that the specific fuel consumption increases as the increase of biodiesel in the blends fuel. On the other hand, CO and HC emissions can be reduced efficiently using Sunan pecan sees-diesel oil at speed.variation. HC emissions can be decreased significantly simultant

with the increase of biodiesel in blends fuel under all engine speed. The experimental data show that the maximum power is obtained to 3,08 kW, specific fuel consumption 189.93 g/kWh and maximum thermal efficiency 45.53% when using diesel oil. The specific fuel consumption increases with the increasing of the percentage of Sunan pecan seed in the blends due to the lower calorific value of Sunan pecan seed. The amount of calorific value of a fuel is influenced by the composition of the constituent elements in it. The higher the concentration of biodiesel in the blends, the smaller calorific value of the fuel. The experimental results show that B20 has the smallest value of calorific value.

Acknowledgments

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