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Evaluation of Diesel Engine Performance Using Biodiesel from Cooking Oil Waste (WCO)

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ABSTRACT

The increasing use of fossil fuels will cause the world's oil reserves to be depleted. In this case, it is necessary to increase the use of alternative renewable fuels, one of which is biodiesel waste cooking oil (WCO). The method used is an experimental test with a mixture of used cooking oil biodiesel and fuel. Before testing, the temperature of each fuel is increased to determine the effect of temperature on the density and viscosity values. The highest density value is found in B50 fuel at 26 °C, with a density of 0.854 gr/ml, while the lowest density is found in diesel fuel at 60 °C, with a density of 0.822 gr/ml. The highest viscosity value is found in B50 fuel at 26 °C and 60 °C, which is 3.26 cSt. After that, testing was carried out on a diesel engine, which produced the highest thermal efficiency value of 21.16% on B50 fuel with a temperature of 60 °C at 1000 rpm rotation and a load of 4000 watts. The lowest thermal efficiency of 6.43% was found in B50 fuel with a temperature of 26 °C at 800 rpm and a load of 1000 watts. The lowest consumption was found in B30 with a temperature of 60 °C at 1200 rpm, which was 420.78 gr/kWh. From the results of the tests that have been carried out, it can be concluded that the lower the density and viscosity of the fuel, the better the performance of the diesel engine on average. High temperatures effectively make the engine performance value better than normal temperatures (26 °C), and the performance of diesel engines is better with WCO fuel, especially in SFC.

1. INTRODUCTION

The purpose of machines is to facilitate and support work activities to meet human needs. With the passage of time, the need for machines is increasing, especially in the fields of industry and transportation. The known types of engines are gasoline engines and diesel engines. In the world of marine transportation, such as ships, the engine can function as a generator or as a prime mover system. In principle, diesel engines and gasoline engines (internal combustion engines) can be interpreted as energy converters that convert the energy from fuel combustion into mechanical energy (effective work) (Tschoeke, 2006).

Diesel engines have different characteristics from other internal combustion engines because the method of ignition in the combustion chamber on a diesel engine does not use spark plugs, but instead fuel is injected into the combustion chamber and then compressed with high-pressure air (Tschoeke, 2006). This has an impact on the level of thermal efficiency of the diesel engine or compression ignition engine (CI engine), which is better than that of the gasoline engine or spark ignition engine (SI engine), resulting in higher fuel efficiency (Fil & Akansu, 2022). However, even though the level of fuel use is quite efficient, the use of diesel engines has greatly increased, and the amount of diesel fuel used is also increasing, which, on the other hand, is depleting fossil fuel supplies. Therefore, many efforts have been made to find renewable and

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environmentally friendly fuels. One of these is biodiesel, which is a renewable biofuel and has more environmentally friendly properties (Duhovnik, 2008).

Currently, Indonesia is implementing the EURO-4 standard regarding engine exhaust emission restrictions, to reduce the level of environmental pollution caused by engine exhaust gases (Kementerian ESDM, 2021). Several studies have been carried out related to fuel modification to produce low emissions. One study found that the mixing of Methanol into biodiesel fuel can reduce engine exhaust emissions (Fathallah et al., 2022). Another study states that the addition of Methanol is effective in reducing hydrocarbon levels and carbon monoxide emissions because the fuel can burn completely when injected into the combustion chamber (Panda & Ramesh, 2021). Considering the fact that petroleum is increasingly scarce, biodiesel has the potential to replace fossil fuels in the future.

Various types of food, such as soybeans and corn, can serve as raw materials for the production of biodiesel fuels, as evidenced by studies conducted by Bernard Freedman (1986) and Lang et al. (2001). Additionally, waste cooking oil (WCO) and palm oil waste can also be utilized as viable alternatives for biodiesel fuel production. In Indonesia, the use of WCO as a raw material for biodiesel production shows significant potential as it falls under alternative renewable fuels. Furthermore, this biodiesel can be a viable substitute for diesel fuel due to its comparable composition and properties. Given the high domestic demand for cooking oil in Indonesia, which amounts to 78,294 tons every 14 days (Kementerian Perindustrian RI, 2022), the use of WCO for biodiesel production can potentially mitigate waste and provide an alternative fuel source.

There are five major palm oil producing countries in the world, with Indonesia ranking first. Southeast Asian countries, namely Indonesia, Malaysia, and Thailand, as well as two other countries, namely Colombia and Nigeria, dominate palm oil production (Indexmundi, 2022). Indonesia's oil palm plantation areas expand annually, resulting in an increase in palm oil production, which indirectly contributes to the increasing amount of WCO. Indonesia alone produces approximately 6.46-9.72 million kiloliters of WCO per year (Direktorat Jenderal EBTKE, 2022). Apart from its relatively abundant availability, the waste of WCO in the environment can cause environmental pollution in the form of an increase in Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) in water bodies, which can lead to a foul odor (Hosseinzadeh-Bandbafha et al., 2022; Prasetyo, 2018).

Transesterification is a chemical process that is carried out to convert triglycerides in vegetable oil into biodiesel. This process removes the triglycerides and results in a lower viscosity of the biodiesel (SRS Biodiesel, 2022). The viscosity and density of the fuel are crucial factors to consider for proper distribution to the injector for injection. High viscosity can cause the engine to work harder. The viscosity grade of fuel for diesel engines should be between 2 mm^2/s to 5 mm^2/s, and the density should be between 815 kg/m^3 to 880 kg/m^3 (Direktorat Jenderal ESDM, 2020).

2. METHODS

This research is based on references from Google Scholar (Google Scholar, 2022) and ScienceDirect (ScienceDirect, 2022) that are related to the process of producing and using WCO biodiesel and measuring engine performance using WCO biodiesel. Two methods will be used in this research, namely the transesterification method (Suzihaque et al., 2022) for the production of WCO biodiesel and an experimental method to test the performance of diesel engines. Based on previous research on fuel temperature variations, it has been shown that increasing fuel temperature has a positive effect on engine performance because it improves fuel spraying and evaporation, resulting in better flame and engine efficiency, and lower exhaust emissions (Choi et al., 2022).

In this study, six fuel samples were prepared. The six samples including 100% diesel oil at room temperature (26 °C) and 60 °C, 30% WCO biodiesel with temperature variations of 26 °C and 60 °C, and 50% WCO biodiesel with temperature variations of 26 °C and 60 °C. The use of temperature variations of 26 °C and 60 °C is intended to increase the viscosity level of the fuel, thereby optimizing the fuel injection process and improving the process of fuel atomization and combustion in the engine cylinder.

Upon completion of the biodiesel production process, the fuel underwent viscosity and density testing according to the domestic diesel fuel specifications standards outlined by the Ministry of Energy and Mineral Resources Republic of Indonesia (Direktorat Jenderal ESDM, 2020). Subsequently, the performance of WCO biodiesel fuel was directly tested on a 4-stroke diesel engine, where a generator and lights were utilized as a load. Engine power, torque, Specific Fuel Oil Consumption, and Thermal Efficiency were among the parameters assessed. The Yanmar TF 85-MH 4 Stroke diesel engine (YANMAR Indonesia, 2022) was employed for the test. Although other vegetable oils such as corn oil, coconut oil, candlenut oil, and animal fat-derived oils are available, this research primarily focuses on the use of WCO or used cooking oil. The abundance of WCO as a raw material and its potential to reduce waste are some of the reasons for this emphasis. The research setting is presented in Figure 1.

Stages of testing are carried out in four stages, such as:

a) The test was carried out in three variations of engine speed, namely (800 Rpm, 1000 Rpm, and 120 Rpm)
b) For each variation of engine speed, the lamp load used when testing the machine will be determined (the load is carried out in stages starting from zero load or no lights are on, 1000 watts of load, 2000 watts of load, 3000 watts of load, and 4000 watts of load)
c) The more the load increases, the engine speed decreases, so during the loading process, the engine speed must be set at 800 Rpm or 1000 Rpm, or 1200 Rpm.
d) In the process of running the engine, measurements of voltage, current, amount of fuel consumption, fuel consumption time, and engine speed are measured.

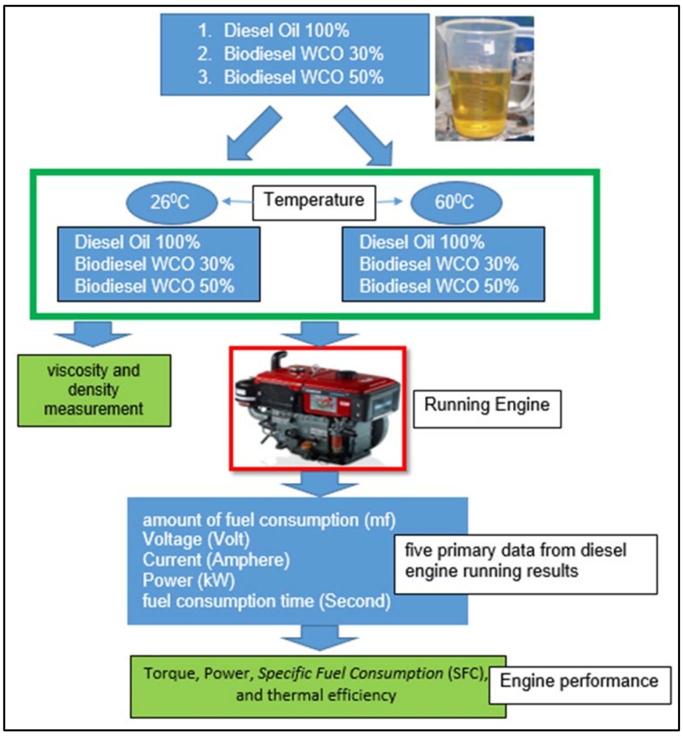

Figure 1. Research Setting

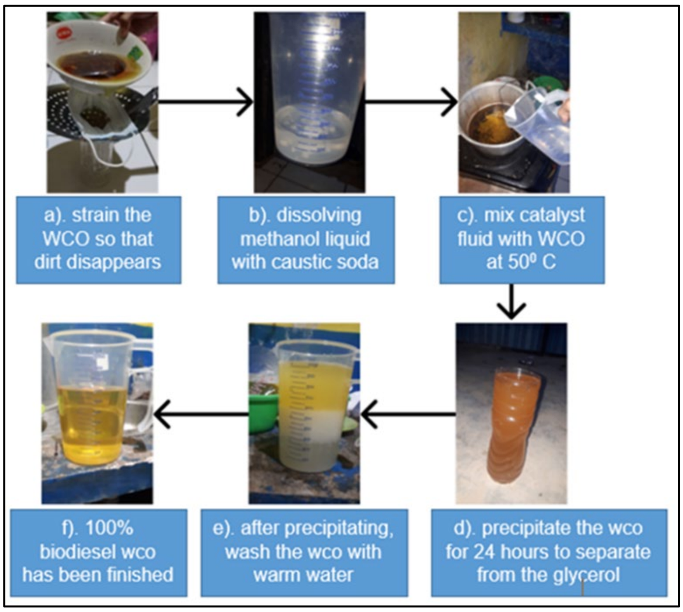

Figure 2. WCO biodiesel Manufacturing Process

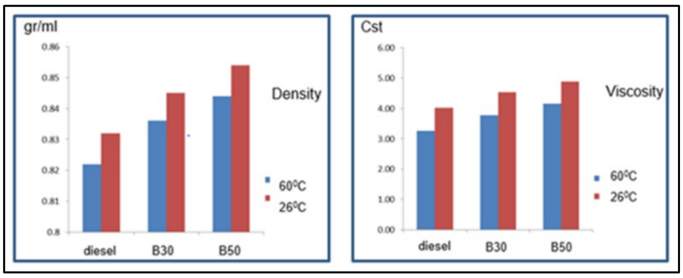

Figure 3. Graphics The results of density and viscosity testing on diesel, B30, and B50 with variations temperature 26 °C and 60 °C

Before biodiesel is tested on a diesel engine, the process of making biodiesel WCO is carried out first. The process for making WCO biodiesel can be seen in Figure 2. The process of producing biodiesel from WCO begins with filtering WCO to separate oil and frying residue, in this study the amount of WCO used is 1 liter, the next step is to dissolve the catalyst methanol (CH_3OH) and caustic soda (NaOH) as much as 200 ml. The filtered WCO is then heated until the temperature reaches 50 °C and mixed with the catalyst liquid that has been made previously. The filtered WCO is then heated until the temperature reaches 50 °C and mixed with the catalyst liquid that has been made previously, after that, the WCO is then allowed to stand for 24 hours to separate the oil and glycerol (fat), then the WCO oil that has been precipitated for 24 hours is separated from glycerol and washed using warm water. The washing process is carried out two to three times to obtain WCO biodiesel which is clearer and lighter in color.

3. RESULT AND DISCUSSION

3.1. Testing the Density and Viscosity of Diesel and Biodiesel Fuels with Variations of Heating

The viscosity and density of the fuels were tested using a viscometer and aerometer. Table 1 shows the results of the density and viscosity tests for Diesel Oil, WCO B30, and WCO B50 at both 26 °C and 60 °C.

The graph of the test results of the properties of Diesel oil, B30, and B50 fuels in two temperature variations 26 °C and 60 °C can be seen in Figure 3.

The graph depicted in Figure 3 demonstrates that viscosity and density values of the fuel decrease as the fuel temperature rises. Additionally, the density and viscosity values of the fuel are influenced by the quantity of WCO mixture used, whereby increasing the amount of WCO mixed raises the density and viscosity of the fuel. It should be noted that the density value obtained from the aforementioned tests remains within the range of limits set by the Ministry of Energy and Mineral Resources Republic of Indonesia, as detailed in Table 2 below.

3.2. Engine Testing

This stage is conducted to evaluate the performance of the diesel engine using conventional fuel, namely diesel. In this study, a 4-stroke Yanmar TF 85-MH diesel engine with 1 cylinder was utilized (YANMAR Indonesia, 2022). The complete specifications of the diesel engine used in the experiment can be found in Table 3.

The experimental setting of engine used can be seen in Figure 4.

Table 1. Properties of Diesel Oil, B30, and B50 with variations temperature 26 °C and 60 °C

Fuel Oil	Temperature	Density (gr/ml)	Viscosity (cSt or mm^2/s)
Diesel	26 °C	0.832	4.01
B30	26 °C	0.845	4.53
B50	26 °C	0.854	4.89
Diesel	60 °C	0.822	3.26
B30	60 °C	0.836	3.77
B50	60 °C	0.844	4.15

Table 2. Biodiesel Specifications set by Ministry of Energy and Mineral Resources Republic of Indonesia

Characteristic	Unit	Min Value	Max Value	Methods
Density	gr/ml	0.815	0.88	ASTM D4052/1298
Viscosity	cSt or mm^2/s	2	5	ASTM D445

(Source : Direktorat Jenderal ESDM, 2020)

Table 3. Diesel Engine specifications

Main Engine	Value	Unit
Model	1 cylinder, 4 Stroke	Vertical
Type	Yanmar, TF 85 MH	
Continous Power	7,5	Kw
Engine Speed	2200	Rpm
Displacement	493	cc
Compression Ratio	18	
Dimention	672x330x496	mm
Weight	87,0	Kg
Main Engine	Value	unit

(Source : YANMAR Indonesia, 2022)

Torque Comparison Analysis with Load at 800 RPM

Based on the test results data above, it can be calculated the torque generated on the diesel engine with the following equation:

$$P = 2\ (\pi n/60)\ T \qquad (1)$$

Where:

P = Power (W)

n = Engine speed (Rpm)

T = Torque generated (Nm)

So to get the torque value, the equation is:

$$T = (P \times 60)/(2\pi n) \qquad (2)$$

With the above equation, it can be calculated torque as follows:

$$T = ((258.85)\ x\ 60)/(2(3.14)(800))$$
$$T = 3.0886\ Nm$$

Based on the calculations above, a graph of the comparison between torque and load at 800 RPM rotation with fuel variations is obtained, namely diesel fuel, B30, and B50 in 26 °C and 60 °C temperatures as shown in Figure 5 below:

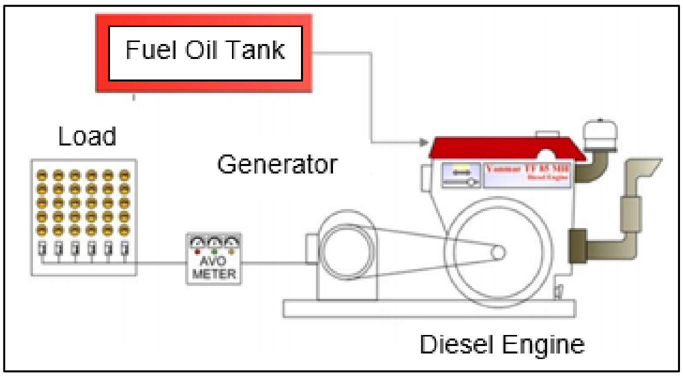

Figure 4. Schematic diagram of diesel engine testing (Source : Suardi, 2019)

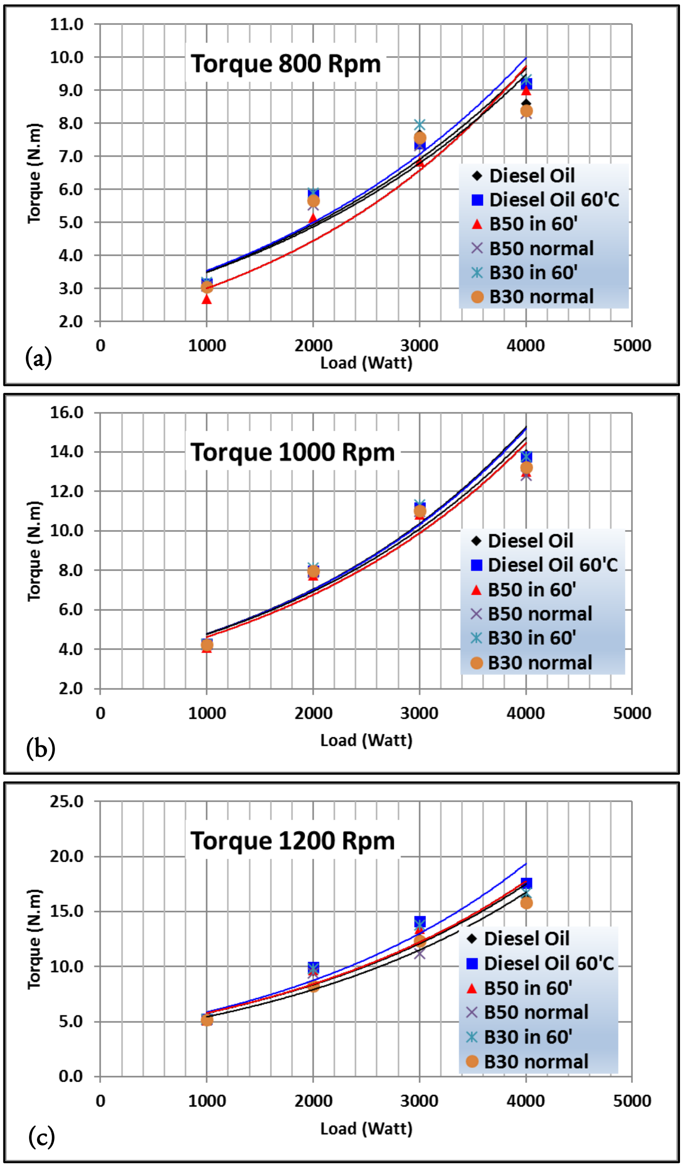

Figure 5. Torque comparison graph with load for each RPM (a) 800 RPM, (b) 1000 RPM, (c) 1200 RPM.

Table 4. Torque in various RPM and Load

RPM	Load (Watt)	Torque (N.m)					
		Diesel Oil	Diesel Oil (60⁰)	B50 (26⁰)	B50 (60⁰)	B30 (26⁰)	B30 (60⁰)
800	1000	3.09	3.15	3.08	2.68	3.05	3.18
	2000	5.72	5.82	5.52	5.15	5.66	5.88
	3000	7.66	7.40	7.32	6.86	7.56	7.95
	4000	8.59	9.20	8.31	9.01	8.38	9.32
1000	1000	4.27	4.26	4.22	4.10	4.22	4.29
	2000	8.01	7.98	7.89	7.75	7.96	8.11
	3000	11.21	11.17	10.99	10.83	11.03	11.33
	4000	13.90	13.77	12.82	13.01	13.26	13.77
1200	1000	5.18	5.25	5.18	5.10	5.18	5.26
	2000	9.63	9.98	9.43	9.67	8.22	9.83
	3000	12.52	14.08	11.20	13.42	12.34	13.78
	4000	16.29	17.57	12.25	15.91	15.78	16.67

The calculation results for torque at load variations and RPM can be seen in Table 4.

Table 4 presents the torque-to-load ratio of diesel, B30, and B50 fuels at 800 RPM rotation and variations in temperature, namely 26°C and 60°C. The highest torque value is obtained from the B30 fuel at a temperature of 60°C and a load of 4000 watts, with a torque value of 9.32 Nm for 1000 RPM rotation. The highest value is found in the diesel fuel graph at 26°C with a load of 4000 watts and a torque value of 13.90 Nm for 1200 RPM rotation. The graph of diesel fuel with a temperature of 60°C at a load of 4000 watts yields the highest value, with a torque value of 17.57 Nm.

Based on the graph and table above, it can be inferred that there is a direct proportionality between the magnitude of load applied and the corresponding increase in torque. This observation is consistent with other studies on engine performance, which also report that increasing engine load leads to a corresponding increase in torque (Fathallah et al., 2022; Panda & Ramesh, 2021). The highest average torque value across all RPM ranges is observed in diesel fuel with a temperature of 60°C, which measures 9.14 Nm. Conversely, the lowest average torque value is seen in B50 fuel with a temperature of 26°C, which measures 8.19 Nm. This observation aligns with visual observations of diesel engines, which often produce higher vibration and noise, and exhibit unstable engine speed at lower torque values.

Comparative Analysis of SFC with Load at 800 RPM

Based on the data from the research above, it can be calculated the SFC generated in the diesel engine with the following equation:

$$SFC = mf/P\ 10^3 \quad (3)$$

Where:

SFC = Specific Fuel Consumption (g/kWh)
mf = Fuel flow rate (kg/hour)
P = Power generated (kW)

In which case, the value of the fuel flow rate can be calculated by the following equation:

$$mf = (\rho.vf)/tf \times 3600 \quad (4)$$

Where:

ρ = Density (kg/liter)
vf = Volume of fuel (liters)
tf = Time for fuel consumption as much as vf (hours)

With the above equation, it can be calculated SFC as follows:

$$mf = ((0.832).(0.02))/(175\ x\ 3600)$$
$$mf = 0{,}3423$$

then get the value of SFC

$$SFC = 1030.3423/0.2589$$

$$SFC = 1322.42\ gr/kWh$$

Based on the above calculations, a comparison graph between SFC and load at 800 RPM rotation with fuel variations is obtained, namely diesel fuel, B30, and B50 with 26 °C and 60 °C temperature as shown in Figure 6 below:

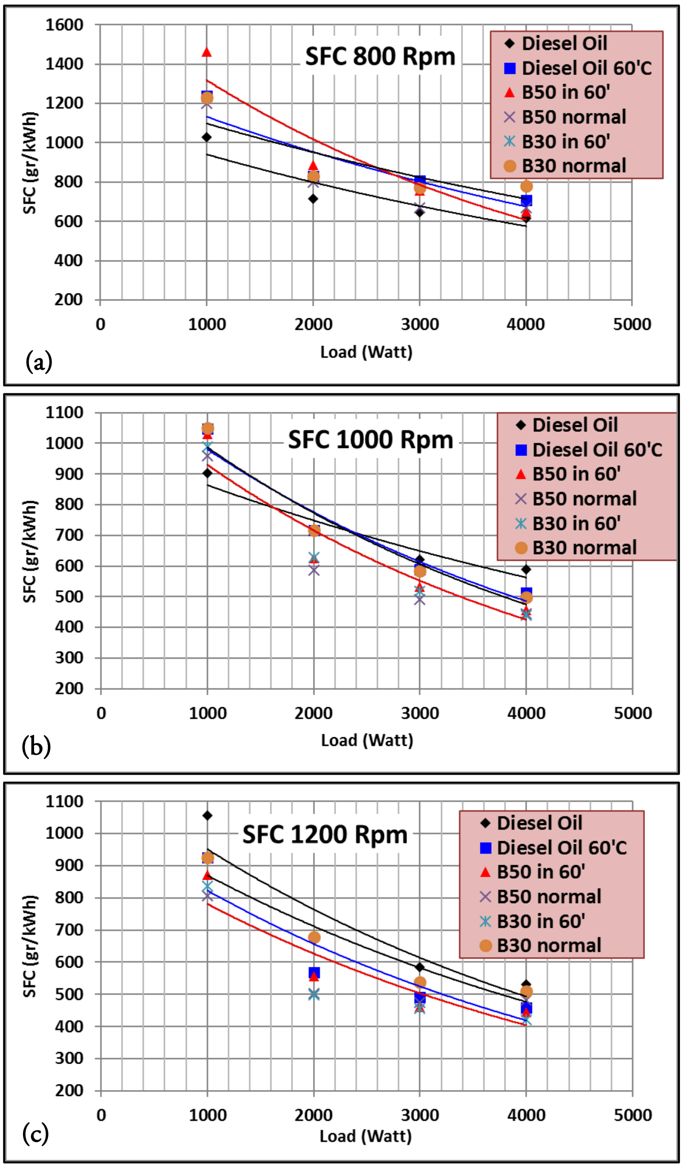

Figure 6. Comparison graph of SFC with Load for each RPM (a) 800 RPM, (b) 1000 RPM, (c) 1200 RPM

The calculation results for SFC on load variations and RPM can be seen in Table 5.

Figure 6 and Table 5 present a comparison of specific fuel consumption (SFC) to the load with variations in diesel fuel, B30, and B50 at 26 °C and 60 °C and 800 RPM rotation. The graph shows that the highest SFC value is found in the B50 fuel graph with a temperature of 60 °C at a load of 1000 watts with an SFC value of 1461.83 gr/kWh. Meanwhile, for 1000 RPM rotation, the highest SFC value is found on the graph of B30 with 26 °C at a load of 1000 watts with an SFC value of 1051.25 gr/kWh. For 1200 RPM rotation, the highest SFC value is found on the graph of diesel fuel at a load of 4000 watts with an SFC value of 1056.55 gr/kWh.

Based on the graph and table above, it can be concluded that lower SFC values are generally achieved at engine speeds of 1000 RPM and above. This is consistent with previous research on engine performance, and the current study also demonstrates that biodiesel is more efficient than Diesel Oil. Furthermore, the thermal efficiency of the diesel engine can be calculated using the data obtained from the engine running results with the following equation:

$$t = W/Ep \times 100\% \qquad (5)$$

Where :

W = Work done by the engine (kJ)

Ep = Fuel energy in a given time (kJ)

Meanwhile, the chemical potential energy of the fuel can be calculated by the formula:

$$Ep = mf \times LHV \times t \qquad (6)$$

Where LHV is the lower calorific value of the fuel in kJ/kg. It is known that the LHV value of Diesel Oil is 41,915 kJ/kg, B30 is 39,735 kJ/kg, and B50 is 38,283 kJ/kg.

So, the equation of thermal efficiency becomes as follows:

$$t = W/Ep \times 100\%$$

$$= 100\%\ (P.t)/(mf.LHV)$$

$$= 100\%\ (P.3600)/(mf.LHV)$$

Where P is in units of kW, mf is in units of kg/hour, and LHV is in units of kJ/kg.

Table 5. SFC in various RPM and Load

RPM	Load (Watt)	SFC (gr/kWh)					
		Diesel Oil	Diesel Oil (60^0)	B50 (26^0)	B50 (60^0)	B30 (26^0)	B30 (60^0)
800	1000	1028.55	1239.65	1201.15	1461.83	1228.75	1146.39
	2000	714.07	830.40	800.18	885.52	828.09	757.29
	3000	647.86	805.26	667.74	759.04	773.96	686.69
	4000	616.56	706.03	669.22	651.26	780.19	628.02
1000	1000	904.00	1048.74	958.32	1030.66	1051.25	988.56
	2000	713.72	716.15	585.93	625.82	715.51	628.19
	3000	622.01	588.31	489.87	531.50	584.98	517.89
	4000	587.76	512.51	444.42	455.85	497.83	439.19
1200	1000	1056.55	926.42	806.41	871.03	924.32	835.83
	2000	668.61	568.56	503.73	555.58	676.89	497.40
	3000	585.48	490.58	474.56	461.36	537.45	456.06
	4000	531.95	459.60	481.05	445.57	511.09	420.78

Table 6. Efficiency in various RPM and Load

RPM	Load (Watt)	Eff thermal (%)					
		Diesel Oil	Diesel Oil (60^0)	B50 (26^0)	B50 (60^0)	B30 (26^0)	B30 (60^0)
800	1000	8.35	6.93	7.83	6.43	7.37	7.90
	2000	12.03	10.34	11.75	10.62	10.94	11.96
	3000	13.26	10.67	14.08	12.39	11.71	13.19
	4000	13.93	12.16	14.05	14.44	11.61	14.45
1000	1000	9.50	8.19	9.81	9.12	8.62	9.16
	2000	12.03	11.99	16.05	15.03	12.66	14.42
	3000	13.81	14.60	19.20	17.69	15.49	17.49
	4000	14.61	16.76	21.16	20.63	18.20	20.63
1200	1000	8.13	9.27	11.66	10.80	9.80	10.84
	2000	12.85	15.11	18.67	16.93	13.38	18.21
	3000	14.67	17.51	19.82	20.38	16.86	19.87
	4000	16.15	18.69	19.55	21.10	17.73	21.53

With the above equation, it can be calculated thermal efficiency as follows:

$$t = \frac{0.259\ kW}{0.342\ kg/jam} \times 41915\ kJ/kg \times 3600 \times 100$$

$$t = 6.49\%$$

Based on the calculations presented above, a graph was generated to compare thermal efficiency with load at 800 RPM rotation using different fuel variations, including diesel fuel, B30, and B50 at temperatures of 26°C and 60°C. The resulting graph is shown in Figure 7.

The calculation results for Thermal Efficiency on load variations and RPM can be seen in Table 6.

Based on the results presented in Figure 7 and Table 6, it can be observed that the highest thermal efficiency values are obtained when using B30 and B50 fuels with temperatures of 60°C and load of 4000 watts. Specifically, the B30 fuel with 60°C temperature shows the highest thermal efficiency value of 14.45% at 800 RPM rotation. At 1000 RPM rotation, the B50 fuel with 60°C temperature and load of 4000 watts shows the highest thermal efficiency value of 21.16%.

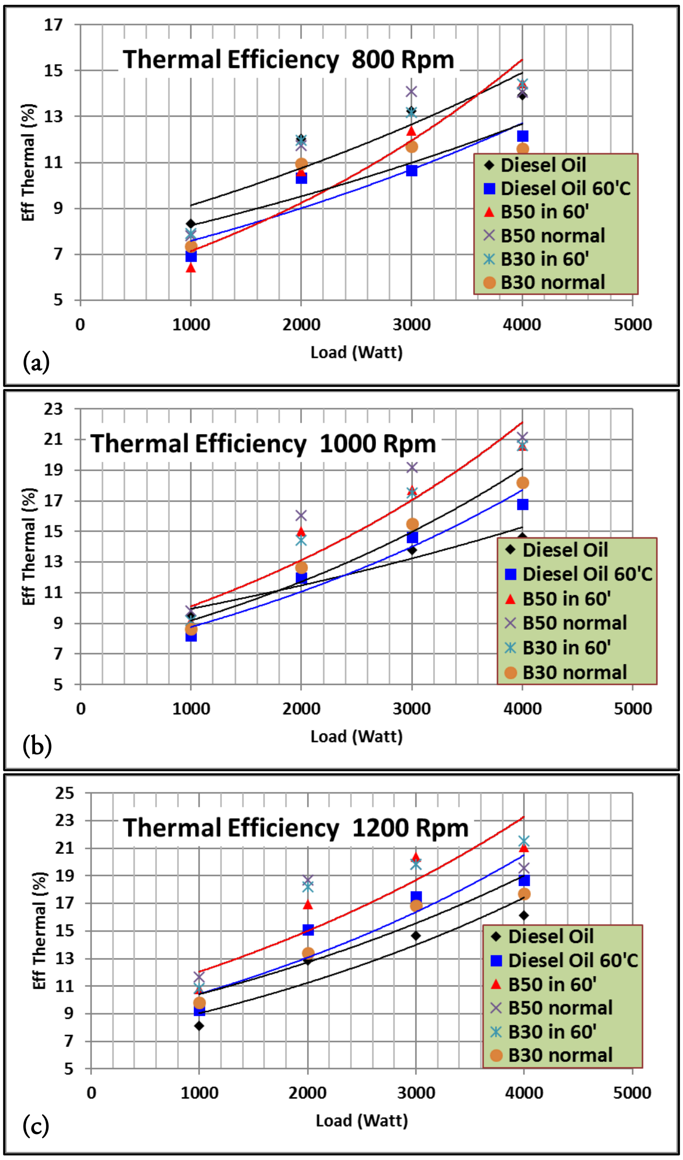

Figure 7. Comparison graph of Thermal Efficiency with Load for each RPM (a) 800 RPM, (b) 1000 RPM, (c) 1200 RPM.

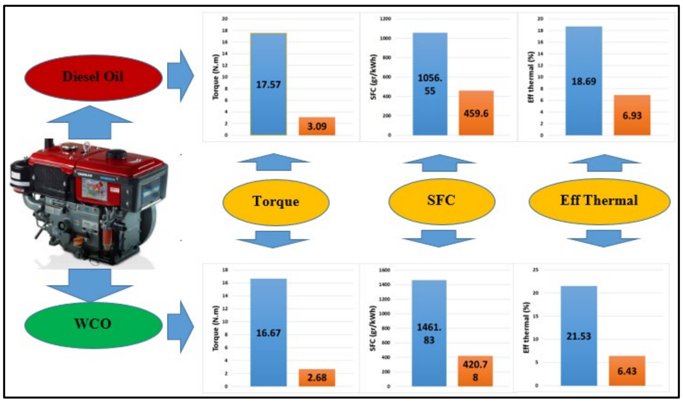

Figure 8. Comparison between torque, sfc, and thermal efficiency between Diesel oil and WCO

Based on the graph presented in Figure 7, it can be inferred that an increase in fuel temperature results in higher thermal efficiency values. This can be attributed to the decrease in fuel density and viscosity, leading to enhanced fuel combustion and improved efficiency. The maximum average thermal efficiency value was recorded for B30 fuel at a temperature of 60 °C across all RPM ranges, at 15.30%, while the minimum was found in diesel fuel at 26 °C, with a value of 11.46%. These findings are consistent with prior research investigating the use of biodiesel derived from palm oil mill effluent (POME), which yielded comparable results, with higher thermal efficiency values recorded for POME biodiesel compared to diesel oil, and an increase in thermal efficiency with increasing fuel temperature (Suardi et al., 2022).

In order for a fuel to be suitable for distribution, it must undergo testing for its properties and engine performance. In this study, B30 and B50 were used and their results were found to be within the standards set by the Biodiesel Specifications set by the Ministry of Energy and Mineral Resources of the Republic of Indonesia, particularly in terms of viscosity and density. Engine testing also showed good performance values in terms of torque, power, SFC, and thermal efficiency. These results suggest that using waste cooking oil (WCO) in biodiesel has potential for further development as a diesel engine fuel in the future.

The addition of WCO biodiesel to diesel fuel oil has an impact on the torque, power, Specific Fuel Consumption (SFC), and thermal efficiency of the diesel engine. The performance of the diesel engine increases with the increase in the blend of biodiesel from WCO to B30. Figure 8 shows that the highest torque value is found in diesel fuel with a temperature of 60 °C at 1200 Rpm with a load of 4000 watts, which is worth 17.57 Nm, while the lowest value is found in B50 fuel at 800 Rpm with a load of 1000 watts at 26 °C, which is 2.68 Nm. The lowest Specific Fuel Consumption (SFC) value is found in B30 fuel with a temperature of 60 °C at 1000 rpm rotation with a load of 4000 watts, which is 439.19 gr/kWh, while the highest SFC value is found in B50 fuel with 26 °C at 800 Rpm with a load of 1000 watts, which is 1461.83 gr/kWh. Meanwhile, the highest thermal efficiency value is found in B50 fuel with a temperature of 60 °C at 1000 rpm rotation with a load of 4000 watts, which is 21.16%, whereas the lowest efficiency value is found in B50 fuel with 26 °C at 800 rpm rotation with a load of 1000 watts, which is 6.43%. Torque and engine power with diesel fuel are still higher than those with WCO fuel, but the SFC and thermal efficiency of engines with WCO fuel are better than those with diesel fuel.

4. CONCLUSION

Based on the engine performance testing, the results indicate that WCO biodiesel can be used as an alternative fuel for diesel engines. B30 and B50 biodiesel properties are still within the standards set by the Ministry of Energy and Mineral Resources of the Republic of Indonesia for biodiesel fuel properties. Fuel temperature variations affect the fuel density and viscosity, with higher fuel temperature resulting in lower density and viscosity values. The density values of diesel fuel oil, B30, and B50 at 26 °C are 0.832 gr/ml, 0.845 gr/ml, and 0.854 gr/ml, respectively, while the viscosity values are 4.01 cSt, 4.53 cSt, and 4.89 cSt. The highest torque value is observed in diesel fuel oil at 60 °C with a value of 17.57 Nm, the lowest SFC value is found in B30 at 60 °C fuel with a value of 439.19 gr/kWh, and the highest thermal efficiency value is found in B50 at 1000 RPM rotation and 60 °C fuel with a value of 21.16%. Therefore, this study demonstrates that WCO biodiesel fuel exhibits better performance in terms of specific fuel consumption and thermal efficiency.

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