# An Investigation of Engine Performance and Exhaust Gas Emissions under Load Variations using Biodiesel Fuel from Waste Cooking Oil and B30 Blend

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# An Investigation of Engine Performance and Exhaust Gas Emissions under Load Variations using Biodiesel Fuel from Waste Cooking Oil and B30 Blend

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**Abstract**: The increasing focus on alternative fuels, especially in internal combustion engines, responds to the growing interest in reducing reliance on fossil fuels and meeting domestic fuel demands. Crude palm oil (CPO) emerges as a viable vegetable oil alternative for diesel engines. This review delves into experimental tests involving biodiesel from waste cooking oil to assess its impact on engine performance and exhaust emissions. The study utilizes waste cooking oil biodiesel and B30 as a reference fuel. Experimental procedures involve testing biodiesel performance characteristics such as brake power (BP), brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and brake torque (BT). The tests are conducted on a diesel engine coupled with a generator loaded with an incandescent lamp. Different load conditions ranging from 0.5 kW to 4.5 kW are employed. Results indicate that waste cooking oil biodiesel leads to lower BP, BT, and BTE by 1.68%, 1.7%, and 21%, respectively. Moreover, waste cooking oil biodiesel exhibits a 36% higher BSFC compared to B30. Notably, HC emissions and smoke opacity are reduced by 14.4% and 73%, respectively, with the use of waste cooking oil biodiesel. The lower calorific value, viscosity, and higher density of waste cooking oil biodiesel compared to B30 impact fuel combustion processes, influencing air-fuel mixture and combustion efficiency.

Keywords: biodiesel; diesel engines; exhaust emissions; performance; waste cooking oil

## 1. Introduction

Indonesia's current energy generation heavily depends on fossil fuels such as petroleum, coal, and natural gas, which poses significant environmental challenges in the long term. Moreover, it is evident that the energy sources in question are experiencing a steady depletion inside the nation, as indicated by the drop in oil production by a significant amount of 706 thousand barrels per day. Therefore, it is crucial to adopt renewable energy resources as a feasible option[1,2,3,4)].

Renewable energy has experienced a significant surge in utilization over the past decade. However, these renewable technologies have the limitation[5)]. The utilization of alternate energies for internal combustion engines is a fascinating item to keep on creating. The utilization of alternate fills can't be isolated from two worldwide issues, in particular the declining accessibility of raw petroleum and the rising issue of exhaust emanations[6,7)]. In its use, the main source of energy till comes from petroleum, especially in the fields of industry, electricity and transportation. In the current energy crisis, there are many ideas to diversify energy as an alternative energy by developing other energy sources[8,9)]. The rising outflow from vehicles has impacted the emphasis on air contamination which represents a serious ecological issue. This makes the change to the utilization of another fuel that is all the more harmless to the ecosystem and simple to support, in particular biodiesel[10,11,12)].

Since 2016, the Indonesian government has made it compulsory to use biodiesel fuel as an alternative fuel through Minister of Energy and Mineral Resources Regulation No. 12 of 2015. Since 2014[13,14,15,16)], the importation of fossil fuels has been reduced and energy independence has been enhanced through the use of biodiesel fuel. An increasing consumption for diesel fuel consumption is an indication of the public's high interest in diesel fuel. Indonesia's consumption of diesel fuel increased by 11.29 million kiloliters in 2011[17)]. Because diesel fuel is produced by processing crude oil, which is fuel formed from fossil, it is not a renewable fuel[18)]. As a result, the biggest problem that needs to be anticipated is the increasing consumption of diesel fuel. Crude oil will become rare and run out in 2053 if diesel fuel consumption is not controlled[19)].

Biodiesel production has the capability to utilize feedstock derived from many plant sources, including but not limited to sugarcane juice, sunflower seeds, corn, castor seeds, oil palm, and microalgae[20,21)]. Biodiesel fuel demonstrates a greater cetane number, increased oxygen content (about 10-11% higher than diesel fuel), and is devoid of aromatics or sulfur content in comparison to diesel fuel[22, 23, 24, 25, 26)]. Nevertheless, the utilization of vegetable oil in diesel engines is sometimes hindered by its high viscosity and the existence of bigger droplets during the combustion process. As a result, a trans-esterification process was employed in the production of biodiesel with the objective of reducing the viscosity value[27, 28, 29, 30, 31)].

The characteristics biodiesel fuel are high density, viscosity, and content of oxygen so that it allows other impacts to arise which can affect engine performance, especially when using different loading variations. Researchers have recently set targets to improve the properties of biofuels in terms of exhaust emissions and engine efficiency[32,33,34,35,36,37)]. Puniyani et al.[32)] examined a new source of biofuel from cottonseed oil, the findings from his research revealed that the utilization of biofuel derived from cottonseed oil led to a notable Brake Thermal Efficiency (BTE) reduction of 21.03%. Furthermore, an increasing of 25.84% in Brake Specific Fuel Consumption (BSFC) was observed. Additionally, the emissions of carbon dioxide ($CO_2$) and carbon monoxide (CO) were significantly reduced. Similarly, Uyumaz [37)] conducted an experiment using a blend of biodiesel made from mustard oil to assess the combustion and emission characteristics of direct injection diesel (DIDE) engines in various load conditions. The analysis shows the indication of the incorporation of mustard oil into diesel fuel (M10). This results the substantial reductions in CO and smoke emissions. For BSFC it is known that it increases by about 4.8% and the thermal efficiency decreases by about 6.8%. In their research, Bari and Hossain[38)] explained that the use of biodiesel fuel from palm oil for various loads resulted in lower torque and thermal efficiency values of 5.3% and 1%, respectively, and resulted in specific fuel consumption (SFC). The performance of biodiesel-fueled engines using the Citrullus colocynthis plant, as observed in the study by Alloune et al.[39)], demonstrated a consistent trend. In comparison to diesel-fueled engines, the biodiesel engines exhibited a 10% increase. Similarly, variations in load conditions led to 9.6% higher Specific Fuel Consumption (SFC). Moreover, based from Tripathi and Gupta[40)] it was concluded that high SFC caused by a high number of biodiesel content mixed in the fuel, and it can decrease the engine performance.

In the study conducted by Purcell et al.[41)], the researchers examined the operational efficiency of a Caterpillar 3304 diesel engine by utilizing biodiesel derived from soybean oil as well as a blend consisting of 30% biodiesel and 70% conventional diesel fuel (referred to as B30). Based on the findings of the conducted tests, it has been determined that pure biodiesel exhibits a power output that is 9% lower and a fuel consumption rate that is 13% higher in comparison to conventional diesel fuel. Similarly, the blended diesel variant, namely B30, demonstrates a power output that is 4% lower and a fuel consumption rate that is 4% higher. In their study, Raheman et al.[42)] observed that the utilization of biodiesel fuel derived from mahua and simarouba oil in diesel engines resulted in a significant decrease in hydrocarbon (HC) emissions by approximately 47.6% when compared to engines fueled with diesel fuel and subjected to specified loading variations. In the context of Indonesia, B30 refers to a type of diesel engine fuel that is widely distributed by the Indonesian government. Consequently, this fuel was used in the investigation[43,44)].

The direct use of biodiesel derived from palm oil as fuel has a number of implications for performance, exhaust emissions, energy output, and fuel consumption[53)]. Along with the issue of palm oil's unique characteristics from each crop. The various properties of palm oil will result in variations in the properties of biodiesel engines. The objective of this study was to assess the effects of utilizing biodiesel derived from waste cooking oil and a blend of 30% biodiesel (B30) on the performance of a diesel engine. The study aimed to examine many variables, encompassing power output, specific fuel consumption, thermal efficiency, torque, and exhaust emissions such as hydrocarbons (HC) and smoke opacity. These criteria were assessed with due consideration to particular loading fluctuations The novelty of this study lies in its comparative analysis of biodiesel derived from waste cooking oil and blend diesel (B30).

## 2. Materials and Methods

This research examines two types of diesel fuel, namely 100% biodiesel produced from waste cooking oil. The second option involves the use of a blended diesel fuel, consisting of 30% biodiesel from waste cooking oil and 70% from crude oil. Table 1 displays the parameters of the engine utilised in this study, which is a Jiang Fa diesel engine with a cylinder volume of 402 cc. The lubricating oil use in this case was Pertamina Meditran SX Bio SAE 15W-40. The halogen lamps use for engine loading are powered by a 5 kW electric generator that is connected to the diesel engine. The load is adjusted in increments of 0.5 kW using a halogen bulb. Using an opacity meter to measure the opacity of the smoke produced and an exhaust gas analyzer to test exhaust emissions Figure 1 shows the test setup in broad strokes. Table 1. shows the specification for diesel engine. Figure 2 depicts the experiment's conceptual diagram, and the conditions of the experimental test can be seen in Table 2.

Table 1. Diesel engine specification

| **Diesel Engine** | **Specification** |
|---|---|
| Model | RD180 |
| Type | 4 horizontal steps |
| Number of Cylinders | 1 |
| Fill Cylinder (cc) | 402 |
| Continuous Power (kW) | 4.1 at 2200 rpm |
| Maximum power (kW) | 4.85 at 2200 rpm |
| Maximum Torque (kg.m) | 2.36 at 1800 rpm |
| Combustion System | Direct Injection |
| Cooling System | Radiator |


**Fig. 1:** Experimental setup

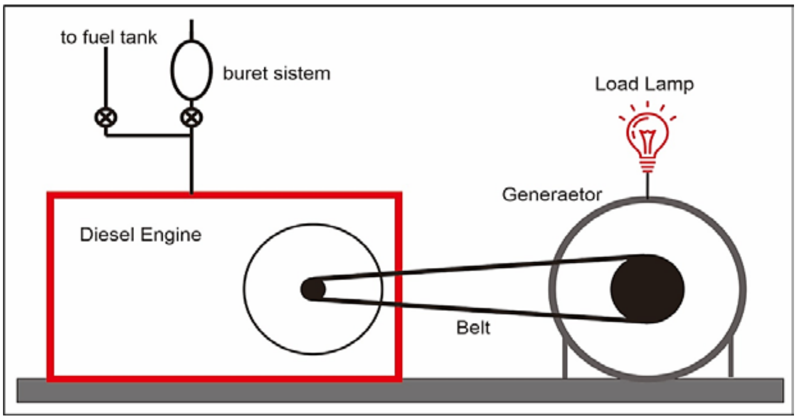


**Fig. 2:** Schematic diagram for the experiment

Table 2. Test Experiment Conditions

| **Parameter** | **Biodiesel engine cooking oil** | **B30 Engine** |
|---|---|---|
| Fuel | Biodiesel waste cooking oil (100%) | B30 (70% diesel fuel from crude oil + 30% Biodiesel waste cooking oil) |
| Machine rotation | 2200 rpm | 2200 rpm |
| Lubricants | Pertamina Mediteran SX Bio SAE 15W-40 | Pertamina Mediteran SX Bio SAE 15W-40 |
| Cooler | Prestone | Prestone |
| Loading | 0.5; 1; 1.5; 2; 2.5; 3; 3.5; 4, and 4.5 kW | 0.5; 1; 1.5; 2; 2.5; 3; 3.5; 4, and 4.5 kW |

In this study, CV. Artha Metro Oil's waste cooking oil biodiesel was utilized as the fuel for the two machines, while B30 was sourced from the Pertamina Petrol Station. Table 3 provides a comparison of the fuel specifications for both fuels. Additionally, the same lubricant, Pertamina Mediteran SX Bio SAE 15W-40, produced by *PT. Pertamina Lubricants*, was employed for both machines. Lubricant is used for smooth performance of interrelated part of the diesel engines[54)].

Shaft power is measured by dividing the total loading output power by the generator efficiency. Then the machine is connected to supporting equipment such as a burette to measure fuel consumption per unit time, rpm sensors, as well as equipment to measure current and voltage. Measuring fuel consumption using a manual technique with a burette that has a capacity of 20 ml, then measuring the time the engine spends 20 ml of fuel using a stopwatch.

Table 3. Fuel specifications.

| No. | Test Parameters | Test Method | Unit | Result of Biodiesel | Result of B30 |
|---|---|---|---|---|---|
| 1 | Density at 40 °C | ASTM D 1298-12b | kg $m^{-3}$ | 862.4 | - |
| 2 | Density at 15 °C | - | kg $m^{-3}$ | - | 845.7 |
| 3 | Kinematic viscosity at 40 °C | ASTM D 445-06 | $mm^2/s$ | 4.53 | 2.92 |
| 4 | Cetane Number | ASTM D6980-12 | | 61.0 | 56.7 |
| 5 | Flash Point | ASTM D 93-02 | °C | 177 | 65 |
| 6 | Carbon residue | ASTM D 4530-07 | % ($mm^{-1}$) | - | zero |
| | (in the original example) | | | 0.040 | - |
| | (in 10% distillation dregs) | | | 0.160 | - |
| 7 | Distillation temperature 90% | ASTM D 1160-06 | °C | 350 | 344 |
| 8 | Oxidation stability | EN 15751-2009 | Minute | 1200 | - |
| | Induction period | | | | >2880 |
| | Rancimat method | | | | |
| 9 | Color | ASTM D 1500 | Colour ASTM | 1.0 | 1.1 |
| 10 | Methyl Ester Content | Calculation | % ($mm^{-1}$) | 98.24 | - |
| 11 | FAME content | - | % v/v | - | 20 |
| 12 | Water content | ASTM D 6304 | ppm | 267 | 159.63 |

## 3. Results and Discussions

### 3.1 Brake power and brake torque

In Fig. 3, the results of evaluating the engine's braking power (BP) and brake torque (BT) under varying loads are shown graphically 85% efficiency for the electric generator is assumed based on the analysis' findings and the efficiency of the belt is 98%[55], the average BP value is obtained produced by a biodiesel-fired engine of waste cooking oil is 1.68% lower than a B30-fueled engine. Engines fueled by waste cooking oil biodiesel have an average BP value of 2.37 kW and engines fueled by B30 have an average BP value of 2.42 kW. Meanwhile, the average BT value produced by a biodiesel fueled engine is 1.7% lower than a B30 fueled engine. Engines fueled by waste cooking oil biodiesel have an average BT value of 10.31 Nm and engines fueled by B30 have an average BT value of 10.48 Nm.

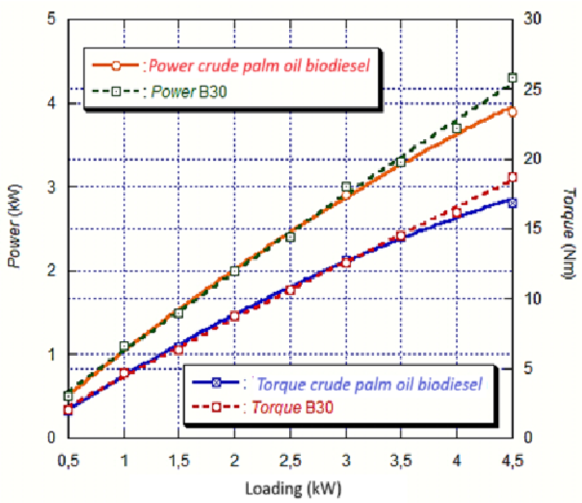


**Fig. 3:** Graph of power and torque against loading

Engines fueled by waste cooking oil biodiesel tend to exhibit a lower average brake power (BP) compared to those fueled by B30. This can be attributed to a higher value of biodiesel viscosity with lower calorific value[52]. According to[53], the fuel atomization conditions worsen due to a high value of viscosity and can affects the process of mixing fuel and air during the combustion. Biodiesel fuel waste cooking oil has 39.9 MJ/kg in calorific value[52] and B30 fuel has 43.828 MJ/kg in calorific value[53]. While according to Table 3, the waste cooking oil biodiesel fuel has viscosity value of 4.53 $mm^2/s$ and B30 fuel has the viscosity value of 2.92 $mm^2/s$. This higher thickness and thickness worth will make the drops from the fuel atomization process bigger when contrasted with fills that have lower consistency and thickness values, for instance B30 fuel. The drop breadth of the huge atomization will influence the surface contact between the fuel and air to be more modest with the goal that the air and fuel combination turns out to be less homogeneous. This less homogeneous mixture in the combustion chamber will cause the fuel and air cobustion to be less perfect. In general, incomplete combustion will result in lower brake power and brake torque.

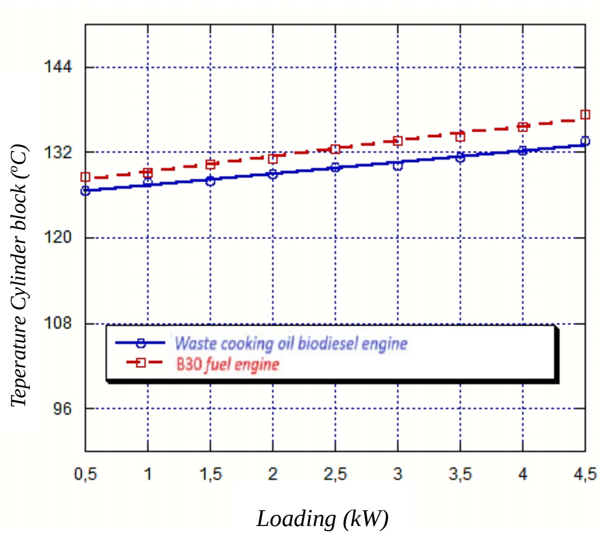


**Fig. 4:** Cylinder block temperature graph against loading

The findings of this test align with the results obtained in tests conducted by other researchers. Mofijur et al., [51] directed research on the power produced by a combination of B5 and B10 fuel from palm oil with diesel fuel as a correlation. In view of the consequences of his exploration, the power produced by motors energized by B0 is higher than motors filled by B5 and B10 and the power created by motors filled by B5 is higher than motors powered by B10.

According to the data presented in Figure 3, it can be observed that the brake power (BP) and brake torque (BT) of engines powered by waste cooking oil and B30 biodiesel exhibit an upward trend when the load is progressively increased. The growing temperature of the cylinder block has an impact on this. According to the data presented in Figure 4, it can be observed that there is a positive correlation between the load applied and the temperature of the cylinder block in both waste cooking oil biodiesel and B30 engines. As the load increases, the temperature of the cylinder block also increases. The mean temperature of the cylinder block in engines fueled by waste cooking oil biodiesel is recorded as 130 °C, while engines fueled by B30 exhibit an average temperature of 132.5°C. Increasing the temperature of the cylinder block has the effect of enhancing combustion, hence resulting in enhanced combustion efficiency. As a consequence, this leads to enhanced combustion of the air-fuel combination, resulting in increased braking power (BP) and brake torque (BT) outputs of the engine at the culmination of the combustion process. This finding is supported by the research conducted by Dharmaraja et al.[52], which states that an increase in combustion temperature leads to a corresponding increase in ignition, hence resulting in an augmentation of the power generated by the engine.

### 3.2 Brake Specific Fuel Consumption

Following the conducted tests, we gathered data on the duration required for both engines to consume 20 ml of waste cooking oil and B30 biodiesel fuel. The results of the brake specific fuel consumption (BSFC) test for the two machines under various conditions of loading are showed graphically in Figure 5. The BSFC calculation is based on the density of the fuel, namely 862.4 kg/m$^3$ for waste cooking oil biodiesel and 845.7 kg/m$^3$ for B30 fuel (Table 3). Based on the analysis results, the average BSFC value produced by waste cooking oil biodiesel fueled engines was 36% higher than B30 fueled engines. Engines fueled by waste cooking oil biodiesel have an average BSFC value of 0.5 kg/kW.hour and engines fueled by B30 have an average BSFC value of 0.36 kg/kW.hour.

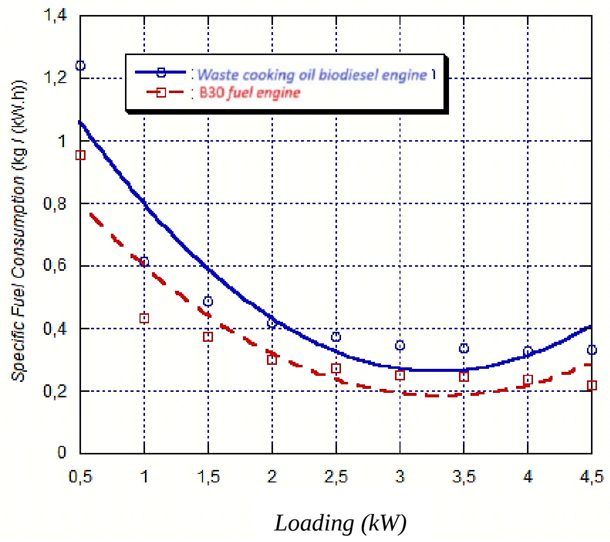


**Fig. 5:** BSFC against loading graphic

The average BSFC value is higher for engines fueled by waste cooking oil biodiesel because biodiesel fuel for waste cooking oil has the characteristics of lower content of energy, higher oxygen content, and higher density value than B30 fuel. Subsequently a lower energy content and higher fuel thickness requires a more noteworthy mass progression of fuel to accomplish a similar energy yield from the motor, prompting an expansion in BSFC to make up for the diminished synthetic energy in the fuel. The concentration of biodiesel in the fuel mixture affects the rise in brake specific fuel consumption (BSFC). A higher biodiesel blend level results in a greater mass flow of fuel being consumed for the same injector nozzle clearance, leading to an increase in BSFC. According to the data presented in Figure 5, it can be shown that the BSFC of engines fueled by waste cooking oil biodiesel and B30 tends to decrease up to a load of 3 kW. However, beyond this point, the BSFC shows a slight increase as the load is further increased. This is caused by the increasing combustion temperature factor in the cylinder heads of the two engines. This increase is evidenced by the cylinder head temperature graph in Figure 6. The average cylinder head temperature for a biodiesel fueled waste cooking oil engine is 138 °C and for a B30 fueled engine it is 143 °C.

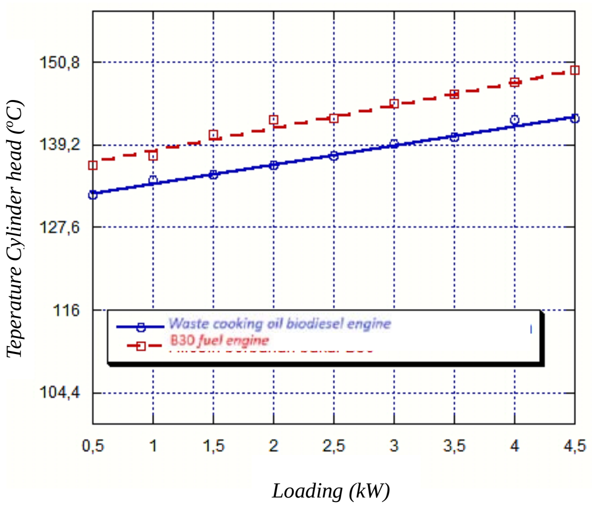


**Fig. 6:** Cylinder head temperature graph against loading

Within the boundaries of the combustion chamber, the elevation of temperatures leads to a more efficient combustion process, hence leading to a subsequent augmentation of pressure. The increased pressure mentioned above subsequently improves many engine performance characteristics such as thermal efficiency, power output, and torque. Zaid[53] states that the decrease in fuel consumption can be attributed to various factors, including: (1) the occurrence of micro-explosion phenomenon, (2) an augmentation in incoming air due to strengthened spray momentum, (3) the initiation of premix combustion resulting from delayed ignition, (4) an elevation in air mixture ratio due to the presence of water in the fuel, and (5) the generation of additional gas, a combustion byproduct, caused by the water and emulsion.

### 3.3 Brake Thermal Efficiency

The calorific values of the two fuels are assumed in the calculation of brake thermal efficiency (BTE). The results of the BTE testing of the two machines for variations in loading are presented in the form of graphic in Figure 7. Based on the analysis results, the average BTE value produced by the waste cooking oil biodiesel fueled engine is 21% lower than the B30 fueled engine. Waste cooking oil biodiesel fueled engines have an average BTE value of 21.5% and engines fueled by B30 have an average BTE value of 27.3%.

Based on the graph in Figure 7, the low BTE value in waste cooking oil biodiesel fueled engines is due to the higher BSFC value due to lower energy content in waste cooking oil biodiesel fuel. A decrease in energy content necessitates a higher fuel consumption in order to generate equivalent work. An increase in BSFC and a decrease in engine brake power resulted in a decrease in BTE. Therefore, the BTE value is influenced by the BSFC value.

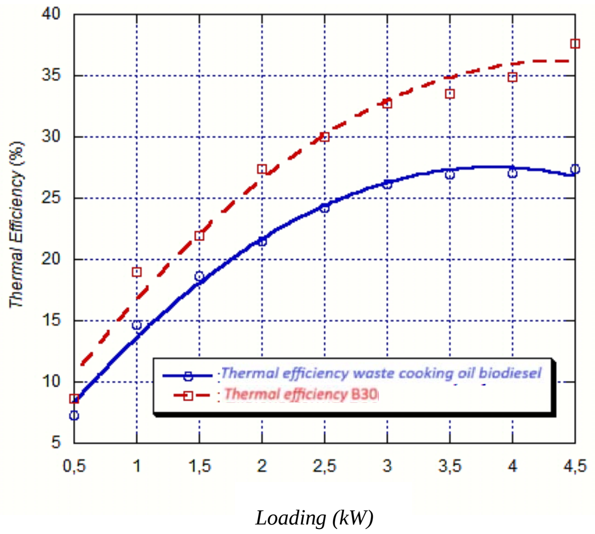


**Fig. 7:** Thermal efficiency graph against loading

Figure 7 demonstrates a consistent increase in the thermal efficiency of engines utilizing waste cooking oil biodiesel and B30 as the load increases. This can be attributed to the direct relationship between thermal efficiency and power output, as does the inverse correlation with the amount of injected fuel in the combustion chamber. Therefore, when power output increases and fuel injection decreases, the engine's thermal efficiency improves, and vice versa.

### 3.4 Hydrocarbon (HC) and Smoke Opacity

Tests for hydrocarbon (HC) exhaust emissions and smoke opacity are introduced in graphical structure in Figures 8 and 9. In light of the analysis results, the typical worth of HC outflows delivered by a biodiesel energized waste cooking oil motor is 14.4% lower than a B30 fueled engine. Engines fueled by waste cooking oil biodiesel produce an average HC emission value of 93.1 ppm vol and engines fueled by B30 produce an average HC emission value of 109 ppm vol.

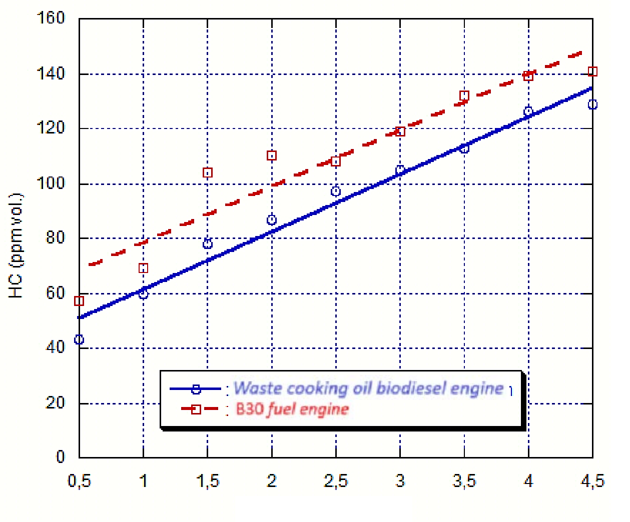


**Fig. 8:** Graph of hydrocarbon (HC) emissions against loading

In addition, when light is displayed directly on the exhaust gas, using an opacity meter, the smoke opacity are measured by measuring the concentration of smoke based on the strength of the absorbed and scattered light. The principle of measurement is to calculate the amount of light absorbed by the flue gas particles after the exhaust gas is drawn into the sample chamber. The average absorption coefficient, which indicates that the value of light absorption by exhaust gas particles produced by engines using waste cooking oil biodiesel is 73% lower than that of engines using B30 fuel, is derived from the analysis results. The average absorption coefficient value of waste cooking oil biodiesel engines is 17.44%, while the average absorption coefficient value of B30 engines is 65%.

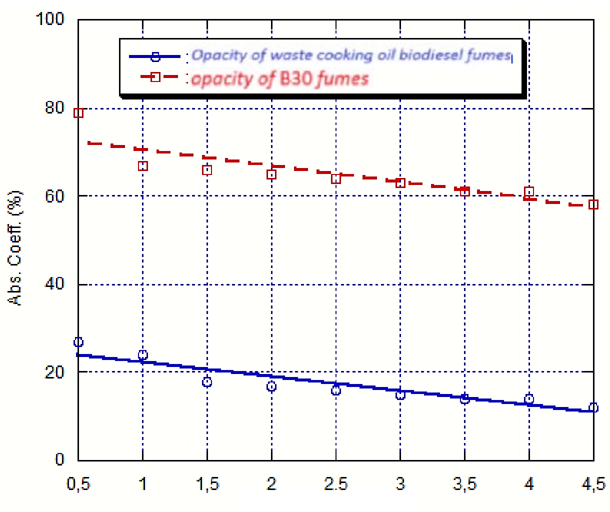


**Fig. 9:** Graph of smoke opacity against loading

It is known from the graphs in Figures 8 and 9 that engines powered by waste cooking oil biodiesel have lower HC emission values than engines powered by B30. Because biodiesel fuel contains more oxygen than B30 fuel, the combustion process will be more complete and produce less unburned fuel. This is influenced by the characteristics of biodiesel fuel.

The concentration of HC in the exhaust gas of engines powered by waste cooking oil biodiesel will decrease as a result, reaching an average of 93.1 ppm vol. Suthrispok's research[52)] demonstrates that biodiesel fuel has an oxygen content of 11% wt, while Jaroonjitsathian et al.[55)] B30 fuel has an oxygen content of 2.6% wt. The oxygen content increases, resulting in a combustion chamber with more oxygen. This results in more complete combustion, with very little unburned fuel from the fuel and air mixture inside combustion chamber, and the HC value will also be detected by the gas analyzer. The higher oxygen content in biodiesel fuel significantly enhances combustion efficiency in the chamber. Ozsezen et al., [56)] that the elevated oxygen content in biodiesel could potentially augment the quantity of fuel combusted during the premixed phase.

The exhaust gas opacity of waste cooking oil biodiesel fueled engines is detected to be very low, with an absorption coefficient of 17.4%, which means that the soot produced by the combustion of waste cooking oil biodiesel is less when compared to the soot from burning B30 which has a value of 65%. From the test results, combustion of waste cooking oil biodiesel-fueled engines produces soot with a tendency of white smoke color. In general, the color of white smoke that is produced from combustion in the engine is caused by unburned fuel or a high water content in the fuel. In the case of waste cooking oil biodiesel fuel, unburned fuel is relatively low as shown in the low HC value. So that the white color of the smoke from combustion is not caused by unburned fuel but rather caused by the high water content in waste cooking oil biodiesel fuel so that the exhaust gas produced by combustion will contain more water vapor which will appear white in color.

## 4. Conclusion

Based on the research findings, it can be concluded that the utilization of biodiesel fuel derived from waste cooking oil generally results in a reduction of brake power by around 1.68%, brake torque by approximately 1.7%, and brake thermal efficiency by approximately 21%. In contrast, when considering brake specific fuel consumption (BSFC), engines fueled by waste cooking oil biodiesel have a significantly elevated value of 36% in comparison to engines powered by B30. Furthermore, the empirical findings pertaining to hydrocarbon (HC) emissions and smoke opacity demonstrate that the utilization of waste cooking oil biodiesel fuel leads to a notable decline of 14.4% in HC emissions and a substantial reduction of 73% in smoke opacity when compared to B30 fuel. The impacts discussed in this context are primarily influenced by two key factors: the increased density coupled with lower calorific value, as well as the viscosity, of waste cooking oil biodiesel fuel. All of these qualities limit the conditions required for fuel atomization and impose an influence on the process of fuel-air mixing during combustion. The selection between waste cooking oil biodiesel and B30 is depend upon certain priorities. If the primary objective is to decrease hydrocarbon (HC) emissions and reduce smoke opacity, waste cooking oil biodiesel may be preferred. However, if the objective is to prioritise the maintenance of higher braking power, brake torque, and brake thermal efficiency, it may be more appropriate to consider utilising the B30.

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