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Performance and Emission Characteristics of a Diesel Engine Fueled with Calophyllum Inophyllum Biodiesel and Gasoline Additives

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Abstract. Production of fuel oil in Indonesia from year to year continues to decline. Calophyllum inophyllum biodiesel fuel is an alternative fuel that can be used in diesel engines. Gasoline is a fuel that can improve the characteristics of biodiesel. This research uses petrodiesel fuel, B30 (70% petrodiesel and 30% calophyllum inophyllum biodiesel), and B30 added with gasoline with a concentration of 10% vol/vol. The experiment was carried out with a direct injection single cylinder diesel engine connected to a generator that was used as a dynamometer and a gas analyzer was installed. Tests were carried out using lamp loads of 200, 400, 600, and 800 watts at a constant engine speed of 2000 rpm. The results of this research inform that the addition of gasoline to B30 fuel can reduce fuel consumption and increase thermal efficiency. The role of gasoline can also reduce CO, HC, and CO_2 emissions. The addition of gasoline needs to be investigated further so that it can be applied to industry and transportation.

INTRODUCTION

Indonesia's energy outlook (2019) data shows a declining trend in oil production. In 2009, oil produced was 346 million barrels (949 thousand bpd), and in 2018 it was around 283 million barrels (778 thousand bpd). The decline was due to the aging of the main oil producing wells. The decline was due to the aging of the main oil producing wells, while the production of new wells was relatively limited. In order to fulfill this need, Indonesia imports crude oil from the Middle East. Dependence on imports reaches around 35% and can be expected to increase in the next few years.

Fossil fuels that tend to decline and dependence on imports are high, causing many researchers to conduct research on biodiesel in an effort to help fill energy needs. Biodiesel is an alternative fuel produced from renewable resources [1]. Ethyl and methyl esters of long-chain fatty acids are other names for biodiesel obtained from renewable sources of raw materials such as vegetable oils or animal fats[2]. Biodiesel has good potential to increase fuel demand, because biodiesel is an alternative resource that is renewable and environmentally friendly [3][2]. Biodiesel has several advantages when compared to petrodiesel fuels, such as biodiesel made from microalgae which has a low viscosity value, high cetane number and produces low emissions [4]. Jatropha curcas, Pongamia pinnata, Calophyllum inophyllum, Croton megalocarpus and Azadirachta indica are the basic ingredients for making biodiesel that can be found in distantly countries [5]. Research on biodiesel is mostly done with vegetable ingredients such as Calophyllum inophyllum which is in the primary category as fuel because it does not conflict with food [6]. Calophyllum inophyllum has the potential as biodiesel fuel because of its high oil content [7]. Calophyllum inophyllum oil has a high acid content [8]. Calophyllum inophyllum is very suitable as manufacturing material for biodiesel in the future because its yield content of 40% - 70% is relatively high compared to jatropha curcas, which is 40% - 60% [7][5][9]. Research on Calophyllum inophyllum biodiesel in diesel engines tends to be lower than pure diesel [10]. Viscosity and high pour point are characteristics of biodiesel that affect performance in conventional diesel engines [11][12]. Mixing B20 produces good performance but with the high mixture of diesel oil, the results of HC, CO, and smoke emissions are higher [13]. B20 fuel requires treatment to work as optimally as diesel oil.

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Research on biodiesel in an effort to increase the performance of diesel engines has been carried out by several researchers in several countries. Gasoline injection into the intake manifold with the use of B20 fuel reduces soot emissions by 4.52% [12]. Mixing gasoline with biodiesel improves the characteristics of biodiesel properties such as reducing viscosity [11]. The used cooking oil biodiesel addition of gasoline as done by Gad & El-seey that the addition of gasoline, can increase the pressure of cylinder. Gasoline blended fuel can reduce NOx, CO, opacity emissions and UHC by 20%, 25%, 30%, and 30% compared to biodiesel [14]. The role of gasoline at low and medium loads reduces emissions, while at high loads it can reduce soot [11]. Mixing gasoline in biodiesel produces better performance as has been done before, so mixing gasoline in Calophyllum inophyllum biodiesel needs to be done.

The performance of a diesel engine depends on the characteristics of the fuel used. Biodiesel renewable energy and Gasoline Compression Ignition technology are interesting topics to solve problems. This study discusses compression ignition engines made from a mixture of B30 petrodiesel - Calophyllum inophyllum biodiesel and gasoline in several volume percentages. The purpose of mixing B30 petrodiesel - Calophyllum inophyllum biodiesel with gasoline is to improve the characteristics of the B30 petrodiesel - Calophyllum inophyllum biodiesel so as to produce better diesel engine performance.

METHODOLOGY

Research on the performance of diesel engines using CIME biodiesel and gasoline is carried out in stages. Starting from fuel mixing, testing fuel characteristics, and testing fuel performance on diesel engines.

Preparing the Fuel

In this study, the biodiesel fuel used was Calophyllum inophyllum methyl ester (CIME) biodiesel. Other fuels such as petrodiesel and gasoline can be obtained from PT. Pertamina. gasoline uses the premium name on the PT Pertamina. The tested fuel is a mixture of the three fuels with the names B0, B30, and B30G10. Table 1 shows the mixture ratio of each fuel.

TABLE 1. The mixture ratio of fuel

Sample	***Petrodiesel* (Vol%)**	**CIME (Vol%)**	***Gasoline* (Vol%)**
B0	100	0	0
B30	70	30	0
B30G10	63	27	10

FIGURE 1. The process of mixing the fuel

Fig. 1 is the process of mixing the fuel. The prepared CIME biodiesel, petrodiesel and gasoline were mixed by volume ratio and stirred using a magnetic stirrer for 2 to 10 minutes. Gasoline and biodiesel can dissolve in each other at any proportion [11].

Fuel Test

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The fuel was tested for density, viscosity, calorific value, flash point, and cetane number to determine the effect of mixing each fuel at the Brawijaya University Motor Fuel Laboratory and Oil and Gas Human Resources Development Center. The character of each fuel is presented in the table 2.

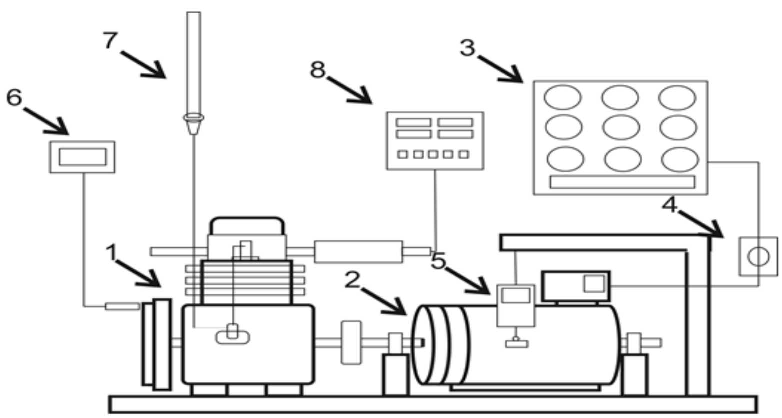
TABLE 2. Properties of Petrodiesel Fuel, B30 and B30G10

Fuel	Viscosity	Density	Calorific Value	Flash point	Cetane number
	@40^0 cSt	@15^0 g/ml	Mj/kg	^{0}C	
	ASTM-D445	ASTM-D1298	ASTM-D240	ASTM-D93	ASTM-D613
B0	2.97	0.844	45.2	71.5	48
B30	3.30	0.858	44.1	76.9	51.5
B30G10	2.69	0.848	45.1	69.7	51.1

In the table 2, it can be seen that the addition of 10% gasoline to B30 fuel can reduce the density, viscosity, flash point, and cetane number. Another advantage of adding gasoline is the increase in calorific value. These results are accordance to those by the literature [14].

Set-up Experiment

Performance testing was carried out at the Energy Conversion 1 Laboratory of the Department of Mechanical Engineering, University of Jember using a diesel engine that was connected directly to the ST-3 electrical generator as an electrical dynamometer. The technical specifications of the diesel engine can be seen in the table 3. Exhaust emissions use HG-520 mounted on the exhaust manifold.



Description :

1. Diesel engine
2. Generator
3. Lamp
4. Switch
5. Digital scales
6. Tachometer
7. Burret
8. Gas Emission Analyzer

FIGURE 2. Schematic Diagram of the Experimental Setup

The arrangement of the schematic diagram of the test can be seen in the fig. 2. The diesel engine is operated at a constant speed of 2000 rpm and is given multiple loads. The electrical load consists of incandescent lamps with a power consumption of 200 Watts to 800 Watts. The load is arranged with 200 Watts intervals. Data collection of fuel consumption and exhaust emissions is carried out under the same conditions simultaneously. The experiment was repeated three times.

TABLE 3. Engine Specification

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Description	Spesification
Model	MDX-170 F
Engine model	OHV, 4 Stroke, Single cylinder with air cooling diesel engine
Bore x *Stroke* (mm)	70 × 55
Cylinder (cc)	211
Compression comparison	1:18.5
Injector pressure (MPA)	22
Output value (kw)	2.8
Max. Output	3.1
Output value (rpm)	3600
Dimension (mm)	450 × 360 × 450
Compression pressure (Kg/cm2)	17.5

RESULT AND DISCUSSION

Brake Specific Fuel Consumption

Brake Specific Fuel Consumption is the amount of fuel consumption used by the engine to produce 1 kW of power in 1 hour. BSFC is used to show the effectiveness of energy consumption of fuels with different energy content (calorific value) [10]. Fig. 3 shows fuel consumption (kg/kWh) against engine load (W).

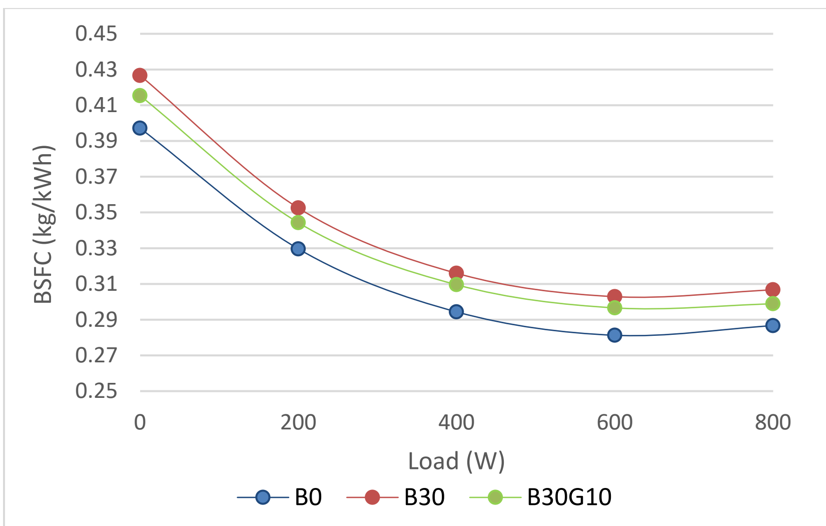

FIGURE 3. Variation of Brake Specific Fuel Consumption (BSFC) Value towards Load

The graph shown in the fig. 3 that all fuels produce the same trend line. The addition of the load causes the BSFC to decrease, this result is in line with the research conducted[14]. The large value at minimum load is due to the amount of fuel used is not proportional to the power generated. The fuels have the highest BSFC, namely B30, B30G10, and B0 respectively. B30 fuel has a higher BSFC value than B0, because B30 fuel has a high viscosity, lower heating value, and contains oxygen. These results are accordance to those by the literature [15]. Fuels with high calorific value and low viscosity can increase the oxidation rate in the combustion process [14]. B30G10 fuel has a low BSFC value because gasoline can increase the calorific value and reduce the viscosity. A low BSFC value at full load indicates better engine performance. The smaller the BSFC value, the more effective the use of fuel energy to produce better engine performance [10].

Brake Thermal Efficiency

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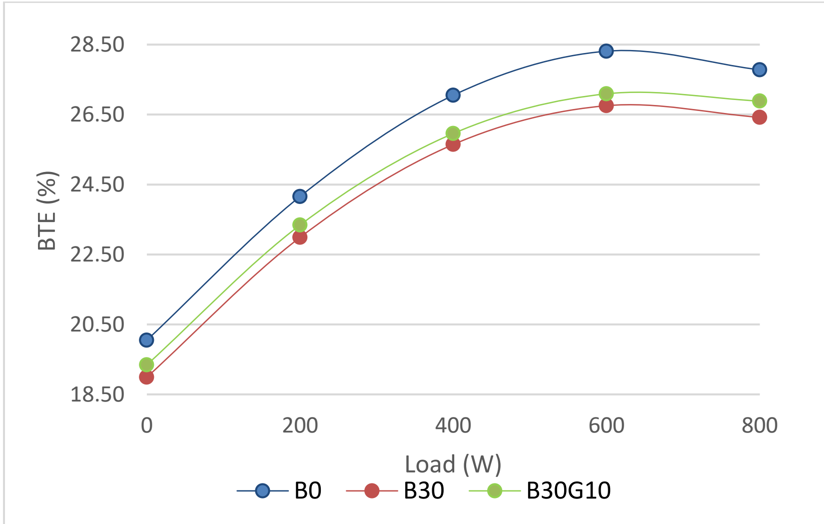

FIGURE 4. Variation of Percentages for Brake Thermal Efficiency (BTE) towards Load

Fig. 4 shows the results of BTE increasing when the load is added. BTE decreases when the load exceeds the engine capacity. These results are in accordance with the research of Gad & El-seesy and Saravanan et al.[14][15]. B30 fuel has a lower BTE value than B0 because biodiesel fuel has a lower heating value than diesel oil [14]. The order of the highest BTE is B0, B30G10, and B30. B30 fuel added to gasoline has the result of an increased BTE value. B30G10 has better value than B30. The addition of gasoline with a percentage of 10% exceeds the value of BTE B30 because gasoline can increase calorific value and reduce the density. This result is in similar with the research of Gad & El-seesy [14] which states that the addition of gasoline can increase BTE.

CO Emission

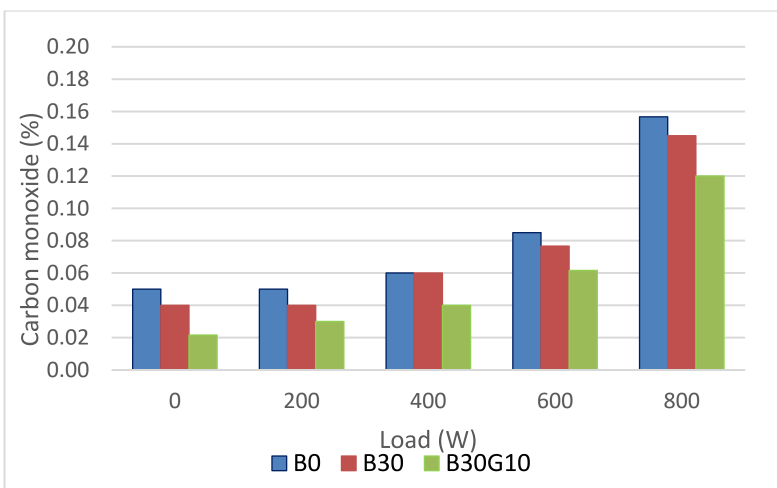

FIGURE 5. Variation of Percentages for Carbon Monoxide (CO) Emissions towards Load

Zero to full load an increase in all fuel used. This result is due to the increase in engine load, the ratio of the fuel mixture becomes richer as the results of research conducted by Gad [16][14]. The fuels with the highest order of CO emissions are B0, B30, and B30G10. B30 fuel has a lower CO emission value than B0, because the addition of biodiesel to diesel oil can change the viscosity, as shown in the table 2 Biodiesel has a better oxidation rate than diesel oil [15]. Combustion of biodiesel produces a lot of CO_2 compounds because biodiesel contains oxygen and this process can help minimize CO emissions. The addition of gasoline to B30 fuel reduces CO emissions. Fig. 5 shows that the more gasoline blends in B30 fuel, the lower CO emissions produced, because the addition of gasoline to B30

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fuel produces a lower viscosity, thus improving the injection characteristics and the combustion process react. These results are the same as the research from Gad & El-seesy [14].

HC Emissions

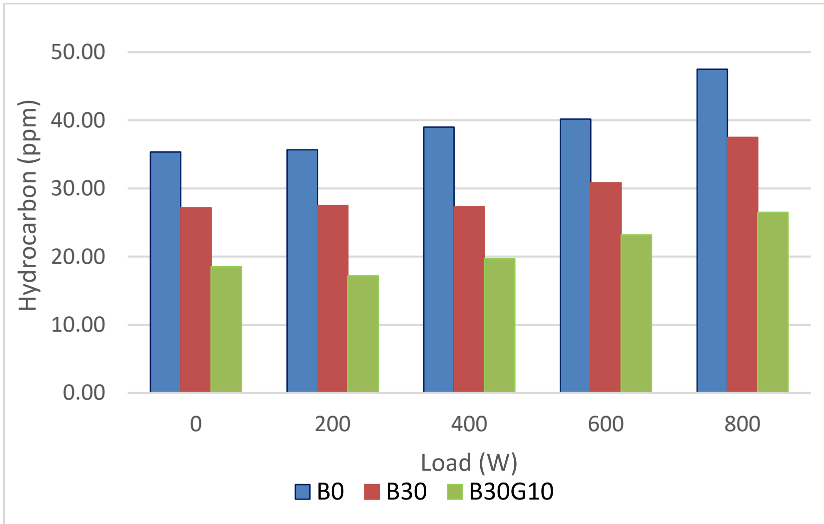

FIGURE 6. Formation of Hydrocarbon (HC) Emissions against Load

HC emissions on each fuel show different results, but at each change in engine speed shows the same trend line. These results are the same as research by Gad & El-seesy [14]. B0 fuel produces the highest HC emission, which is 45.5 ppm at 2000 Rpm engine speed and 800-watt load.

Diesel fuel with the addition of 30% CIME biodiesel (B30) showed a decrease in HC emissions. The lowest HC emission is obtained by B30G10 fuel. This is because the addition of gasoline will reduce the viscosity, thus improving fuel spray. The addition of gasoline also changes the stoichiometric mixture of the fuel so that in this research the B30G10 fuel produces lower HC emissions.

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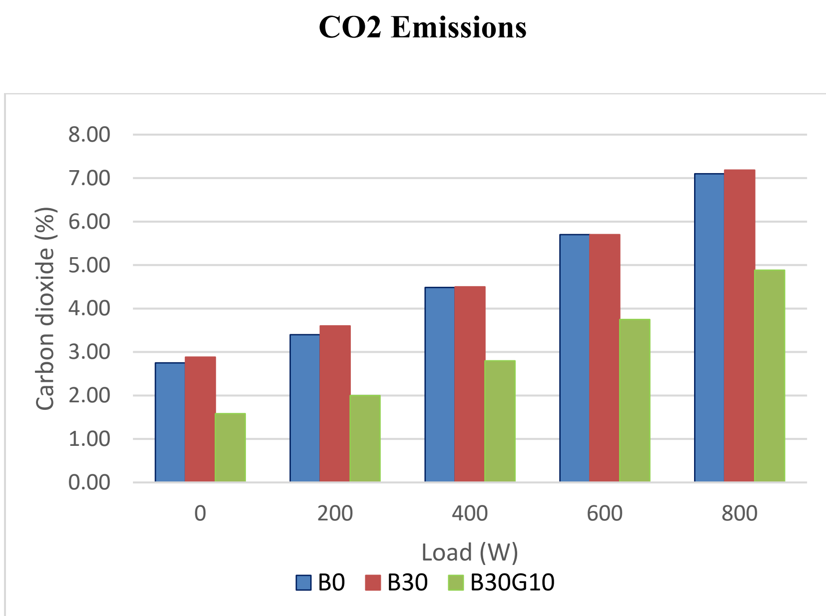

FIGURE 7. Variation of Percentages for Carbon Dioxide (CO_2) Emissions against Load

The emission of CO_2 exhaust gas depends on various factors such as viscosity, atomization process, compression ratio, oxygen, engine speed, and others [4]. CO_2 emissions have the same trend line for all fuels, which is higher at high loads. B0 fuel has the highest CO_2 emission value. B30 fuel almost coincides with B0. With the addition of CIME biodiesel, CO_2 emissions have an insignificant change but CO_2 emissions are higher. This is because biodiesel contains oxygen so that the biodiesel mixture burns more completely. These results are the same as the research by Maawa et al. [17]. The fig. 7 shows that the fuel added with gasoline reduces CO_2 emissions. This result can be attributed to the lower amount of carbon in gasoline compared to diesel fuel so that the percentage of CO_2 emissions produced is much lower.

CONCLUSION

The main problem in using CIME biodiesel fuel is characteristics such as high viscosity and low calorific value. In addition, this fuel has poor thermal efficiency and consumption. Therefore, this article aims to analyze the effect of adding gasoline to B30 fuel, which was tested on a diesel engine with several loads and constant rotation of 2000 rpm.. These findings can be shown as follows:

1. The addition of 30% Calophyllum inophyllum biodiesel fuel to petrodiesel can increase the viscosity, density, flash point, cetane number, and decrease the calorific value. The addition of 10% gasoline to B30 fuel can reduce the viscosity, density, flash point, cetane number and increase the calorific value.
2. The consumption of petrodiesel fuel with the addition of 30% Calophyllum inophyllum biodiesel will increase further, but with the addition of gasoline, it will decrease. The addition of 10% gasoline increases the BTE of biodiesel fuel.
3. The addition of 30% biodiesel reduces carbon monoxide and Hydrocarbon emissions but increases carbon dioxide emissions. The addition of 10% gasoline to the biodiesel mixture can reduce CO, HC, and CO_2 emissions.

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