

# Performance and Emissions of Mixed Ethanol-Biodiesel Calophyllum Inophyllum Fueled Diesel Engine

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## ABSTRACT

This article evaluated the use of biodiesel from the Nyamplung seed oil (*calophyllum inophyllum*) and ethanol for petrodiesel mixture without modifying the diesel engine test instrument. The three tests were applied to each load on the test machine from 0 to 800 W with increments of 200 W at a constant engine speed of 2400 rpm. In this study, the percentage of biodiesel was 30%, while the ethanol was 10% and 20%, respectively. The percentage of petrodiesel decreased with the percentage of ethanol. From the analysis result of engine performance characteristics and exhaust emissions, it can be concluded that the addition of 20% ethanol and 30% biodiesel indicated the best engine performance characteristics with decreasing specific energy consumption up to 4.19% and the enhancement of effective thermal efficiency up to 1.60%. Furthermore, preferable combustion quality also reduced carbon monoxide emissions up to 28.57% and hydrocarbon emissions up to 32.02%.

**Key words :** Ethanol, Biodiesel, Nyamplung, Diesel Engine.

## 1. INTRODUCTION

The energy consumption is dominated by BBM (fuel oil) sourced from fossils (non-renewable energy) [1]. Indonesia Energy Outlook (2019) explains that the transportation sector is the largest sector in energy consumption (43%) of the total national energy consumption. The fulfillment energy based on fuel oil has an impact on the production of crude oil deficit and condensate (natural gas liquids), so the energy supply based on new and renewable energy needs to be increased.

Biodiesel is a type of liquid biofuel used as an alternative to petrodiesel (petroleum diesel) mixed fuel. The biodiesel features are good lubrication, non-toxicity, high cetane number, no aromatics content, and can reduce exhaust emissions [2]. Biodiesel-base from vegetable or animal oils contains saturated free fatty acids that can increase kinematic viscosity, density, cloud point and pour point. Therefore, the use of these raw materials in the transportation sector is restricted [3]–[5].

Ethanol is an inexpensive oxygenate produced through the fermentation process of biomass raw materials [6] and used as

a mixed fuel of diesel engines without modification [7]. The low viscosity and density of ethanol improve the spray characteristics and the mixed air-fuel process [6].

Paul et al., (2017) conducted research on the use of biodiesel and ethanol on the CI (compression ignition) engine performance with biodiesel from Malapari (*pongamia pinnata*) [9]. The concentration of biodiesel is 50% and ethanol is 5% which increased to 20% an increasing interval of 5%. The results showed that the optimal engine performance is obtained by adding 15% ethanol pointed by an enhancement of BTE (brake thermal efficiency) as 21%, a reduction of BSEC (brake specific energy consumption) as 4.61% and, a reduction of NOx (nitrogen oxide) and HC (hydrocarbon) exhaust emissions.

Based on the previous research, the augment of biodiesel and ethanol can improve diesel engine performance and reduce harmful exhaust emissions. This study aims to determine the diesel engines performance and exhaust emissions by biodiesel fuel Nyamplung seed oil (*calophyllum inophyllum*) and 99.5%-purity ethanol.

## 2. MATERIAL AND METHODS

### 2.1 Fuel Preparation

Biodiesel is produced from Nyamplung seed oil (*calophyllum inophyllum*) by esterification and transesterification processes. The esterification process aims to reduce the free fatty acids value using methanol as a solvent and H<sub>2</sub>SO<sub>4</sub> as a catalyst at 60°C for 120 minutes with a solvent-to-oil ratio of 22:1 mol/mol and a catalyst-to-oil ratio of 2% vol/vol. The transesterification process was conducted with methanol and KOH as a catalyst at 60°C for 180 minutes with a solvent-to-oil ratio of 6:1 mol/mol and a catalyst-to-oil ratio of 1% g/g. The ethanol fuel with a purity of 99.5% was obtained from PT Energi Agro Nusantara, Mojokerto, East Java, Indonesia. Meanwhile, the petrodiesel fuel is obtained from PT Pertamina Tanjung Wangi, Ketapang, Banyuwangi, East Java, Indonesia.

Biodiesel as 30% and petrodiesel as 70% (B30) mixed with ratio vol/vol. The ethanol concentration of 10% mixed with B30 becomes B3010. The ethanol concentration of 20% mixed with B30 becomes B30E20. Each mixed fuel is observed for 24 hours to ensure mixed stability.

2.2 Fuel Characteristics

Table 1. Physical chemistry of mixed biodiesel-ethanol fuel

| Blends   | Viscosity | Density              | Caloric value | Cetane number | Ref. |
|----------|-----------|----------------------|---------------|---------------|------|
|          | (cSt)     | (kg/m <sup>3</sup> ) | (kJ/kg)       |               |      |
| B20      | 2.8       | 853                  | 43221         | -             | [4]  |
| B20E5    | 2.6       | 843                  | 39761         | -             |      |
| B2.5E2.5 | 2.6       | 830                  | 47389         | 57.2          |      |
| B5E5     | 2.6       | 830                  | 46239         | 56.2          | [10] |
| B10E5    | 1.6       | 808                  | 42290         | -             |      |
| B10E10   | 1.4       | 808                  | 41614         | -             |      |
| B10E15   | 1.3       | 808                  | 40032         | -             | [11] |
| B17E5    | 3.4       | 848                  | 37040         | 55.0          |      |
| B49E10   | 3.2       | 854                  | 35980         | 54.6          |      |
| B20      | 3.7       | 843                  | 43890         | -             | [12] |
| B20E5    | 3.3       | 839                  | 43120         | -             |      |

Table 1. presented the physical chemistry of mixed biodiesel-ethanol fuel from various references. Ethanol affects the physical chemistry of the fuel. The enhancement of ethanol reduces the kinematic viscosity, density, calorific value, and cetane number of fuel, it is similar to [4], [10]–[13].

2.3 Experimental Settings and Procedures

This study used the MDX-170 Matsumoto diesel engine, single-cylinder, four-stroke, and natural air system. 1-phase Daiho SD-3 generator has functioned as a dynamometer. The data collection was conducted 3 times by connecting the rotor to the engine shaft. The stator is located opposite the rotor and connected to the casing. In the casing, an arm is installed where the end of the arm is a load cell (load measuring instrument). Allocating lights on the stator as 0-800 W or 0-100% with an increasing interval of 200 W at a constant engine speed of 2400 rpm. The braking force will be read on the load cell which is equal to the engine shaft rotational force (F). Figure 1. showed the scheme on the experimental setup.

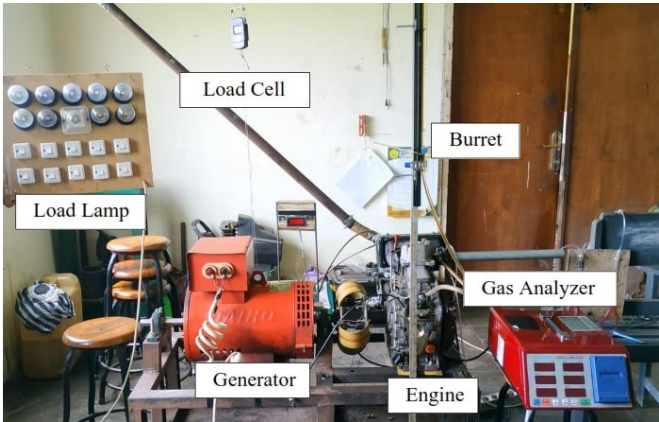


Figure 1. The scheme on the experimental setup

The gas analyzer HG-520 Hashbon is used to measure exhaust gas emissions of CO (carbon monoxide), CO<sub>2</sub> (carbon

dioxide), and HC (hydrocarbon) with the instrument accuracy of 0.01%, 0.1%, and 0.01 ppm, respectively.

3. RESULTS AND DISCUSSIONS

3.1 The Effect of Biodiesel and Ethanol on Engine Performance

Parameters used to characterize diesel engine performance were specific energy consumption, effective thermal efficiency, and specific fuel consumption.

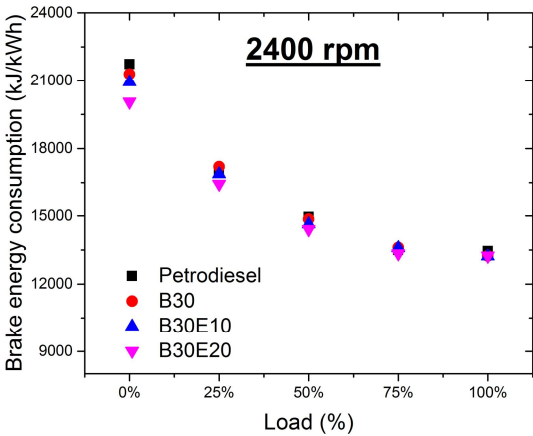


Figure 2. Brake specific energy consumption (kJ/kWh)

Figure 2. showed the graph of brake specific energy consumption or BSEC (kJ/kWh). BSEC indicated the engine efficiency on the input of the energy fuel used by the engine during combustion [9]. The results of the mixed fuel tested on different load conditions showed that the augment of 20% ethanol (B30E20) was adequate to reduce BSEC than B30E10, B30, and petrodiesel fuels. In the minimum load, the B30E20 reduces BSEC by 4.19%. It was lower than petrodiesel. This result was similar to Işık, (2020) [14]. The consistent reduction of BSEC indicated the preferable utilization of chemical energy becomes useful energy [9]. The high oxygen in ethanol plays a role in the combustion phase and easy the release of higher fuel energy during oxidation [14], [15].

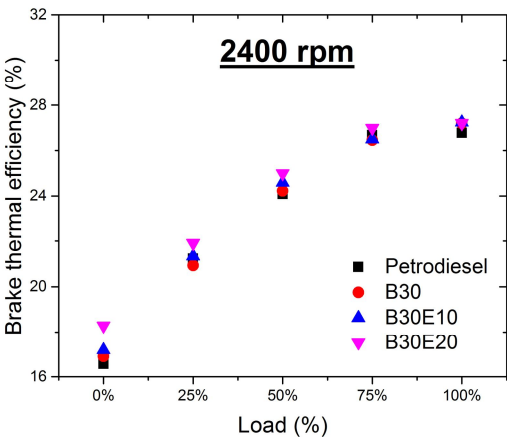


Figure 3. Brake thermal effective (%)

Figure 3. showed a graph of the brake thermal effective or BTE (%). BTE is used to evaluate the engine quality in converting the thermal energy of the fuel to mechanical energy [9]. The results of the mixed fuel tested at different load conditions revealed that B30E20 fuel had a higher BTE than other fuels, such as B30E10, B30, and petrodiesel. In the maximum load, the B30E20 increased BTE by 1.60% higher than petrodiesel fuel. This result is similar to Bhurat et al., (2019) [16].

The high percentage of ethanol had an effect on reducing the fuel viscosity, thus this condition allowed preferable fuel injection. The improvement of injection quality simplifies the fuel atomization. It allowed the large and small chain hydrocarbons from biodiesel and petrodiesel to bond rapidly into the smaller elements during combustion [9]. The oxygen in ethanol also participated in the fuel combustion process, thus the BTE B30E20 is detected to be higher than other mixed fuels [17].

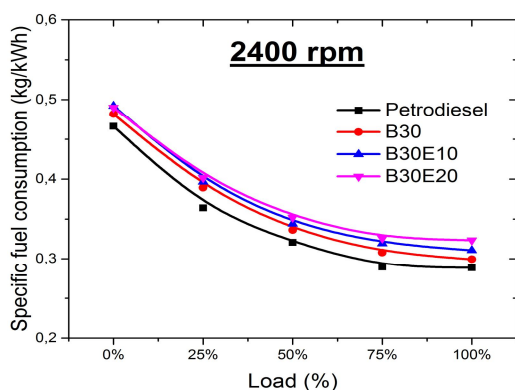


Figure 4. Specific fuel consumption (kg/kWh)

Figure 4. showed a graph of specific fuel consumption or SFC (kg/kWh). The SFC is the fuel consumption rate used by the engine to produce force. The results of the mixed fuel tested at different load conditions showed an enhancement of SFC and ethanol concentration. A high concentration of ethanol reduced the heating value and density of the mixed fuel [18]. Lowering the heating value reduced the fuel energy discharge, thus it required a high rate of fuel consumption to obtain the same force [15].

The results of the mixed fuel tested at different load conditions showed that B30E20 had a higher SFC than other fuels, such as B30E10, B30, and petrodiesel. In the maximum load, the B30E20 increased SFC as 12.08% higher than petrodiesel fuel. These results were similar to Bhurat et al., (2019) [16].

### 3.2 The Effect of Biodiesel and Ethanol on Exhaust Emissions

Parameters used to characterize exhaust emissions of diesel engines were carbon monoxide, carbon dioxide, and hydrocarbon..

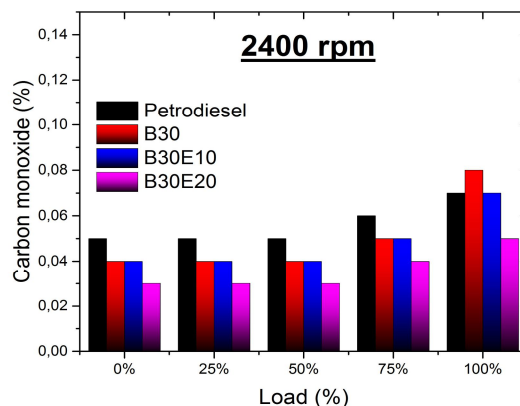


Figure 5. Carbon monoxide (%)

Figure 5. showed a graph of carbon monoxide or CO (%) exhaust emissions. The results of the mixed fuel tested on different load conditions showed that the CO emission of B30E20 fuel was lower than B30E10, B30, and petrodiesel fuels. It was similar to Paul et al., (2017) who stated that in the maximum load, B30E20 fuel reduces CO emissions as 28.57% lower than petrodiesel fuel [9]. The rate of CO emission depended on the air-fuel ratio. The enhancement of oxygen and the augment of ethanol assisted to increase the oxygen ratio of the mixed fuel in the rich fuel areas, thus leading to complete combustion [19].

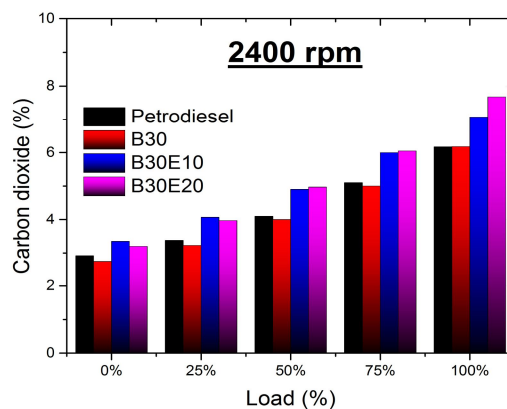


Figure 6. Carbon dioxide (%)

Figure 6. showed a graph of carbon dioxide or CO<sub>2</sub> (%) exhaust emissions. This graph showed that the augment of ethanol in the mixed fuel constantly increased CO<sub>2</sub> emissions. The CO<sub>2</sub> emissions increased because ethanol released 'OH' during oxidation. The 'OH' radicals supported the CO emissions oxidation to CO<sub>2</sub> emissions [9]. The results of the mixed fuel tested at different load conditions showed that B30E20 had the highest CO<sub>2</sub> emissions, followed by B30E10, B30, and petrodiesel fuels. This result similar to Işık et al., (2020) who mention that in the maximum load, B30E20 fuel increased CO<sub>2</sub> emissions as 24.47% higher than petrodiesel fuel [14].

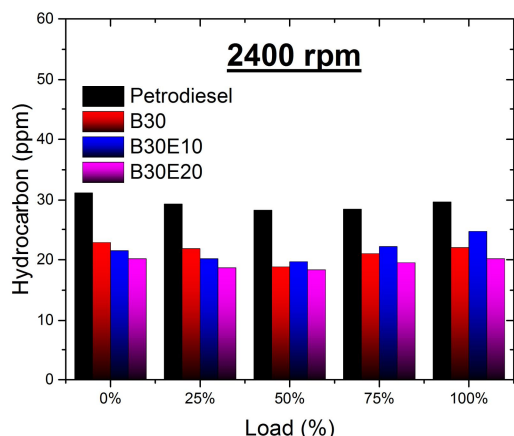


Figure 7. Hydrocarbon (ppm)

Figure 7. showed a graph of hydrocarbon or HC exhaust gas emissions (ppm). The results of the mixed fuel tested on different load conditions showed that the HC emission of B30E20 fuel was lower than B30E10, B30, and petrodiesel fuels. This result was similar to Rizwanul Fattah *et al.*, (2014) who stated that in the maximum load, B30E20 fuel reduced HC emissions by 32.02% less than petrodiesel fuel [20]. The unburned HC emission was related to combustion quality [18]. The oxygen content in ethanol contributed to the fuel combustion process in the complete combustion [19], so it was competent to reduce HC emissions [20].

## 5. CONCLUSION

In this study, the experimental research was conducted on diesel engine to explore the biodiesel and ethanol effects on the performance and exhaust emissions of diesel engine. The biodiesel percentage was still constant at 30%, while the ethanol had increased from 10% to 20%. The petrodiesel percentage decreased continuously with the ethanol percentage. Based on the results, it can be concluded that the augment of 20% ethanol and 30% biodiesel (B30E20) can improve engine performance, such as reducing BSEC and increasing BTE better than petrodiesel. However, the SFC was higher than petrodiesel. In terms of exhaust emissions, the B30E20 reduced CO and HC emissions but increased the CO<sub>2</sub> emissions.

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