Performance of diesel engine using cooking oil biodiesel (B20) with additional bioaditive essential oils (Eucalyptus)

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Abstract. This research is geared by the depletion of the availability of fossil fuels in nature. This is inversely proportional to the level of fossil fuel consumption, which is getting higher from year to year. Thus, there is a need for alternative fuels. One of which is biodiesel. The existence of an assessment in preparing biodiesel as an alternative fuel is significant. This study aims to determine the effect of the addition of bioaditive essential oil (eucalyptus) on the performance of diesel engines. The method used in this research was the manufacture of biodiesel through esterification and transesterification steps, then testing the diesel engine to determine the performance and gas emissions were also carried out. The results show that brake torque has decreased along with the loading at each engine speed. The value of brake power increases from 1700 rpm to 1900 rpm and then decreases to 2300 rpm. Brake fuel consumption increases with increasing engine speed, and thermal brake efficiency decrease with increasing engine speed. The CO emission is constant, but in the B20 biodiesel sample with 0.1% eucalyptus oil additive, the CO emission increases to 2100 rpm. CO₂ and HC emissions fluctuate with an increasing trend with increasing engine speed. O₂ emissions fluctuate with a decreasing trend along with the increase in engine speed, the O₂ content produced by pure biodiesel B20 is lower than B20 with additives

Keywords: Performance, Exhaust Emissions, Diesel Engines, Fuels, Biodiesel, B20 Palm Cooking Oil, Bioaditive, Essential Oil

1. Introduction
Indonesia is one of the countries with the largest energy consumption in Southeast Asia and fifth in the Asia Pacific after China, India, South Korea, and Japan [1]. Energy demand should also be accompanied by stable production. In 2018, the total production of primary energy consisting of the petroleum, natural gas, coal, and renewable energy reached 411.6 Million Tons of Oil Equivalent (MTOE). It is also reported that 64% or 261.4 MTOE of the total production was exported coal and LNG particularly. Total final energy consumption (without traditional biomass) in 2018 is around 114 Million Tons of Oil Equivalent (MTOE) [2]. In 2018, the average energy demand growth consisting of various sectors was as follows, for the transportation sector 40%, then industry 36%, households 16%, commercial and other sectors 6% and 2%, respectively.
Petroleum-based fuels (BBM) are used very widely in the transportation sector around the world [3]. Diesel fuel is one of the most urgent fuels to be developed because of its extensive needs, which includes the transportation of ships, cars, rolling stock, construction equipment, and agricultural machinery [4]. A serious threat can arise if dependence on fossil energy cannot be avoided, namely the depletion of petroleum reserves [4]. The significant use of diesel oil (diesel) can result in a greenhouse effect and air pollution due to exhaust emissions resulting from burning diesel oil (diesel), such as CO, NO\textsubscript{x}, and SO\textsubscript{x} [5].

Renewable energy sources in the last decade must be initiated and developed. One of them is biodiesel because the need is increasing every year. Indonesia has made a biodiesel production program as renewable energy and has produced 2.7 million kiloliters (KL) of palm biodiesel throughout 2016 [6]. However, there are still many weaknesses in this development, namely price volatility due to greater demand from oil production [7], and an increase in global warming due to air pollution from burning fossil fuels [8]. One of the basic materials that have the potential to be used as biodiesel, a new and renewable fuel, is used cooking oil.

Used cooking oil or fatty acid methyl ester has great potential to be processed into biodiesel because of its abundance and is considered useless waste [9]. Palm oil production in Indonesia attracts researchers to process it into a substitute fuel for diesel oil, namely biodiesel [6]. Indonesia has an extensive vegetable oil raw material. This is linear with the development of alternative fuels. According to the News Trade Industrial Community on the 2011-2017 Oleochemical and Biodiesel Production Trends Research, in 2016-2017, there was an increase in the average production capacity of cooking oil by 80%. [10].

The alternative renewable fuel chosen in the present research is the mixing of 20% biodiesel and 80% diesel fuel (B20) used palm oil, when compared to diesel/diesel fuel, used cooking oil biodiesel is more environmentally friendly, renewable, biodegradable, and has lubricating properties for piston engines. Besides, it is included in the non-drying oil group and is able to eliminate the greenhouse effect. The continuity of availability of raw materials is guaranteed and added with bioaditive essential oil (eucalyptus oil) rich in oxygen [11], which is capable of being dispersed in the fuel.

Based on this explanation, this research was carried out to examine biodiesel on a diesel engine using a Mazda diesel engine model R2 2184 cc. This test aims to determine the performance of a diesel engine using a mixture of biodiesel and diesel, namely biodiesel (B20) with the addition of bioaditive essential oil, namely B20 (pure biodiesel 80% + 20% diesel), B20 + 0.1% eucalyptus oil, B20 + 0.15% eucalyptus oil, and B20 + 0.2% eucalyptus oil. From this analysis, it is possible to determine the performance of a diesel engine in the form of brake torque, brake power, brake fuel consumption, specific brake fuel consumption, thermal brake efficiency, and resulting exhaust emissions.

2. Experimental methods

2.1 Sample preparation

The process of making biodiesel employed two chemical reactions, namely the esterification reaction and the transesterification reaction. Esterification was used to reduce the levels of FFA contained in used cooking oil. In the esterification process, used cooking oil was reacted with methanol in a ratio of 1:6 using 1% wt H2SO4 catalyst at 60 °C, which was then stirred with a magnetic stirrer for 120 minutes.

After the FFA level was dropped less than 2%, the transesterification process was continued for making biodiesel. In the transesterification process, a reaction between used cooking oil and methanol (1:6) occurred with the help of a KOH catalyst 0.5% wt, 1% wt, and 1.5% wt at 60 °C for 120 minutes. Then, a 24-hour precipitation process was carried out to separate biodiesel and
glycerol, which was the result of the transesterification reaction. Furthermore, biodiesel was washed with distilled water three times or more until the distilled water was clear. Biodiesel was then heated at about 100 °C to remove water content [12].

The next stage was mixing biodiesel and diesel fuel. The ratio of 20% used cooking oil biodiesel, and 80% of diesel fuel was mixed using a magnetic stirrer for 30 minutes, then the finished B20 was added with bioadditive essential oil. The process of adding B20 to essential oil was carried out using an Ultrasonic Homogenizer (KG-MT-UPDHM-3N) set at an amplitude of 50% and 0.5 cycles for 2 minutes to prevent hazards to the chemical properties of the fuel and fuel elements. The mixing process should take no more than two minutes to avoid harmful chemical properties and the elements themselves. The temperature was maintained between 30 °C – 32 °C to maintain chemical properties [13].

2.2 Test engine
Testing on a diesel engine (compression-ignition engine) requires 3 liters of each fuel to be tested. The engine that was tested was a diesel motor unit of the Mazda R2 4 Cylinders 2184 cc with the manufacturing country of Japan. Each rpm showcased the results of performance testing, including torque, power, fuel consumption (FC), specific fuel consumption (SFC), and thermal efficiency (ET). The exhaust emission analysis was carried out using Stargas 898.

| Sample                  | Density (kg L⁻¹) | Flash Point (°C) | High Heating Value (HHV) (MJ kg⁻¹) | Low Heating Value (LHV) (MJ kg⁻¹) | Viscosity |
|-------------------------|------------------|------------------|-----------------------------------|-----------------------------------|-----------|
|                         |                  |                  |                                   |                                   | Dyn. (cP) | Kin. (cSt) |
| B20                     | 0.8363           | 104              | 43.70                             | 40.64                             | 4.6       | 5.500      |
| B20 + 0.1% Eucalyptus Oil | 0.8366           | 96               | 43.59                             | 40.53                             | 4.6       | 5.498      |
| B20 + 0.15% Eucalyptus Oil | 0.8374           | 96               | 43.33                             | 40.28                             | 4.53      | 5.414      |
| B20 + 0.2% Eucalyptus Oil | 0.8395           | 94               | 42.91                             | 39.86                             | 4.5       | 5.360      |

3. Results and discussion

3.1 Brake torque
Figure 4 shows the brake torque of several fuel samples operated at different engine speeds. The highest brake torque is obtained at 1700 rpm with B20 biodiesel fuel with 0.1% Eucalyptus oil additive of 14,943 Nm, while the lowest is at 2300 rpm with B20 biodiesel fuel of 10,945 Nm. In general, the resulting brake torque value decreases with engine speed due to loading, the lower the engine speed, the higher the load is given. This finding is in accordance with previous studies [7,14,15].
Figure 1. Comparison chart of engine speed and brake torque

Figure 2. Comparison chart of engine speed and brake power

3.2 Brake power
Figure 5 shows the brake power of several fuel samples operated at different engine speeds. The highest brake power was obtained at 1900 rpm with B20 biodiesel fuel with Eucalyptus oil additive 0.2% of 37,477 PS, while the lowest power was at 1700 rpm with B20 biodiesel fuel of 34,501 PS. The value of brake power increases from 1700 rpm to 1900 rpm then decreases to 2300 rpm. This result is in line with research conducted by [16].

3.3 Brake specific fuel consumption
Figure 3 shows a graph of the relationship between engine speed and brake specific fuel consumption for several samples at different engine speeds. The lowest brake specific fuel consumption is biodiesel B20 with 0.15% Eucalyptus oil additive of 0.044 kg h$^{-1}$ at 1700 rpm, while the highest consumption is biodiesel B20 of 0.092 kg h$^{-1}$ at 2300 rpm engine speed. The brake
specific fuel consumption increases with increasing engine speed. This shows that when the
engine speed increases, the frictional power increases at high speed, which leads to the amount of
fuel being consumed, which results in increased specific fuel consumption. This finding is in line
with other studies [17,18].

![Figure 3](image1.png)

**Figure 3.** Comparison chart of engine speed with brake specific fuel consumption

![Figure 4](image2.png)

**Figure 4.** Comparison chart of engine speed with thermal brake efficiency

### 3.4 Brake thermal efficiency

Figure 4 shows the fuel thermal efficiency brake tested on a diesel engine with different engine
speed variations. Efficiency is the ratio of total power and energy supplied by fuel injection, which
is the product of the heating value of the fuel and the rate of fuel flow [19]. It can be seen that the
highest efficiency value occurs in biodiesel B20 with 0.15% bioaditive eucalyptus oil at 35.299 % at
1700 rpm engine speed, while the lowest efficiency occurs in B20 biodiesel fuel with a value of
16.907% at 2300 rpm engine speed, p. This indicates that the higher the engine speed, the lower the efficiency is. This phenomenon is in line with previous research [14].

3.5 CO
Figure 5 above shows the CO emissions from several fuels operating at different engine speeds. The highest CO emission was obtained at 2100 rpm with B20 biodiesel fuel with 0.1% eucalyptus oil additive of 0.0028% Vol, and CO emissions increased to 2100 rpm, then decreased again, CO emissions in other samples were worth 0% Vol. The higher the engine speed, the lower the CO emission is [14]. Complete combustion results in complete combustion by releasing CO₂ gas instead of CO gas [20] [14].

![Figure 5. Comparison graph of engine speed with CO emissions](image)

3.6 CO₂
Figure 6 above shows CO₂ emissions from several fuels that are operated at different engine speeds. The highest CO₂ emissions were obtained at 2300 rpm with B20 biodiesel fuel with 0.15% Eucalyptus oil additive of 3.3% Vol, while the lowest was at 1700 rpm with B20 biodiesel fuel with 0.1% Eucalyptus oil additive of 1.64% Vol. In general, the resulting CO₂ emissions increase. This is in line with previous research contending that CO₂ emissions increase with the increase in engine rotation speed [14]. The increase in engine speed results in better mixing of the fuel and air particles so that it can accelerate the formation of CO₂ indirectly [14].

3.7 HC
Figure 7 above shows the HC (hydrocarbon) emissions from several fuels that are operated at different engine speeds. The highest HC emission was obtained at 1900 rpm with B20 biodiesel fuel of 42 ppm Vol, while the lowest was at 2100 rpm with B20 biodiesel fuel with 0.1% eucalyptus oil additive of 0 ppm Vol. In general, the resulting HC emissions fluctuate with an increasing trend with engine speed. The above results are in line with previous studies, which stated that HC emissions increased with increasing engine speed [21]. HC emissions will decrease if there is complete combustion in the fuel-rich zone [21]. This complete combustion can be caused by an increase in oxygen levels. The oxygen content of eucalyptus oil was 8.44% [8].
Figure 6. Comparison graph of engine speed with CO$_2$ emissions

Figure 7. Comparison graph of engine speed with HC emissions

3.8 $O_2$

Figure 8 shows the $O_2$ emissions from several fuels operating at different engine speeds. The highest $O_2$ emissions were obtained at 2100 rpm with B20 biodiesel fuel with Eucalyptus oil additive 0.15% at 20.47% Vol, while the lowest was at 2300 rpm with B20 biodiesel fuel with Eucalyptus oil additive 0.15% at 16.25% Vol. In general, the resulting $O_2$ emission decreases with the increase in engine speed. This is in line with research conducted by [22]. From the graph above, it is known that the $O_2$ content produced by pure biodiesel B20 is lower than B20 with additives because Biodiesel B20 with additives has a higher oxygen content than pure B20 [8,14,22].
4. Conclusion
The Brake Torque value of all samples has decreased along with the engine speed because the higher the load, the lower the engine speed is, as indicated by the higher the torque produced. The value of brake power increases from 1700 rpm to 1900 rpm and then decreases to 2300 rpm. The value of the brake power is related to the value of the torque and engine speed. Brake fuel consumption increases along with the increase in engine speed, if the engine speed increases, the friction power will increase so that fuel consumption will also increase. Brake thermal efficiency decreases with increasing engine speed, the higher the engine speed, the lower the efficiency. CO emissions are constant, but in the B20 biodiesel sample with 0.1% eucalyptus oil additive, CO emissions increase to 2100 rpm then drop back down to 2300 rpm. CO₂ emissions fluctuate with an increasing trend with increasing engine speed. This is because an increase in engine speed results in better mixing of the fuel and air particles so that it can accelerate the formation of CO₂. HC emissions have a fluctuating value with an increasing trend with increasing engine speed, the higher the engine speed due to decreased brake loading, which causes the combustion in the fuel-rich zone to be imperfect. O₂ emissions fluctuate with a decreasing trend as the engine speed increases, the O₂ content produced by pure biodiesel B20 is lower than that of B20 with additives because B20 with additives has a higher oxygen content than pure B20.

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