Performance Test of a Diesel Engine with Biodiesel from Kemiri Sunan (*Rutealis sperma*.)

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**Abstract.** With decreasing fossil oil reserve, alternative plant-based fuel become more important. One of the source of such fuel is kemiri sunan (*Rutealis trisperma*). Kemiri sunan has an advantage that it is not competing for food use. Biodiesel from kemiri sunan needs to be tested on diesel engine. The objective of this research was to test the performance of a diesel engine with a mixture of biodiesel from kemiri sunan and fossil-based diesel fuel. This study was conducted in an experimental-descriptive manner by using several level of mixture of biodiesel from 0% (B0) to 70% (B70) using dynamometer. Measured parameter were torsion, power, fuel consumption, thermal efficiency and flue gas emission. Experimental results showed that biodiesel from Kemiri sunan can be used in unmodified, conventional diesel engine with maximum content of 20% (B20).

1. **Introduction**

With the decrease of national oil reserve and continuing increase of energy demand, alternative fuel from renewable sources become more important than ever. Being a tropical country with huge land area, Indonesia is blessed with huge potential for biofuel production such as palm, coconut, jatropha and kemiri sunan (*Rutealis trisperma*). To make the transition from fossil fuel to biofuel, the government has set the goal of increasing the fraction of biodiesel mixture to be 30% in the year of 2020 for agriculture, animal husbandry, micro business and transportation sector (ESDM, 2015).

Currently, most of commercialy produced biodiesels are derived from palm oil due to its abundance compared to other sources such as jarak, nyamplung and kemiri sunan (*Rutealis trisperma*). Nevertheless, since palm oil is also used for cooking oil and other things related to food, its demand will increase due to increase of the population such that it is feared that there will be some dilemma of its use between food and fuel in the future. On the other hand, kemiri sunan, because it contain some toxic materials, cannot be used for food such dilemma can be avoided. The other advantage of this plant is that it can be grown in infertile land with minimum input.

Although kemiri sunan is not productive as plam oil, it can produce high quantity of biodiesel. Kemiri sunan nut contain up 52% raw oil (Anggrahini, 2018). One hectar of kemiri sunan (100 -150
trees) can produce up to 6-8 ton biodiesel. Kelebihan lain dari Kemiri sunan adalah bahwa biodiesel yang dihasilkannya mempunyai sifat yang dekat dengan sifat minyak solar. Although there are many research on the production of biodiesel from kemiri sunan oil, there are not many of its performance test on diesel engine. This paper will present the performance test of biodiesel oil from kemiri sunan on an unmodified diesel engine.

2. Materials and Method
This research was conducted in the Department of Agricultural and Biosystem Engineering, Padjadjaran University, Bandung in August to December 2018 using experimental method. During the experiment, several mixture of biodiesel (table 1) and diesel fuel were used at various engine speed.

| No | Code | Diesel fuel (%) | Biodiesel (%) |
|----|------|-----------------|--------------|
| 1  | B0   | 100             | 0            |
| 2  | B10  | 90              | 10           |
| 3  | B20  | 80              | 20           |
| 4  | B30  | 70              | 30           |
| 5  | B40  | 60              | 40           |
| 6  | B50  | 50              | 50           |
| 7  | B60  | 40              | 60           |
| 8  | B70  | 30              | 70           |

Experimental set-up is given in figure 1. The experiment used single cylinder Kubota RD85DI-1S with displacement of 500 cc. Fuel mixture is stored in special tank which located up on digital balance. Engine was run successively at a speed of 1200 rpm and 1200 rpm. Output power was measured by measuring exerted force using load cell when a brake was applied on its flywheel. A rotary encoder was used to measure engine speed. Fuel consumption was measured by continuously measuring fuel tank mass. A microcontroller control the sensor reading and then send them to the computer. As for flue gas, it was measured manually using gas analyzer IMR-400.

![Figure 1. Experimental setup](image-url)
3. Results and Discussion

3.1. Output Power and Efficiency

Fuel used in this experiment is a mixture of diesel fuel and biodiesel. There are 2 parameters of paramount importance for engine performance, i.e., density and energy content. Energy content is given in LHV (Low Heating Value). As can be seen in figure 1, as the content of biodiesel increase, the density also become higher due to higher density of biodiesel. On the other hand, the higher the biodiesel content, the lower the energy content due to lower energy content of biodiesel.

![Figure 1. Property of biodiesel mixture](image)

As can be seen in table 2, engine with pure diesel fuel give higher torque than that of biodiesel mixture. Very significant decrease start to appear from B30 onward. This occurred due to lower calorific value of biodiesel fuel. Furthermore, higher viscosity of biodiesel fuel impeded the work of fuel pump. Fuel diesel has a viscosity of 1.0 to 3.96 mm\(^2\)/s, while that of kemiri sunan biodiesel is 2.69 mm\(^2\)/s.

| Speed (rpm) | B0   | B10  | B20  | B30  | B40  | B50  | B60  | B70  |
|-------------|------|------|------|------|------|------|------|------|
| 1200        | 18.36| 15.49| 19.51| 13.06| 19.08| 16.50| 15.78| 15.06|
| 1400        | 17.21| 16.35| 16.07| 17.93| 20.94| 14.78| 16.50| 15.64|
| 1600        | 21.80| 15.92| 16.21| 19.94| 22.38| 19.79| 18.07| 15.21|
| 1800        | 24.24| 19.79| 19.51| 21.08| 18.22| 19.94| 23.95| 19.79|
| 2000        | 24.10| 22.66| 23.52| 21.37| 19.51| 17.50| 20.22| 16.50|
| 2200        | 24.81| 21.66| 26.25| 17.64| 13.63| 17.79| 20.22| 18.79|
| Average     | 21.75| 18.65| 20.18| 18.50| 18.96| 17.72| 19.13| 16.83|

Torque is highly related to engine output power. At the same speed, the higher the torque the higher the output power because power is the product of torque and engine speed. Results of measurements is given in table 3. Engine with diesel fuel gave higher maximum power than that of biodiesel mixtures. Nevertheless, its value was not much different until B20. At higher biodiesel contents, engine output dropped drastically. Again this is due to lower calorific value of biodiesel fuel.
Tabel 3. Relationships between maximum output power (hp) with biodiesel content at several engine speeds

| Speed (rpm) | B0  | B10 | B20 | B30 | B40 | B50 | B60 | B70 |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 1200        | 1.51| 1.55| 2.08| 1.54| 1.96| 1.74| 1.54| 1.50|
| 1400        | 1.79| 2.20| 1.83| 2.22| 2.26| 1.49| 1.74| 1.80|
| 1600        | 2.67| 2.11| 1.86| 2.37| 2.33| 2.26| 2.14| 1.87|
| 1800        | 3.43| 2.91| 2.60| 2.44| 2.13| 2.27| 2.81| 2.06|
| 2000        | 3.27| 3.26| 3.33| 2.49| 2.46| 2.30| 2.55| 1.97|
| 2200        | 3.33| 2.72| 3.56| 2.41| 1.77| 2.30| 2.80| 2.49|
| Average     | 2.66| 2.46| 2.54| 2.24| 2.15| 2.06| 2.26| 1.95|

Table 4 presents the results of measurement of thermal efficiency of the engine at several biodiesel contents. Thermal efficiency is a ratio of mechanical output energy and chemical energy inputted into the engine as fuel. Due to higher compression ratio, diesel engine normally has higher thermal efficiency compared to Otto engine. Result of experiment (table 4) shows that thermal efficiency of the engine was between 17.75 to 38.13%. This is within normal value of conventional diesel engine (without common rail). Although theoretically thermal efficiency is dependent on the calorific value of used fuel, the maximum value occurred with B0 and B10 where fuel calorific value reached its peak. This phenomenon occurred due to the nature of combustion in the engine. It is predicted that at higher biodiesel contents, kinematic viscosity is higher which in turn make biodiesel droplet size is bigger than that of diesel fuel. This in turn results in suboptimum combustion which is indicated by higher CO content in its flue gas.

Table 4. Thermal efficiency (%) at various biodiesel contents

| Speed (rpm) | B0   | B10  | B20  | B30  | B40  | B50  | B60  | B70  |
|-------------|------|------|------|------|------|------|------|------|
| 1200        | 25.06| 25.06| 35.63| 26.45| 37.53| 33.14| 31.98| 32.66|
| 1400        | 29.63| 29.63| 27.34| 34.12| 35.09| 27.35| 30.74| 33.20|
| 1600        | 36.39| 36.39| 23.15| 29.19| 30.48| 30.10| 30.20| 28.45|
| 1800        | 38.13| 38.13| 26.18| 25.02| 23.56| 24.70| 31.26| 24.31|
| 2000        | 31.34| 31.34| 28.68| 22.89| 24.29| 21.25| 24.98| 20.40|
| 2200        | 31.07| 31.07| 24.54| 19.68| 15.74| 17.66| 23.38| 21.81|
| Average     | 31.94| 31.94| 27.58| 26.23| 27.78| 25.70| 28.76| 26.81|

3.2 Chemical Content of Flue Gas

Ideal combustion process will result in CO₂ and H₂O gas in flue gas. Nonetheless, in reality this seldom occurred in a conventional diesel engine. If there are less oxygen than necessary, there will be CO gas in flue gas. On the contrary, there will be O₂ gas in the flue gas when there are more air enter the engine. In both cases, thermal efficiency will be less than the optimum one. Carbon monoxide content of flue gas is given in table 5. The table shows that at higher biodiesel content, carbon monoxide content tends to increase. This is due to the increase in fuel droplet size which in turn make it harder to burn completely. Although there are excess air entered the engine (table 6), it did not help improve the combustion process due to very short time available during the process.
Although diesel engine has higher thermal efficiency, it has notorious disadvantage of having higher NO\textsubscript{x} content in its flue gas. Although, nitrogen normally considered as an inert gas, at high temperature which typical for a diesel engine, this gas will react with oxygen into several chemical compound which is generally known as NO\textsubscript{x}. As can be seen in Table 7, except for B0, additional biodiesel in fuel will decrease NOx content in flue gas. This is inline with other finding with biodiesel from different sources\textsuperscript{5,6,7}.

**Table 5.** Carbon monoxide content (ppm) of flue gas at various biodiesel contents

| Speed (rpm) | B0   | B10  | B20  | B30  | B40  | B50  | B60  | B70  |
|-------------|------|------|------|------|------|------|------|------|
| 1200        | 408.6| 346.8| 375.1| 354.0| 376.1| 415.7| 451.2| 456.5|
| 1400        | 326.5| 323.8| 346.4| 302.7| 378.4| 376.9| 397.8| 381.8|
| 1600        | 285.0| 282.7| 262.5| 274.9| 275.2| 317.7| 434.2| 324.7|
| 1800        | 294.4| 317.4| 239.4| 240.9| 227.7| 279.8| 434.2| 298.0|
| 2000        | 292.3| 295.5| 225.3| 209.6| 187.8| 239.3| 280.4| 270.6|
| 2200        | 270.4| 265.3| 257.1| 274.9| 275.2| 317.7| 434.2| 273.9|
| Average     | 312.9| 305.2| 284.3| 261.6| 269.2| 311.9| 364.5| 334.3|

**Table 6.** Excess air (%) at various biodiesel contents

| Speed (rpm) | B0   | B10  | B20  | B30  | B40  | B50  | B60  | B70  |
|-------------|------|------|------|------|------|------|------|------|
| 1200        | 7.30 | 7.45 | 7.69 | 8.24 | 7.69 | 8.49 | 8.12 | 9.95 |
| 1400        | 7.70 | 7.34 | 8.00 | 8.44 | 8.35 | 8.89 | 8.81 | 13.28|
| 1600        | 10.35| 7.90 | 8.56 | 8.75 | 8.73 | 9.15 | 8.98 | 10.72|
| 1800        | 8.48 | 8.42 | 9.07 | 9.47 | 9.04 | 9.53 | 9.18 | 11.15|
| 2000        | 8.22 | 8.87 | 9.35 | 9.86 | 9.69 | 9.24 | 9.13 | 10.89|
| 2200        | 8.45 | 8.96 | 34.51| 9.00 | 9.96 | 8.53 | 8.34 | 10.24|
| Average     | 8.42 | 8.15 | 12.86| 8.96 | 8.91 | 8.97 | 8.76 | 11.04|

**Table 7.** NO\textsubscript{x} gas content of flue gas at various biodiesel contents

| Speed (rpm) | B0   | B10  | B20  | B30  | B40  | B50  | B60  | B70  |
|-------------|------|------|------|------|------|------|------|------|
| 1200        | 94.2 | 108.3| 103.8| 92.3 | 108.6| 91.7 | 89.7 | 76.1 |
| 1400        | 126.0| 123.5| 110.0| 104.2| 99.4 | 82.8 | 80.7 | 72.9 |
| 1600        | 109.7| 108.8| 96.9 | 94.6 | 86.3 | 82.1 | 69.5 | 74.1 |
| 1800        | 97.7 | 97.0 | 87.4 | 85.0 | 81.2 | 76.2 | 77.8 | 69.1 |
| 2000        | 89.8 | 89.0 | 80.7 | 77.7 | 70.2 | 83.8 | 76.3 | 70.1 |
| 2200        | 79.3 | 76.4 | 87.5 | 81.7 | 71.7 | 97.8 | 90.8 | 81.3 |
| Average     | 99.5 | 100.5| 94.4 | 89.2 | 86.2 | 85.7 | 80.8 | 73.9 |

Based of aforementioned findings on torque, output power, and flue gas chemical composition, it can be said that biodiesel from kemiri sunan oil can be used on conventional, unmodified diesel engine with a maximum content of 20%. Fuel mixture with higher content of biodiesel may result in the decrease in quality of combustion which cause low thermal efficiency, and higher carbon monoxide content in its flue gas. In order to use higher content of biodiesel from kemiri sunan oil, it is necessary to modify the engine or the fuel. This is results of short time test. To understand long time effects on the engine, further tests are required.
4. Conclusions
Based on aforementioned finding, it can be concluded the following
a. Biodiesel from kemiri sunan can be used in unmodified, conventional diesel engine up to maximum mixture of 20% (B20).
b. Biodiesel from kemiri sunan can be used with higher content but with significant loss in performance and increase in carbon monoxide content in its flue gas.

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