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Production and Performance Test of Biodiesel Produced from Waste Cooking Oil

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ABSTRAK

Biodiesel merupakan sumber energi terbarukan yang berasal dari minyak nabati. Penggunaan biodiesel sebagai bahan bakar mesin diesel di Indonesia, akan terus meningkat hingga mencapai B100. Salah satu bahan baku yang dapat digunakan untuk memproduksi biodiesel adalah minyak jelantah. Pembuatan biodiesel dari minyak jelantah, dibuat menggunakan metode esterifikasi dan transesterifikasi. Kemudian biodiesel dicampur dengan bahan bakar minyak diesel hingga memiliki komposisi campuran B20, B30, dan B50. Setiap campuran akan dilakukan pengukuran performa dan emisinya. Dalam pengujian ini, B30 tidak mengalami penurunan performa yang signifikan namun hasil uji emisi (opasitas) lebih tinggi apabila dibandingkan dengan B20. B50 mengalami penurunan performa yang signifikan jika dibandingkan dengan B20, namun memiliki hasil uji emisi (opasitas) yang paling rendah.

Kata kunci : Biodiesel; Opacity Test; Transesterification Process; Waste Cooking Oil

ABSTRACT

Biodiesel has become an essential source of substitution fuel for diesel engines. As an alternative fuel for diesel engines, it is becoming increasingly important due to diminishing fossil fuel reserves and the environmental consequences of exhaust gases from petroleum-fuelled engines; therefore, it needs to be further investigated how biodiesel blend percentage could affect the performance and emission of diesel engines. Waste cooking oil (WCO) is one of the raw materials used in biodiesel. WCO converted into biodiesel is made using esterification and transesterification methods. Then, biodiesel is mixed until it has the composition of B20, B30 and B50. The mixture is then tested for performance and emissions. In testing, B30 did not show a significant decrease in performance, but the emission test results (opacity) were higher than those of B20. B50 has a significant decrease in performance when compared to B20 but has the lowest opacity test results.

Keywords *: Biodiesel; Opacity Test; Transesterification Process; Waste Cooking Oil*

1. INTRODUCTION

Fossil fuels, as non-renewable energy resources, contribute mainly to the world's energy supply [1]. In contrast, the production and use of fossil fuels have raised environmental concerns, such as the fact that the combustion of diesel fuel emits greenhouse gases. In recent years, many countries have been concerned about renewable energy as their source of energy. Indonesia is one of the countries that are concerned about that topic. The Indonesian government has already set their national energy plan for 2050, and the portion of renewable energy is set to 31% of national energy needs. In order to achieve that target, one of the Indonesian government's strategies is to increase biodiesel blending in its diesel fuel. The biodiesel blending percentage in diesel fuel is marked with BXX. The Indonesian government will continue to increase the blending percentage of biofuels until its diesel fuel gets to B100. Since 1st January 2020, the Indonesian government has already increased the biodiesel blend from B20 to B30.

In Indonesia, most biodiesel fuels are made from Crude Palm Oil (CPO). CPO is produced from palm, and as we know, Indonesia is the largest CPO producer in the world. Based on that fact, Indonesia already has a source of biodiesel from their CPO [1]. But, while Indonesia has a massive amount of CPO as a biodiesel feedstock, CPO prices are quite expensive as a biodiesel feedstock.

Waste cooking oil (WCO) is also a derivative product of CPO, and WCO could be defined as garbage because it cannot be used again for food production. WCO could be recycled as a biodiesel feedstock because it's basically a cooking oil with a higher amount of Free Fatty Acid (FFA). The usage of WCO as a biodiesel feedstock could reduce the total production cost of biodiesel. The production cost could be reduced because of WCO affordability. Even we could get WCO for free.

In this study, Biodiesel will be produced using a two-step method [2]. The first step is Esterification, and Transesterification is the next step. Esterification is a carboxylic acid reaction with alcohol and produces water as a product of the reaction [3]. Esterification serves to reduce levels of free fatty acids in vegetable oils. Esterification works by mixing acid with methanol, which is then mixed into biodiesel feedstock. Transesterification is the process of changing vegetable oil into biodiesel. In the transesterification process, the alcohol used is generally methanol because methanol is an alcohol that has a low price and wide availability. A catalyst is used to accelerate the conversion of oil into biodiesel during the transesterification process.

Biodiesel that has been produced must meet the standards set by an institution in the country where the biodiesel will be used or marketed. In Indonesia, the standard for biodiesel fuel is set to meet the Indonesian National Standard (SNI). The standard used is SNI-7182, which was issued in 2015 by the National Standardization Agency [4]. In this standard, several parameters can be used to determine whether biodiesel is feasible or not to be used as biodiesel fuel.

Diesel fuel, which is mixed with biodiesel, is commonly referred to as biosolar in Indonesia. Biosolar, which is currently circulating in Indonesia, is biodiesel with a mixing rate of 20%, known as B20. It is necessary to look at the effect of the performance of diesel engines when using B20 biodiesel fuel. In general, engine performance is seen from the power and torque released by the engine and the exhaust gas emissions produced by the engine. The effect of engine performance can be seen by comparing the power, torque and exhaust emissions produced by using unmixed diesel fuel and biodiesel fuel that has been mixed [5]. Power and torque play an essential role in an engine because they determine the engine's performance and whether or not it is sufficient for use at maximum load. Meanwhile, emissions play a role in maintaining the environment, whether the exhaust emissions of a machine can meet the exhaust emissions set by a country.

2. RESEARCH METHODOLOGY

2.1 Production of Biodiesel

The process of making biodiesel from WCO begins with the collection of WCO. WCO collected from the cafeteria at UTHM. The WCO that has been collected is then heated to a temperature of 50°C. The purpose of heating the WCO is to reduce the viscosity. After it is heated, the oil is put into a filter to filter food debris contained in the oil. Oil that has been heated is easier to filter because the viscosity is lower, thereby accelerating the flow rate of used cooking oil that passes through the filter [6].

After filtering, WCO is mixed with methanol and H2SO4 for the esterification process. Then, the mixture was heated to 70°C for 2 hours and stirred with a magnetic stirrer [7]. Then, rest the mixture in a separation funnel for about 12 hours to ensure the oil is separated from methanol and impurities.

Figure 1. Triglyceride and methanol after the esterification process.

The reaction produced two layers of liquid phase, which are triglyceride and methanol and other impurities, as shown in Fig 1. Take the triglyceride and mix it with methanol and NaOH for the transesterification process. Then, the mixture was heated to 70°C for 1 hour and stirred with a magnetic stirrer [8]. Then, rest the mixture in a separation funnel for about 8 hours to ensure the biodiesel (methyl-ester) is separated from glycerol. As shown in Fig 2, methyl-ester (biodiesel) is at the upper layer and glycerol is located at the bottom layer. We can quickly know glycerol by its darker colour than methyl-ester.

Figure 2. Methyl-ester and glycerol after transesterification.

After the separation is done, the biodiesel needs to be washed to remove soap and other contaminants/impurities. Biodiesel was washed using hot water and repeated several times until the water became clear [9]. After the washing step, biodiesel has a high water content. In order to reduce the water content, biodiesel was heated to over 100°C. After the drying step is complete, then the biodiesel is ready to be tested for chemical properties. Four properties will be tested: kinematic viscosity, acid value, flash point and density. Then, the biodiesel will be mixed with petroleum diesel to create a mixture of B20, B30 and B50.

2.2 Procedure of Engine Test

Performance and emission testing is performed on a Mitsubishi Pajero Sport engine. The characteristics of the diesel engine are listed in Table 1. For the first running, B0 was used to determine its reference point. The test will be conducted using three different fuels: B20, B30 and B50.

Table 1 Engine specification.

Engine Type	Engine Capacity (cc)	Bore x Stroke (mm)	Compression Ratio
2.5L DOHC Common Rail Turbocharged and Intercooled, 4 Cylinder in-line (4D56)	2477 cc	91,1 x 95,0	17:1

The engine performance will be measured using DashCommand apps using an OBDII port. DashCommand is an application developed by Palmer Performance Engineering to determine engine horsepower and torque.

Each biodiesel blend will be tested twice. The performance test was conducted at Personal Motor, Bandung with a chassis dynamometer. Emission tests are carried out to measure the opacity of the exhaust gas. The opacity was measured using AGS-688 and coupled to the OPA-100 Opacity Analyzer, as shown in Fig 3-4. Emission test was conducted at PT. Dipo International Pahala Otomotif in Pluit, North Jakarta data were taken three times for every blends.

Figure 3. OPA-100 Opacity analyser.

Figure 4. AGS-688 Gas emission analyser.

3. RESULTS AND DISCUSSION

3.1 Biodiesel Production

After the esterification process is completed (shown in Fig 5), the triglyceride that has been formed will continue the transesterification process to convert the triglyceride into FAME or biodiesel. Both samples were treated the same, with a composition comparison attached in Table 2 for esterification and Table 3 for transesterification.

At the time of the transesterification process, sample 2 undergoes saponification. In the first 30 minutes of the transesterification process, sample 2 did not experience any signs of a saponification reaction. At minute 45, sample 2 begins to experience a saponification reaction, which is characterised by the thickening of the sample 2 solution, as shown in Fig 6.

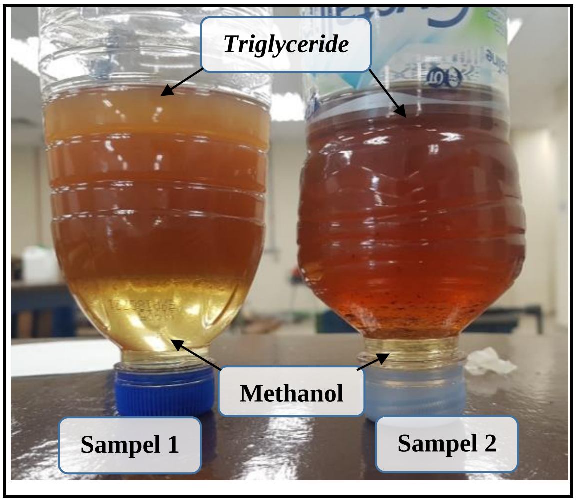

Figure 5. Comparison of esterification.

Table 2. Comparison of esterification sample composition.

Properties	Sample 1	Sample 2
Oil	450 ml	450 ml
Methanol	480 ml	480 ml
Oil:Methanol (Molar)	1:8	1:8
H_2SO_4 6,5%	55,4 ml (2%wt Oil)	27,7 ml (1%wt Oil)
Reaction Time	1 Hour	1 Hour
Yield	405 ml	425 ml

Table 3. Comparison of transesterification sample composition.

Properties	Sample 1	Sample 2
Triglyceride	405 ml	425 ml
Methanol	431 ml	452 ml
Oil:Methanol (Molar)	1:6	1:6
NaOH (pellet)	3,7 gram (1%wt Oil)	3,9 gram (1%wt Oil)
Reaction Time	1 Hour	1 Hour

(a) (b)

Figure 6. Saponification reaction (a) started to build up. (b) final reaction of saponification.

The transesterification reaction in sample 1 was carried out for 60 minutes. During the transesterification process, symptoms of the saponification reaction that occurred in sample 2 did not happen in sample 1.

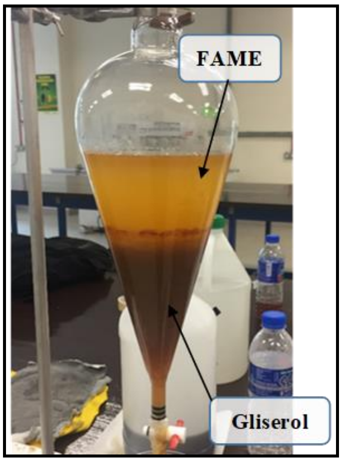

Figure 7. Sample 1 in a separation funnel.

Biodiesel (FAME) that has been produced (shown in Fig 7) is separated from glycerol, and it was found that the amount of biodiesel produced is 385 ml. The biodiesel that has been made still stores unwanted impurities and can potentially cause damage to the engine if used immediately. A washing process needs to be carried out to remove impurities.

A heating or drying process is carried out to make biodiesel clear and reduce water content. Biodiesel that has been washed, put into a container, and then heated to more than 100°C. Biodiesel will be heated continuously until no water bubbles form from the bottom of the container. The biodiesel's colour changes to bright yellow and not turbid (clear), as seen in Fig 8. The final volume obtained after biodiesel undergoes a drying process is 345 ml. So the total volume of oil lost due to the esterification, transesterification, washing and drying process is 105 ml. The total oil that can be converted into biodiesel is 76.67%.

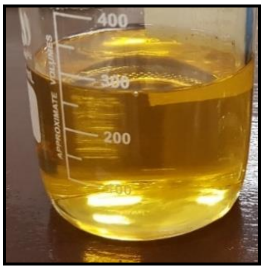

Figure 8. The final product of biodiesel from WCO

3.2 Biodiesel Properties

Biodiesel made with waste cooking oil as raw material needs to be tested to determine whether it is in accordance with applicable standards in Indonesia. In testing kinematic viscosity, density, acid number and flash point, biodiesel that has been produced by the author will be tested using the Indonesian Standard (SNI). In addition, tests were also conducted for B5 (Euro 5 Standard) and B7 fuels taken from Petronas Malaysia gas stations, and then B20, B30 and B50, which were blended with biodiesel.

It can be seen that biodiesel made by the author meets SNI standards for biodiesel. On the flash point data, B100 made by the author is below the biodiesel general flash point but still passes the Indonesian standard. Biodiesel generally ranges from 170-180°C, which is evident in the B100 that the author got from BPPT. The thing that can make biodiesel made by the author has a lower flash point than general biodiesel fuel because there are still relatively high levels of methanol in the biodiesel that the author made. The methanol might reduce the flash point value of biodiesel made by the author.

Table 4. Characteristics of biodiesel blend.

Analyses	Unit	Limits of Biodiesel		Results						
		Min	Max	B5 Euro 5	B7 MY	B20 MY	B20 ID	B30 ID	B50 ID	B100 ID
Flash Point	°C	100	-	128	128.5	148.5	52	152.5	154.5	118
Density @40°C	$\frac{kg}{m^3}$	850	890	827.2	839.04	845.56	870	844.64	839.96	859.2
Kinematic Viscosity	cSt	2.3	6	3.506	4.171	4.494	4.361	4.262	4.167	5.936
Acid Value	mgKOH	-	0.5	0.692	0.653	0.266	0.6	0.273	0.404	0.334

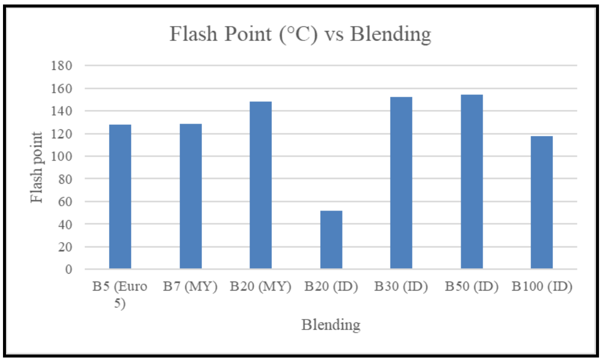

Figure 9. Flashpoint vs blending

In the flashpoint vs blending graph (shown in Fig 9), the higher the amount of biodiesel and diesel mixture, the higher the flash point. In the kinematic vs. blending viscosity graph (shown in Fig 10), the viscosity immediately rises at B20, but gradually it decreases along with increasing biodiesel mixture. The addition of biodiesel does not significantly impact the density of the blends.

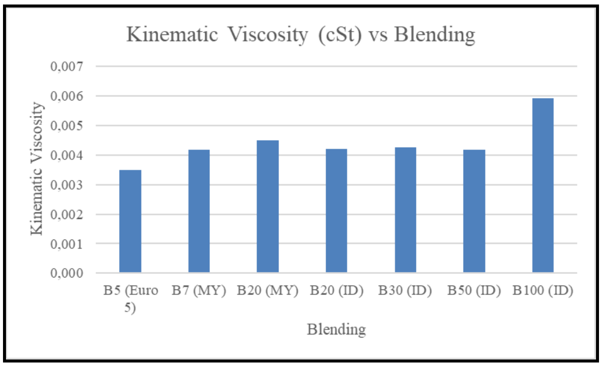

Figure 10. Kinematic viscosity vs blending graph.

3.3. Performance Test

A performance test is used to determine the effect of biodiesel blends on engine performance (power and torque).

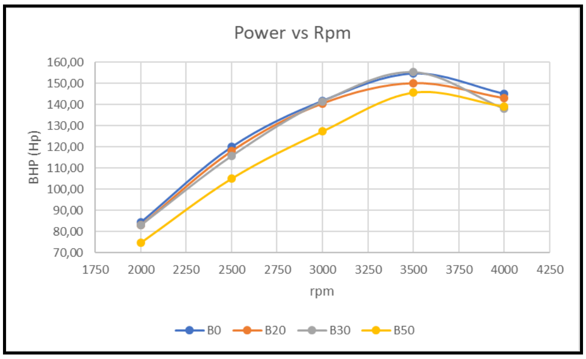

Figure 11. Power vs rpm graph comparison.

The power graph in Fig 11 shows that the power produced by B20 and B30 is almost the same. B20 has better performance at 3500 rpm and 4000 rpm compared to B30. Testing the power on the engine using B50 fuel affects engine performance. Power expended by the engine decreases at each test rpm.

Based on tests conducted, the use of B20 and B30 on diesel engines did not show a significant decrease or increase in power. However, at 2000 rpm to 3000 rpm, the power produced by B20 and B30 can be said to be the same. B20 has a better output power at high rpm, especially at 3500 rpm to 4000 rpm. This might happened because their kinematic viscosity is similar.

As for using B50, there is a significant decrease in power in each range of rpm tested. Power reduction in using B50 as fuel ranges from 7.4% -10.7%. In accordance with the graph shown, the higher the biodiesel mixture incorporated into the mixture of ingredients, the lower the power produced by the machine. Reduce in power happened because of higher flash point and made it harder to made the fuel harder to be completely burned.

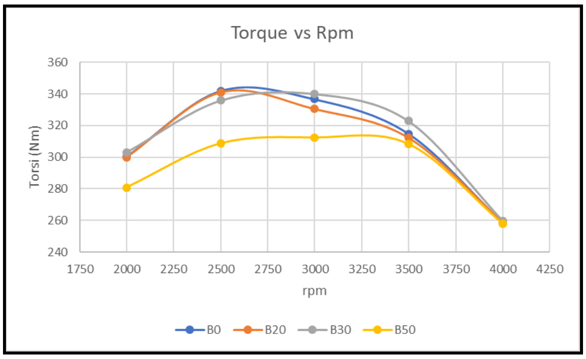

Figure 12. Torque vs rpm graph comparison.

The torque graph above shows that the torque output when using B20 and B30 fuels is almost the same. Based on the B30 test data, the torque at B30 emits a greater torque than the B20 at high rpm. So, the average torque increases by about 1%, which does not have much impact on torque output.

In the B50 test, a decrease in torque occurred since 2000 rpm. At low rpm, B50 has a significant reduction in torque. However, between 3500 rpm - 4000 rpm, the torque produced is almost the same as the B20 and B30. Decreased torque experienced, when compared with B20, can reach 10% at 2000 rpm to 3000 rpm.

The use of B30 in the engine does not affect the torque released by the engine compared to the B20. However, using B50 is enough to affect the torque produced by the engine, as shown in Fig 12. Compared to B20, the average torque output reduced to 5.2-6%.

3.4. Emission Test

The test was carried out using SNI standard 19-7118.2-2005. Operation of the test is carried out by raising the engine speed to reach 2900 rpm to 3100 rpm, then holding for 60 seconds and returning the engine speed to the idle position. Next, enter the test probe into the exhaust pipe 30 cm deep, step on the maximum throttle (full throttle) as soon as possible until reaching the maximum engine speed, then hold for 1 to 4 seconds and release the gas, wait until the engine turns back into stationary and repeat until at least three times. As shown in that standard, the opacity maximum for diesel engines manufactured below 2010 is 70%, which was reduced to 40% after 2010.

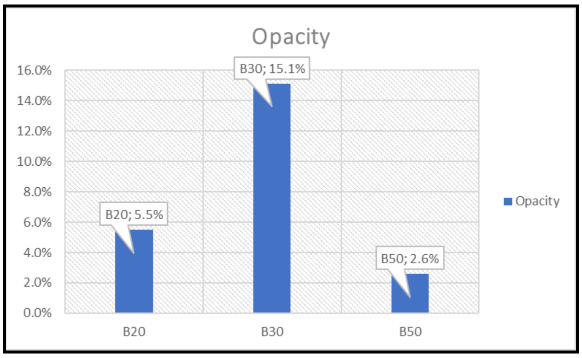

Figure 13. Opacity test result.

Emission test results showed that B50 has the lowest opacity when compared with the other two samples, as shown in Fig 13. B30 has the highest opacity at 15.1%. High opacity is caused by incomplete combustion during the opacity test; one of the factors is that B30 has a lower flash point than B20. So, it can be concluded that using B50 has the lowest opacity of all fuel samples tested.

CONCLUSION

Biodiesel production from waste cooking oil that meets the Indonesian National Standard (SNI) succeeded. Biodiesel was made using the esterification and transesterification processes. Meanwhile, the properties of biodiesel were tested using four parameters: Acid Value, Kinematic Viscosity, Density, and Flash Point. Biodiesel made by the author complies with these four parameter standards.

On the performance side, the author's result demonstrates that using the blends of WCO biodiesel (B20, B30 and B50) leads to decreased power and torque output. From the data that the author gathered, it is known that B50 has a reduction in power of up to 10% and has a decrease in torque of up to 6%. When the engine is given B30 fuel, it is shown that power is reduced by up to 1.3%. It shows no significant change in the power output between B30 and B20 as the performance baseline. Meanwhile, the torque output increases at higher rpm, but overall, there is no significant change in the torque output between B30 and B20.

On the emission side, we could see from the opacity graph that B50 has the lowest opacity of all of the biodiesel blends. It is quite odd that B30 has the highest opacity of all 3 biodiesel blend samples. From the author's perspective, the opacity should be lower when the percentage of biodiesel blend increases. Because it has a lower percentage of carbon compared to diesel fuel.

However, research from Houssem et al. and Khalid A. et al. showed that a power increase might lead to an increase in opacity [10, 11]. It can explain why the decrease in performance on using B30 is not significant, but the opacity is increased.

Finally, this study shows that B30 usage didn't show a significant decrease in engine performance, but it shows that there is an increase in opacity. Using B50 as fuel leads to a significant decrease in engine performance, but it shows that ther is a significant reduction in opacity.

The decrease in power and torque is in line with the increase in the biodiesel mixture compared to diesel fuel sourced from petroleum. This is in line with what was stated by Abdolsaeid Ganjehkaviri and Nursal, who stated that the higher the mixture of biodiesel with petrodiesel, the lower the calorific value [12, 13]. Because the calorific value of biodiesel is lower than the calorific value of petrodiesel, the torque and power output will be lower, too. Decrease in power and torque was caused by the energy produced by biodiesel, which is not as great when only using diesel fuel sourced from petroleum.

In 2020, Indonesia implemented a B30 mixture in its diesel fuel. Based on the data that the authors gathered, usage of B30 in diesel engines when compared with B20 does not have a significant difference in addition or reduction of power output . But for torque, the use of the B30 can increase engine torque, even though it only ranges between 1.3-3%. While on the emission side (opacity), it is seen that using B30 in vehicles increases the opacity of the combustion results when compared to B20.

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