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Alteration of Biodiesel Properties and Automotive Diesel Engine Performance due to Temperature Variation of the Transesterification Process

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Abstract

This study aimed to examine the effects of transesterification reaction temperature on the biodiesel properties and diesel engine performance. Biodiesel properties evaluated in this work included viscosity, density, and methyl ester content. Meanwhile, the diesel engine performance testing comprised the examination of the engine's torque and power. The research was conducted in several stages, viz. producing biodiesel from fresh cooking oil with variations in transesterification temperature of 45°C, 55°C, and 65°C; testing the characteristics of biodiesel produced; blending biodiesel with petroleum diesel to result in B30 biodiesel fuel; and testing biodiesel fuel (B30) in diesel-engined vehicles. It was revealed that the higher transesterification temperature led to the lower biodiesel viscosity, the decreasing value of biodiesel density values, and the higher methyl ester content. Furthermore, it was also demonstrated that increase of the transesterification temperature resulted in the higher value of torque and power generated. However, compared to the petroleum diesel fuel (B0), biodiesel fuel (B30) exhibited the lower values of the engine's torque and power. The highest average values of torque and power of B30 fueled diesel-engine were 108.11 Nm and 43.51 kW, respectively, provided by the biodiesel produced at the transesterification reaction temperature of 65°C.

Keywords: transesterification temperature, biodiesel, biodiesel characteristics, diesel engine, engine performance.

1. Introduction

Indonesia has many sources of energy, namely gas, geothermal, petroleum, water, solar, coal, wind, and others that can be utilized for various purposes. However, Indonesia's energy sector is highly depended on fossil fuels (Sugiawan and Managi, 2016). Petroleum cannot be exploited continuously since it is a non-renewable natural resource. Alternative fuels were developed to reduce the dependence on fossil fuels. One of the fuels that can be used as an alternative fuel in diesel engine is biodiesel. Biodiesel is derived from vegetable oil or animal fats. It is recommended as a substitute for petroleum diesel since it can be easily produced using domestic feed-stocks.

Besides, it has numerous advantages such as low emissions, environmentally friendly, renewable, and biodegradable characteristic (Zhang *et al.*, 2003; Kusumaningtyas and Bachtiar, 2012). Biodiesel combustion products are cleaner and more environmentally friendly due to the presence of additional oxygen molecules in biodiesel, leading to the completion of the combustion (Arumugam and Ponnusami, 2017).

Abundant amount of plant oil can be used as biodiesel raw material through the transesterification process. Transesterification, which is also called alcoholysis, is the transfer of alcohol from esters by other alcohols in a process similar to hydrolysis, except that alcohol is used instead of water (Fukuda *et al.*, 2001). The transesterification method requires heat or temperature to accelerate the reaction rate. Reaction temperature in transesterification process needs to be controlled since it will determine the reaction rate and affect the yield of biodiesel (Istiningrum *et al.*, 2017). Biodiesel processing has been widely studied by many researchers, and it is reported that biodiesel yielded has met the standard of fuel. However, the effects of transesterification temperature on the performance of the diesel engines fueled with biodiesel have never been discussed.

Diesel engine is one of the engines developed to meet the needs of a large power in a wide uses. Diesel engine is a type of internal combustion engine, where fuel is injected into the combustion chamber when the piston reaches the top dead center at the end of the

compression stroke (Usman, 2016) to make the combustion occurs. Combustion occurs because the fuel is sprayed in high-pressure, high-temperature air in the combustion chamber at the end of the compression stroke (Simanungkalit and Sitorus, 2013).

The combustion properties of biodiesel are similar to diesel fuel. Utilization of biodiesel for alternative fuel can strengthen the country's economy and create jobs. In addition, biodiesel is renewable and an ideal fuel for the transportation industry since it can be used in various diesel engines (Risnoyatiningasih, 2012). Biodiesel is made through a process called transesterification by reacting vegetable oils or animal fats with alcohols such as methanol (Gerpen, 2005). Esters are transformed into others through the exchange of alkoxy parts (Schuchardt et al., 1998). In transesterification reaction, triglycerides or vegetable oils are converted into alkyl esters through a reaction with alcohol. This reaction results in glycerol byproduct.

Methanol is most commonly used compared to the other monohydric alcohols as it is cheap and has the highest reactivity (Fatmawati and Shakti, 2013). Triglycerides react with methanol to form esters and glycerin. The process is carried out with a good stirring to deal with the mass transfer resistance, the excess amount of alcohol, and the addition of catalysts. Catalysts are needed to increase the reaction rate since the transesterification is a slow reaction. The catalyst used is generally KOH because it is easier to use and can accelerate the reaction faster than NaOH. A mixing is necessary mainly because triglycerides and alcohols are not completely soluble (Dias, 2010). Hence, an adequate stirring will help the system to be more homogeneous. Furthermore, transesterification is a reversible reaction. Thus, the excess amount of reactant is applied to shift the equilibrium towards the product formation.

One of the main operation parameter in transesterification reaction that needs to be controlled is the reaction temperature because it will determine the reaction rate and affect the yield of biodiesel (Istiningrum et al., 2017). The quality of biodiesel is also determined by the purification of biodiesel to remove unwanted components, to meet the standards, and to extend the shelf life of biodiesel before being used.

Temperature control in transesterification process is essential to ensure the optimum

yield of biodiesel. Based on the kinetics point of view, the higher the temperature, the greater the reaction rate. On the contrary, based on the thermodynamic point of view, transesterification reaction is an exothermic reaction in which the increase in temperature could shift the reaction towards the reactants formation, causing the decrease on conversion and products formation. If the temperature is too high, then the alcohol will evaporate. Reaction temperature also affects the characteristics of biodiesel. Thus, the optimum reaction temperature will result in the high reaction conversion and biodiesel yield. It is stated that the reaction temperature must be below the boiling point of alcohol. If methanol or ethanol are used in the reaction, then the reaction temperature is generally 60-65°C (Budiman et al., 2014).

Some investigation showed that the main factors affecting transesterification were the amount of alcohol, catalyst, reaction temperature, pressure, time, free fatty acid (FFA) and water content in oil (Ghadge and Raheman, 2006). A study has reported the work on the transesterification process at the temperatures between 32°C to 80°C. It was found that the optimal reaction temperatures were 50°C and 65°C. The higher the reaction temperature, the faster the reaction rate, the shorter reaction time, and the more optimal the results will be obtained. The temperature should not exceed the boiling point of methanol (64.7°C) because the methanol will evaporate and cause an incomplete transesterification process. The use of biodiesel 20% blended with petrodiesel demonstrated the best power of the engine (Wahyuni et al., 2015). Akhihero evaluated the temperature variations in the range of 32°C to 65°C with a reaction time of 120 minutes. It was found that the optimal temperature is 65 °C with an optimal reaction time of 75 minutes (Akhihero et al., 2013).

Other studies showed that the higher the transesterification temperature resulted in the higher conversion of biodiesel (Zeng et al., 2017). The highest conversion was above 93%, obtained at the reaction temperature of 50°C (Vyas et al., 2011). Making biodiesel using soybean oil as a raw material produced the highest conversion exceeding 95% in 30 minutes. The reaction was conducted using the 12:1 methanol to oil molar ratio and the addition of 3% SrO catalyst at the temperature of 65 °C (Liu et al., 2007). An investigation on the effects of process temperature and biodiesel settling time on the quality of biodiesel from waste cooking oil showed that the highest yield was 76%,

obtained at a processing temperature of 50°C. Additionally, biodiesel produced had the density and viscosity of 864.648 kg/m³ and 5.923 cSt, respectively. When the temperature was enhanced to 80°C, the yield was increased, but methanol quickly evaporated because it exceeded the boiling point of methanol (64.7°C). This condition has caused incompleteness of the reaction (Wahyuni et al., 2015). Before being used, biodiesel must be purified to remove unreacted reactants and byproducts (Nguyen et al., 2018). Biodiesel properties determination is also carried out after the separation process.

Transesterification process will affect the quality of biodiesel and the engine's performance when it is used as fuel in diesel machine. In its application to diesel engines, the quality of biodiesel as fuel will affect the combustion in the diesel engine combustion chamber and influence the performance of diesel engines (torque and power). Torque is a measure of the engine's ability to do work and as an important parameter of a vehicle (Fleming, 1982). The unit used for torque is Newton meter (Nm). Power is a work that can be performed per unit of engine operating time to overcome all of the engine loads (Rahman et al., 2017). The principle of torque testing and engine power determination on a dynamometer can be seen in Figure 1.

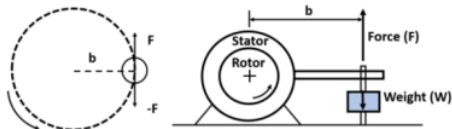


Figure 1. The dynamometer principle

The rotor is the rotating part associated with the machine to be tested. The stator is the stationary part of the dynamometer component which is connected to the arm and the force gauge. The rotor and stator will be connected through the braking mechanism. Therefore, when the rotor rotates and the braking mechanism works, there will be a reaction force (F) on the dynamometer arm. This reaction force is measured by force gauge. The notation n in Figure 1 shows the engine speed (rpm), b is the arm length of the dynamometer (m), and F is the reaction force (N) caused by the braking action (loading).

The torque value can be determined by using Equation (1) if the value of the force (F) working on the arm (b) which is perpendicular to the force (Heywood, 1988):

$$T = F \cdot b \quad (1)$$

T is the torque (Nm), F is the reaction force (N), and b is the arm length of the dynamometer (m). If the value of the Torque is known, the power can be calculated by Equation (2).

$$P = \frac{2\pi n T}{6000} (\text{kW}) \quad (2)$$

where P is power (kW), n is engine speed (rpm), and T is torque (Nm).

Many studies related to the application of biodiesel as diesel engine fuel have been found in the literature. Radhakrishnan et al. (2018) reported that biodiesel derived from vegetable oils through transesterification can be used directly as fuel or as a substitution without modifying diesel engines. Aziz (2010) tested the performance of diesel engines using biodiesel from used cooking oil. The results revealed that the use of petrodiesel fuel (B0), biodiesel B20, and biodiesel B40 resulted in the engine power of 35.8398 kW, 36.3911 kW, and 35.2884 kW, respectively, at 3000 rpm. CO gas emission produced by biodiesel B40 and B20 were smaller than petrodiesel fuel.

Based on the above studies, it is known that the effect of the temperature variations in transesterification process has been carried out and the performance tests of biodiesel on diesel engines have also been investigated. However, the effect of transesterification temperature on the biodiesel characteristics and diesel engine performance have not examined yet. For this reason, this research aimed to examine the effect of transesterification temperature on the characteristics of biodiesel (viscosity, density, and methyl ester content) and the performance of diesel engines, including diesel engine torque and power.

2. Materials and Methods

2.1. Materials

The materials for producing biodiesel were fresh cooking oil, methanol, and KOH. The main reactor for biodiesel processing was a stainless steel tank equipped with the stirrers, heaters; and temperature controller.

2.2. Biodiesel Characterization

The instruments used to test the characteristics of biodiesel were a pycnometer for determining biodiesel density; viscometer for measuring biodiesel viscosity; Gas Chromatography-Mass

Spectrometry (GC-MS) for analyzing the compounds composition in biodiesel, especially the content of methyl esters.

Furthermore, a chassis dynamometer was utilized to test diesel engine performance (torque and power) on vehicles. The specifications of the chassis dynamometer used were the MAHA Dynamometer type LPS 3000 Roller set R100/1; Eddy Current Brake; Air cooling system; Max speed test 260 km/h; Wheel power max. 260 kW; Traction max. 6 kN; and Measurement accuracy of $\pm 2\%$. The diesel engine used for this research was a diesel engine on an Isuzu Panther vehicle 2015. The specifications of the vehicle used were: MSG5K engine; 2,498 cc cylinder Capacity; Maximum Power of 80 PS / 3,500 rpm; Maximum torque of 19.5 kgm / 1,800 rpm; Number of cylinders: 4 in line; Diameter x stroke 95.4 mm x 87.4 mm; 5 speed transmission.

2.3. Synthesis of Biodiesel

Biodiesel synthesis was carried out in several steps: 1) setting-up a stirred and heating biodiesel production unit; 2) preparing a methoxide solution with a 200 ml methanol and 10 gram KOH as catalyst; 3) putting 1 liter of cooking oil in the reactor; 4) turning on the stirrer and heater in accordance with a predetermined temperatures for biodiesel synthesis (45°C, 55°C and 65°C); 5) adding the methoxide solution into the reactor; 6) stirring and heating the reaction mixture at a controlled temperature for 60 minutes; 7) removing the mixture from the reactor and putting it in a container; 8) settling for 24 hours; 9) separating glycerin from methyl ester (biodiesel); 10) heating biodiesel at a temperature of 70°C to remove the methanol content; 11) washing biodiesel to remove soap content; 12) precipitating the washing product to form two layers (biodiesel and water phases); 13) separating water from biodiesel, and 15) heating washed biodiesel at a temperature of 105°C to remove the remaining water content.

Biodiesels produced from various transesterification process temperatures were tested in the laboratory to reveal the characteristics of biodiesel i.e. density, viscosity and methyl ester content. Biodiesel blended with petrodiesel was then applied as fuel in the diesel engine. The subsequent test was examining the performance of diesel engines on vehicles using a chassis dynamometer. The biodiesel tested were biodiesel and petrodiesel fuel blends with a ratio of 30% biodiesel and 70% petrodiesel

fuel (B30). There were four types of fuels tested on the vehicle, namely B30 produced from the transesterification process at 45°C, 55°C, 65°C, and pure petrodiesel fuel (B0) as a comparison.

2.4. Performance of Biodiesel

The procedures for testing the diesel engine performance in vehicle were: 1) positioning the car on the dynamometer; 2) tying the car using safety belts to keep it in the fixed position; 3) preparing the blower and placing it in front of the car to maintain the engine temperature; 4) inserting the oil temperature sensor stick into the oil stick holder; 5) checking the engine cooling water; 6) preparing the fuel reservoir and attaching it to the fuel line instead of the fuel tank; 7) putting diesel fuel in the reservoir; 8) starting the engine and warming up the machine until reaching engine working temperature; 9) turning on the computer on the dynamometer; 10) adjusting the settings on the computer to the car's specifications; 11) shifting the transmission in 4th gear position; 12) stepping on the acceleration pedal until the dynamometer reading is completed; and 13) conducting the identical steps for B30 with transesterification process of 45°C, 55°C, 65°C and by changing fuel on the reservoir.

Each variation of fuel was tested twice and the average result was taken from the test. After the tests were completed, the following steps were carried out: turning off the engine, turning off the blower, printing the results of the computer calculation of torque and power, turning off the computer, and removing the safety belts. The test scheme is simply shown in Figure 2.

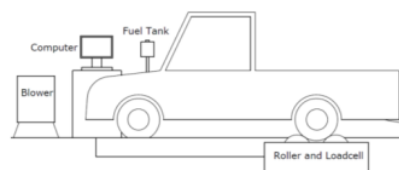


Figure 2. Schematic of the diesel engine performance testing

Data obtained from the roller and load-cell were processed by a computer to produce the torque and diesel engine power values of the vehicle being tested.

3. Results and Discussion

The biodiesel from vegetable oil produced in this work showed a lighter color than that of

the diesel fuel. The characteristics of biodiesel produced from various temperature of the transesterification process can be seen in Table 1.

Table 1. The characteristics of biodiesel from the transesterification process at 45°C, 55°C, and 65°C

No	Properties	Transesterification Temperature			SNI
		45°C	55°C	65°C	
1	Viscosity (mm ² /s)	3.32	3.28	3.20	2.3-6.0
2	Density (kg/m ³)	863	852	844	850-890
3	Methyl Ester Content (%-mass)	97.99	98.50	98.51	Min. 96.5

Based on the data in Table 1, the higher the temperature in the transesterification process, the viscosity and density tended to decrease. This is in accordance with Budiman *et al.* (2014) that the higher temperature in the esterification process can decrease the viscosity (Gulum *et al.*, 2017). This also showed that the transesterification process have run perfectly. According to Kartika *et al.* (2011), if the transesterification process does not completely convert triglycerides into methyl esters, it will produce intermediate compounds such as mono- and diglycerides which increase the viscosity. Based on the data in Table 1, it can be concluded that the methyl esters content tended to increase along with the rise of the transesterification temperature. This result was in accordance with the work of Akhiehiero (2013). It was stated that the higher transesterification reaction temperature generated the higher reaction conversion and biodiesel yield (Vyas *et al.*, 2011; Kusumaningtyas *et al.*, 2017). The increasing yield of biodiesel was also denoted by the increasing of the methyl ester content with the raised reaction temperature (Nisar *et al.*, 2017). It can be described by the theory stating that the high temperature causes the more frequent collisions between molecules which makes fatty acids and methanol react more to produce esters (Frederic, 2013).

The biodiesel properties at various transesterification temperature are presented in Table 1. Compared with SNI (Indonesia National Standard), the viscosity and methyl ester content has met the standards at all transesterification process temperatures. Furthermore, results of the density test showed that the higher temperature in the transesterification process tended to

decrease the density (Aini and Tjahjani, 2013). The densities of biodiesel produced at the reaction temperatures of 45°C and 55°C still met the standard (SNI), but biodiesel yielded at 65°C transesterification process was under the predetermined standard. Diesel engine performance test results are shown in Table 2 and Table 3.

Table 2. Torque of diesel engine with biodiesel fuel from the transesterification process at 45°C, 55°C, and 65°C

No	Enggine Speed (rpm)	Engine Torque (Nm)			
		DO	B30-45	B30-55	B30-65
1	2750	117.65	115.73	112.25	119.06
2	3000	113.23	111.86	114.47	114.44
3	3250	109.02	107.55	110.01	110.45
4	3500	107.49	105.74	108.09	108.75
5	3750	104.91	101.48	106.28	106.57
6	4000	105.27	100.21	104.92	105.90
7	4250	103.65	102.99	104.78	105.99
8	4500	105.42	103.83	104.45	105.52
9	4750	105.47	102.63	103.50	104.31
10	5000	101.22	98.85	100.24	100.14
Average		107.33	105.09	106.90	108.11

Note: DO = Diesel Oil (diesel fuel, B0); B30-45 = B30 fuel with biodiesel from the transesterification process at 45°C; B30-55 = B30 fuel with biodiesel from the transesterification process at 55°C; and B30-65 = B30 fuel with biodiesel from the transesterification process at 65°C.

Based on the data shown in Table 2, it can be explained that the increase in the transesterification temperature enhanced the torques of diesel engine. This was possibly caused by the viscosity of the fuel. Biodiesel viscosity decreased with the raise in the reaction temperature. Whereas, according to Sahoo and Das (2009), low fuel viscosity can make a better fuel atomization since the fuel can be sprayed into combustion chamber more easily and mixed with the air faster. Therefore, combustion of fuel in the diesel engine combustion chamber is more optimal and the engine torque is rising, as well.

Based on Table 3, it can be explained that the higher the transesterification temperature led to the increase of the diesel engine power. It was due the effect of rising esterification temperature which decreased the viscosity of the fuel. The lower viscosity has resulted in a better fuel injection and fuel atomization which affected the combustion and increased diesel engine power. Based on the testing of the vehicles using a chassis dynamometer, the characteristics (torque) of a diesel engine with pure diesel fuel and a 30% mixture of biodiesel from transesterification at various temperatures can be observed in Figure 3.

Table 3. Power of diesel engine with biodiesel fuel from the transesterification process at temperatures of 45°C, 55°C, and 65°C

No	Engine Speed (rpm)	Engine Power (kW)			
		DO	B30-45	B30-55	B30-65
1	2750	33.88	33.33	32.34	34.29
2	3000	35.57	35.14	35.96	35.95
3	3250	37.11	36.61	37.44	37.59
4	3500	39.40	38.75	39.62	39.86
5	3750	41.20	39.85	41.74	41.85
6	4000	44.10	41.98	43.95	44.36
7	4250	46.13	45.84	46.64	47.17
8	4500	49.68	48.93	49.22	49.73
9	4750	52.46	51.05	51.48	51.89
10	5000	53.00	51.76	52.49	52.43
Average		43.25	42.32	43.09	43.51

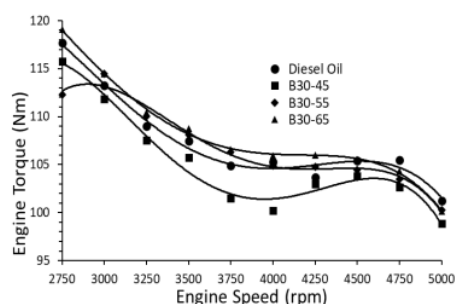


Figure 3. Relationship between engine speed and engine torque

Referring to Figure 3, torque decreased with increased engine speed. This occurred due to the higher rotation which reduced the efficiency of the air intake into the combustion chamber. In addition, the increasing engine speed brought about the greater friction in the cylinder wall. The piston did not have enough time to suck the air fully. Hence, the amount of the air entering the combustion chamber reduced, the compression pressure decreased, and the combustion process became imperfect. Consequently, the resulting torque also decreased (Ichsan *et al.*, 2018). However, the performance of diesel engines with biodiesel fuel was still reasonable as demonstrated in Figure 4 (Gad *et al.*, 2018).

Referring to Figure 4, in general, the torques of diesel engine with B30 fuel were lower than the torque of diesel engines with pure diesel fuel. It was not surprising since biodiesel fuel had a lower heating value to diesel oil as reported by Abed *et al.* (2018) and Siva *et al.* (2019). This work revealed that the rising of transesterification temperature led to the higher torque of the diesel engine. However,

the overall average torque resulted by biodiesel blends fuel was 106.7 Nm, which was below the torque of the diesel engine fueled by diesel fuel (107,33 Nm). On the contrary, diesel engine fueled by B30-65 showed a slightly higher torque (0.73%) than diesel engine with pure diesel fuel (D). This happened since biodiesel produced by transesterification process at the temperature of 65°C had a lower viscosity. The lower viscosity, enabled the better atomization during injection (Kusuma *et al.*, 2019). Beside that, the injected fuel became smoother and easy to mix with air. This condition caused a more optimal fuel combustion (Sahoo and Das (2009).

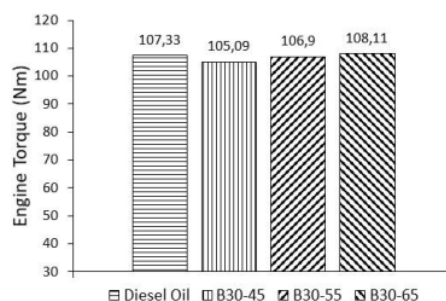


Figure 4. Average torques of the diesel engine with diesel fuel (DO), B30-45, B30-55, and B30-65

Power generated by diesel engine fueled by diesel fuel (DO), B30-45, B30-55, and B30-65 is presented in Figure 5.

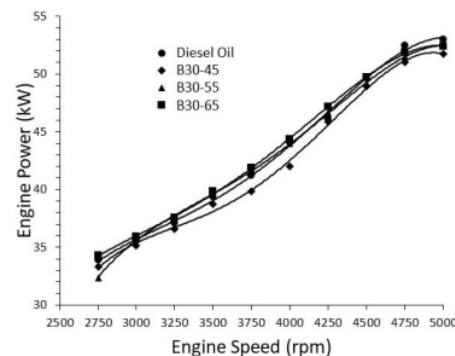


Figure 5. Relationship between engine speed and power

Based on Figure 5, it was found that as the engine speed raised, the power increased, as well. It happened since the higher rotation enhanced the work of the diesel engine per unit of time according to Equation 2. The effect of transesterification temperature

during the biodiesel production on the diesel engine power can be observed in Figure 6.

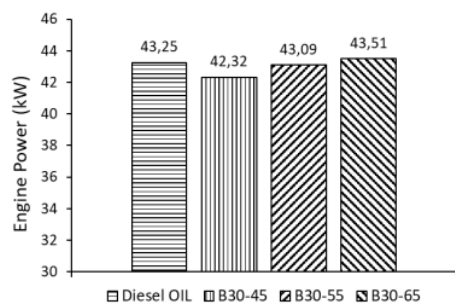


Figure 6. Average power of diesel engine fueled by diesel fuel, B30-45, B30-55, and B30-65

Figure 6 indicates that the powers of the diesel engine fueled by biodiesel blends fuel were lower (overall average of 42.97 kW) than that of the diesel engines fueled by diesel fuel (43.25 kW). According to Abed *et al.* (2018) and Siva *et al.* (2019), this phenomenon occurs since the heating value of diesel fuel is higher than biodiesel. For B30 fuel, the increased temperature of the transesterification tended to improve the diesel engine's power to some extent. It was also demonstrated that the diesel engine power fueled by B30-65 was slightly higher (0.60%) compared to that fueled by diesel fuel. It came about since biodiesel produced from the transesterification process at the temperature of 65°C had a lower viscosity, and thus the atomization of fuel in the combustion chamber was better (Kusuma *et al.*, 2019), smoother and easier to mix with the air.

Fuel combustion can be optimized (Sahoo and Das, 2009) so that the power was slightly higher. Among the important properties of biodiesel is the methyl ester content. Methyl ester molecule is a straight carbon chain similar to diesel fuel which has oxygen molecules at the end of the chain carbon (Darmanto and Sigit, 2006). The existence of oxygen in the biodiesel molecular structure is beneficial to make the combustion more completed (Arumugam and Ponnusami, 2017).

4. Conclusion

Transesterification temperature had an influence on the characteristics of biodiesel produced. The higher transesterification temperature caused the lower values of viscosity and density. On the contrary, it resulted in the higher methyl ester content.

The characteristics of biodiesel with transesterification processing temperature at 45°C, 55°C, and 65°C fulfilled the SNI standards for viscosity and methyl ester content. Biodiesel density produced at 45°C and 55°C were appropriate, but the one produced at 65°C was lower than the SNI standards.

Temperature of the transesterification process also affected the performance of diesel engines. The higher the temperature of transesterification process, the higher the engine torque and power. However, it was demonstrated the torque and power of diesel engines fueled by biodiesel blends were lower than those of diesel engines fueled by diesel fuel. The lowest torque and power was shown by the diesel engines fueled by biodiesel blend (B30) produced from 45°C transesterification temperature with the torque and power values of 105.09 Nm and 42.32 kW, respectively.

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