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The Effect of the Number of Stirrer Blades in the Transesterification Reactor on the Characteristics of Biodiesel and Diesel Engine Performance

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ABSTRACT

Biodiesel is one of the alternative fuels that can be used in diesel engines instead of diesel oil. Transesterification is used to create biodiesel from cooking oil. The stirring procedure in the reactor is one of the elements influencing the transesterification process. The purpose of this research is to investigate the influence of the number of stirrers in the transesterification reactor on biodiesel and diesel engine performance. This study was carried out by converting cooking oil into biodiesel via a transesterification process. Stirrers with one pair, two pairs, and three pairs of stirrer blades are employed in the stirring process in the transesterification reactor. The resulting biodiesel was tested for its properties before being used in a diesel engine to determine the performance of a diesel engine using transesterified biodiesel fuel. The resulting biodiesel is utilized as a diesel oil substitute at a ratio of 20% biodiesel to 80% diesel oil (B20). To determine diesel engine performance, the fuel mixture was tested on a diesel engine. The results demonstrated that the produced biodiesel met the Indonesian National Standard (SNI). Diesel engine performance demonstrates that there is no substantial change in the performance of diesel engines using Pertamina (Indonesian State Oil and Gas Mining) diesel fuel.

1. Introduction

It is widely acknowledged that the era of fossil fuels is coming to an end. The increasing accumulation of carbon dioxide in the atmosphere, resulting in a drastic increase in global temperature, does not allow the current pace of consumption of these fuels in the world, and thus man must search out clean and renewable energy alternatives to reduce reliance on fossil fuels [1]. Fossil fuels account for more than three-quarters of Greenhouse gas (GHG) emissions causing climate change, making them a priority for climate policymakers. Overwhelmingly, mitigation policy has emphasized limiting demand for fossil fuels, either through carbon pricing or by promoting the development of alternative energy sources to displace fossil fuels [2,3]. Diesel engines are mostly employed in transportation and power generation. Due to the rapid depletion of fossil fuels such as

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diesel, there is also a need to discover alternative fuel sources for the transportation and power sectors [4]. Fatty acid methyl ester (FAME), also known as biodiesel, is an alternative fuel that has the potential to be developed further [5-7].

Among several alternative fuel sources, the use of vegetable oil is always compromising, affordable, and feasible. The major benefit of using transesterified vegetable oil in diesel engines is that when utilized at lower quantities, vegetable oils can be used directly without any engine modifications [8]. The transesterification method is used to make biodiesel, which tries to lower the viscosity or thickness of the oil to that of diesel fuel. The transesterification process is typically used to manufacture biodiesel from raw materials with low free fatty acid (FFA) levels of less than 5% [9]. Triglycerides are reacted with short-chain alcohols such as methanol or ethanol to form biodiesel and glycerol [10]. Vegetable oil raw material has a high potential as a biodiesel raw material since it is widely available in the community. Another benefit of using cooking oil as a raw material for biodiesel manufacturing is that it contains few free fatty acids [11]. Vegetable oil is a significant raw ingredient used in the manufacturing of biodiesel. However, as compared to petroleum diesel, its direct usage as fuel is hampered by its high density, poor volatility, high viscosity, and particle deposition in engines. A transesterification technique is often used between vegetable oil and alcohol to make mono-alkyl esters, which are known as biodiesel, to give it qualities similar to petroleum-based diesel [12,13].

Efforts to increase the quality of biodiesel continue by performing research and tests on the stirrer model of biodiesel production. The rotation of the stirrer influences the success of the biodiesel production process. According to Triwibowo *et al.,* [14], the method of mixing in a stirred tank attempts to swiftly respond, transfer mass, and change the properties of a mixture while also increasing the transfer of momentum between particles in a fluid being stirred. A mixed flow forms in the shaft during the mixing operation. This flow has a significant influence that is beneficial to the mixing process. The flow profile and degree of turbulence are crucial factors influencing mix quality [15]. Several studies have been conducted to assess the impact of reactor design on biodiesel production. However, the output of biodiesel is also affected by the pace at which the raw ingredients are mixed. The process must be optimized to increase yield while decreasing costs. Mixing properties such as stirrer design, blade diameter, and stirrer placement were therefore optimized. Stirrer designs used in biodiesel manufacturing include a cross stirrer, a straight stirrer, a blade stirrer, a centrifugal stirrer, and a pitched blade stirrer [16].

The usage of a cross stirrer, a straight stirrer, a blade stirrer, a centrifugal stirrer, and a pitched blade stirrer was examined based on the investigations described above. However, only one set of stirrers was employed. In this study, a biodiesel production test was carried out using a blade-type stirrer with one, two, and three pairs incorporated in one stirrer shaft. The purpose of this study is to look at the influence of the number of stirrer blades on biodiesel characteristics, the effect of utilizing biodiesel fuel on diesel engine performance, and the effectiveness of each stirrer model variation in terms of biodiesel quality and diesel engine performance.

2. Methodology

As illustrated in Figure 1, the biodiesel used in this investigation was produced using biodiesel processing equipment. Transesterification was used to create biodiesel from new cooking oil as a basic source. 10 grams of KOH were used for 1.5 Liters of cooking oil, which was dissolved in 250 ml of methanol. The following are the steps in the production of biodiesel: 1) thoroughly mixing 10 g of KOH into 250 ml of cooking oil; 2) pumping KOH and methanol into the transesterification reactor, which already contains 1.5 Liters of cooking oil at 60^{o}C; 3) perform the stirring (with one pair of stirrer blades) by running the stirrer motor at 200 rpm for one hour while keeping the temperature at 60°C. 4) Pour the reactants into the separator tank for 24 hours; 5) separate the biodiesel and glycerol; 6) wash the biodiesel; and 7) dry the biodiesel. Repeat steps 1–7 with two pairs of blades and three pairs of blades, yielding three types of B1, B2, and B3 biodiesel from three esterification processes. Each mixing blade has a 45° slant (Figure 1).

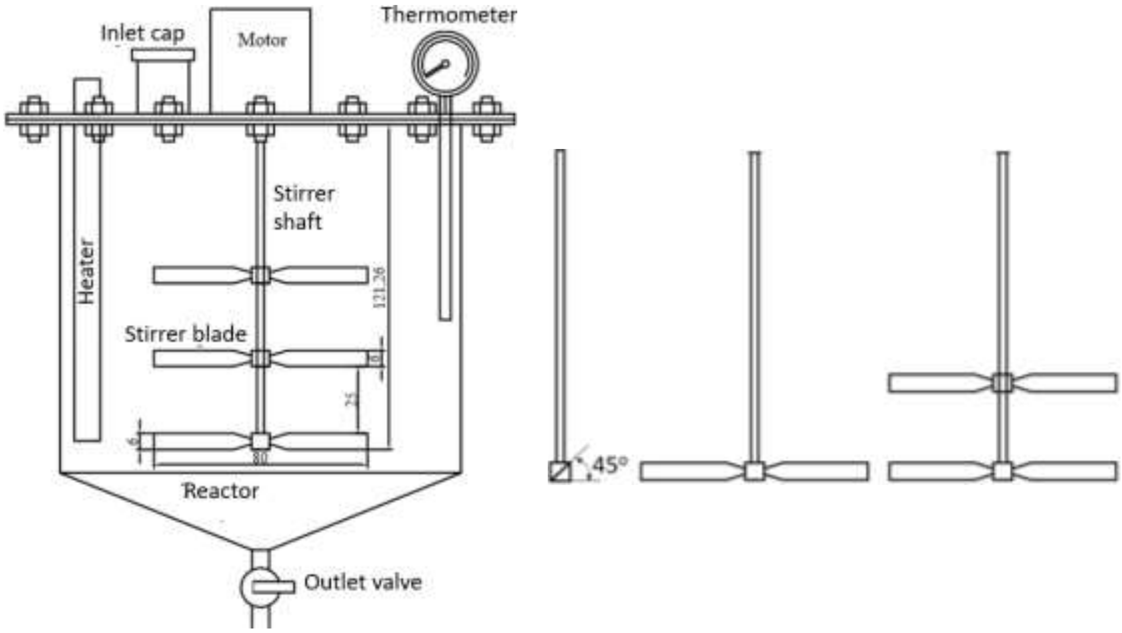

Fig. 1. Transesterification reactor and three types of stirrer blades

The employment of three types of stirrers for the transesterification process was justified by the idea that the greater the number of stirrers, the more collisions between reactant particles. This impact will help to break down the surface tension of the oil and alcohol, allowing them to react more effectively. As a result, it is vital to do so in order to achieve the best biodiesel conversion rate. Biodiesel viscosity testing according to ASTM D-445, density testing using a picknometer according to ASTM D70, and methyl ester content measurement using a GCMS equipment were all examples of biodiesel testing. The following specifications were used to test the performance of a diesel engine using a Chassis dynamometer: Supply Voltage 1 x 230V; Frequency 50 Hz; Rated Current 15 A; Fuse 16 A; Maximum Axle Load 2500 Kg. Test vehicle is a 2015 ISUZU Panther Pick Up Turbo with a 2.5-liter engine, four-stroke four-cylinder engine, direct injection, and a manual transmission.

In this study, four types of fuel were tested on diesel engines: 1) diesel oil bought from Pertamina gas stations; 2) a mixture of diesel oil with 20% B1 (B20-1); 3) a combination of diesel oil with 20% B2 (B20-2); and 4) a mixture of diesel oil with 20% B3 (B20-3). The processes for testing the performance of a diesel engine in a vehicle were as follows: 1) putting the automobile on the dynamometer; 2) strapping the car down with safety belts to keep it in place; 3) prepping the blower and positioning it in front of the car to keep the engine temperature stable; 4) placing the new oil temperature sensor stick into the old oil temperature sensor stick; 5) testing the engine cooling water; 6) prepping the fuel reservoir and connecting it to the fuel line rather than the fuel tank 7) filling the reservoir with diesel fuel; 8) starting the engine and warming up the machine till the engine reaches operating temperature; 9) turning on the computer on the dynamometer; and 10) configuring the computer settings to the car's specifications; 11) moving the gearbox into fourth gear; 12) pressing the accelerator pedal until the dynamometer reading is complete; and 13) repeating the 7th steps for

B20-1, B20-2, and B20-3 and changing the fuel in the reservoir. Each fuel variation was tested twice, with the average result being used. Figure 2 depicts the simple test scheme.

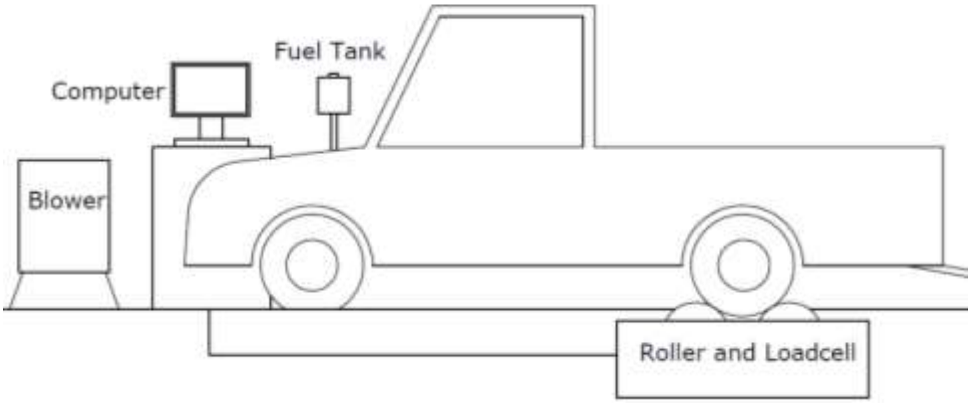

Fig. 2. Schematic of the diesel engine performance testing

A computer processed data from the roller and load cell to provide torque and diesel engine power values for the vehicle being evaluated. Following the completion of the testing, the following steps were taken: shutting down the engine, shutting down the blower, printing the results of the computer calculation of torque and power, shutting down the computer, and removing the safety belts.

3. Results

The findings of testing the properties of biodiesel, such as viscosity, density, and methyl ester content. The density and viscosity of a liquid define its resistance to flow. The fuel injection process in engines and the atomization process of fuels during injection are affected by the viscosity and density of the fuel [17]. One of the most essential qualities of biodiesel is its viscosity. Because of its impact on engine performance and emission characteristics, kinematic viscosity is one of the most critical biodiesel features. The fuel viscosity influences the atomization process, the size of the fuel droplets, and the in-cylinder penetration of the fuel spray [18].

According to Table 1, adding stirrer blades to the transesterification reactor causes a small drop in viscosity. It decreased by 3.68% for B20-2 and 7.36% for B20-3, respectively, from 4.62 mm^2/s for B20-1. All viscosity values, however, are in accordance with the SNI (Indonesian National Standard). There is no major change in viscosity, and it still fulfills SNI criteria. The biodiesel kinematic viscosity required for production is 1.9-6.0 mm^2/s [19,20]. As a result, every biodiesel produced in this study has a viscosity that meets the guidelines. Adding stirrer blades to the transesterification reactor causes a little density change, but not significant. All density measurements are consistent with the SNI. Biodiesel density is between 860 and 900 kg/m^3, and between 843 and 890 kg/m^3 [21-24]. As a result, every biodiesel produced in this study has a density that meets the standards.

Table 1
Biodiesel characteristics

Biodiesel Characteristic	B20-1	B20-2	B20-3	SNI
Viscosity (mm^2/s)	4.62	4.45	4.28	2.3-6.0
Density (kg/m^3)	867	868	866	850-890
Yield of Biodiesel (%)	99.45	99.29	99.24	96.5

The addition of stirrer blades to the transesterification reactor has no effect on the rate of biodiesel yield. The biodiesel conversion rate decreased slightly by 0.16% for two pairs of blades and slightly by 0.21% for three pairs of stirrers compared to a pair of stirrers with a conversion rate of 99.45%. This decrease is very insignificant, so it can be concluded that increasing the number of stirrer blades has no effect on the biodiesel conversion rate. The conversion rate for all biodiesel is still included in the SNI standard.

According to Table 2 and Figure 3, diesel fuel produces the best torque of a diesel engine, with an average torque of 152 Nm. Torque is a rotating force produced by the crankshaft of an engine. The more the torque produced by an engine, the greater its ability to accomplish work [25]. Torque of a diesel engine with B20 fuel: the maximum torque achieved by a diesel engine with B20-3 fuel is 150.04 Nm. Torque was reduced by 1.73% (B20-1), 1.88% (B20-2), and 1.68% (B20-3) when compared to diesel fuel.

Table 2
Diesel engine performance

Engine Speed (rpm)	Torque (Nm)				Power (kW)			
	Diesel fuel	B20-1	B20-2	B20-3	Diesel fuel	B20-1	B20-2	B20-3
2000	167.80	164.60	164.30	165.10	33.91	33.10	33.00	33.46
2500	155.90	154.00	152.90	153.40	39.39	38.70	38.40	38.88
3000	151.60	147.20	149.00	148.90	45.97	44.39	44.88	45.28
3500	150.70	148.20	148.10	149.20	53.31	52.16	52.09	52.69
4000	137.00	135.80	134.30	133.60	55.41	53.96	53.98	54.18
Mean	152.60	149.96	149.72	150.04	45.60	44.46	44.47	44.90

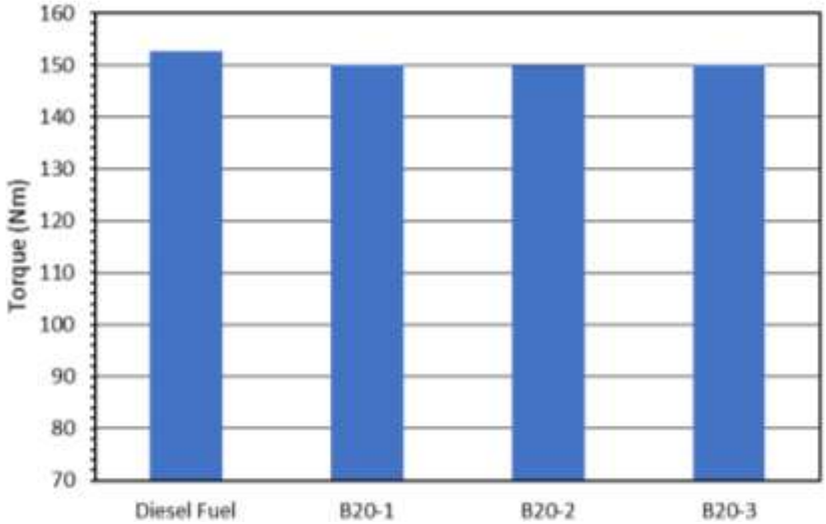

Fig. 3. Torque of diesel engine with various fuel

As a result, the torque of a diesel engine running on a 20% biodiesel combination is 1.76% lower than the torque of a diesel engine running on diesel fuel. With an average torque difference of 0.13% (extremely minor), the torque of the diesel engine using B20-3 fuel is somewhat higher than the torque of the diesel engine using B20-1 and B20-2 fuel. With this distinction, it is possible to deduce that increasing the number of stirrer blades in the transesterification reactor has no effect on the torque of the diesel engine. The torque of a diesel engine running on a biodiesel/diesel oil mixture is lower than the torque of a diesel engine running on diesel fuel. This is due to the fact that biodiesel has a lower calorific value than diesel oil. As a result, diesel oil containing biodiesel has a lower calorific value than diesel oil. This is consistent with Gautam and Kumar [26] that biodiesel has a lower calorific value than diesel oil, with a difference of roughly 9.25%.

The torque produced by the transesterification process using a stirrer with three pairs of blades has the highest diesel engine torque among B20 fuels. When it comes to fuel viscosity, the fuel produced via transesterification with three pairs of stirrers has the lowest. This reduced viscosity will result in greater fuel atomization in the combustion chamber of a diesel engine [26]. This enables for more efficient combustion. As a result, torque might be increased when compared to fuel with a higher viscosity. When compared to the torque of a diesel engine running on diesel fuel, the torque of a diesel engine running on B20-3 fuel is still lower.

According to Table 2 and Figure 4, diesel fuel produces the most power from a diesel engine, with an average power of 45.60 kW. The power of the diesel engine with B20 fuel is 44.90 kW, which is the greatest power achieved by a diesel engine with B20-3 fuel. Power was reduced by 2.50% (B20-1), 2.47% (B20-2), and 1.53% (B20-3) when compared to diesel fuel.

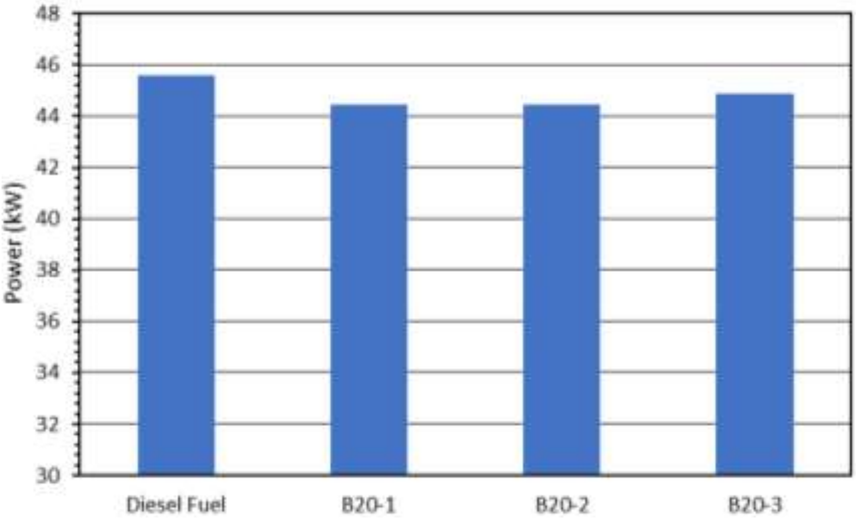

Fig. 4. Power of diesel engine with various fuel

As a result, the power of a diesel engine running on a 20% biodiesel mixture is 2.17% lower than the power of a diesel engine running on diesel fuel. The reduced power is due to the fact that the calorific value of the biodiesel mixture is less than that of diesel oil. This is consistent with the findings of Tran *et al.,* [27], who discovered that using a biodiesel/diesel oil blend reduces diesel engine power. Diesel engines powered by B20-3 fuel produce slightly more power than diesel engines powered by B20-1 and B20-2 fuels, with an average power differential of 0.13% (extremely minor). With this distinction, it is possible to deduce that increasing the number of stirrer blades in the transesterification reactor has no effect on the power of the diesel engine. The increased number of stirrers causes the reactor's reactants to rotate in practically all sections of the reactor. Because the spin speed of the reactants is homogeneous, there are few collisions between them. As a result, one pair of stirrers is adequate for the stirring operation in the transesterification reactor.

Among B20 fuels, the power produced by the transesterification process utilizing a stirrer with three pairs of blades has the highest diesel engine power. The fuel produced via transesterification with three pairs of stirrers has the lowest viscosity. This lower viscosity will result in more fuel atomization in a diesel engine's combustion chamber [26]. This makes combustion more efficient. As a result, when compared to fuel with a higher viscosity, output may be enhanced. The power of a diesel engine operating on diesel fuel is still inferior when compared to the power of a diesel engine running on B20-3 fuel. This is because biodiesel has a lower heating value than diesel oil. Because of the presence of oxygen in biodiesel, its heating value is decreased. This can result in a heating value that is approximately 10% lower than the heating value of diesel oil. However, biodiesel's higher oxygen content may be more effective at reducing PM particles, which are mostly generated during diffusion combustion and at high loads, where the majority of the combustion process is diffusive [28,29].

4. Conclusions

Stirrer blades added to the transesterification reactor have no influence on biodiesel characteristics and still meet SNI. The addition of stirrer blades to the transesterification reactor reduces viscosity slightly. When stirrer blades are added to the transesterification reactor, the density changes somewhat but not significantly. The torque and output of a diesel engine powered by a biodiesel/diesel oil mixture are less than those of a diesel engine powered by diesel fuel. With this distinction, it is feasible to conclude that increasing the number of stirrer blades in the transesterification reactor has no influence on diesel engine torque and power.

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