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Candlenut oil-based biodiesel development as an alternative to palm oil-based biodiesel

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Abstract

The purpose of this study is to develop candlenut oil-based biodiesel as an alternative to palm oil-based biodiesel, which has caused many problems ranging from unhealthy oil to ecological damage and environmental destruction. The B30 biodiesel was produced by the transesterification process of candlenut oil and methanol, which were mixed and heated at 60°C – 65°C on a magnetic stirrer for 30 minutes using different masses of the catalyst, KOH. The effect of catalyst mass on density, viscosity, pour point, and flash point of biodiesel was reported, with density and viscosity measured using a standard physics laboratory procedure. The pour point was determined using the ASTM D 97 method, and the flash point was measured using the Pensky-Martens Closed Cup and the ASTM D 93 method. The results showed that 90% of the data for density and viscosity met the Indonesian government's values. Pour point data (6°C, 9°C, and 12°C) and flash point data (132°C, 138.5°C, and 135.5°C) met the government's values, namely a maximum of 18°C for pour point and a minimum of 55°C for flash point. These findings demonstrated the success of developing candlenut oil-based B30 biodiesel. The practical implication of these findings is that the opportunity to produce healthier, more environmentally and ecologically friendly biodiesel is wide open.

Keywords: B30 biodiesel, Candlenut oil, Flash point, KOH catalyst, Palm oil, Pensky-Martens closed cup, Pour point.

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1. Introduction

World geopolitical instability, with wars still raging in Ukraine and the Middle East, is not only reshaping the social, political, and military landscape but also the financial and economic posture, including rising oil prices [1]. The trade war between the United States and China, high tensions between Mainland China and Taiwan, and disputes over China's claims to the South China Sea have caused economic growth to slow down. Political uncertainty causes volatility in many commodity prices, including energy [2, 3]. The price of Brent crude oil on December 11, 2024, is USD 73.52 per barrel. This means that with an oil import level of one million barrels per day, the Indonesian government must spend 73.52 million US dollars or 1.16 trillion rupiah per day (1 USD = 16,000 Rupiah). With a relatively high population growth rate and increasing energy needs, more and more of the budget must be spent to meet energy requirements.

It is understood that nuclear power plants produce large, stable, and clean energy [4]. However, the high cost and any inherent risks to safety and security may have caused governments to delay the construction of nuclear power plants [5, 6]. The Indonesian government changed its policy to develop safer renewable energy sources, including biodiesel. Raw materials for developing biodiesel are abundant, ranging from fish oil and animal oil to vegetable oil. Traditionally, coconuts have been exploited to produce cooking oil for hundreds of years and can be used as a raw material for biodiesel [7]. At the industrial level, palm oil (Elaeis guineensis) has been used as the main source of biodiesel production in many countries, including Indonesia [8, 9]. With a growth rate of production of 9% per year, Indonesia is estimated to produce 60 million tons per year by 2045 [10]. However, only 12 million tons (20%) are committed to support the biodiesel industry per year. This restriction was imposed to maintain the stability of palm oil prices because fluctuations in oil prices cause political and social instability. This figure is equivalent to 236.7 barrels per day. The gap between the need for imported oil and the availability of palm oil to produce biodiesel is still large. In addition, increasing environmental and social concerns regarding large-scale palm oil production raise questions about environmental issues and the future sustainability of palm fruit as a raw material for biodiesel [11]. This opens great opportunities to develop raw materials other than palm fruit to produce biodiesel.

Candlenut grows in most parts of Indonesia, with optimal growth at an altitude of 0-800 m. Candlenut growth reaches a height of 40 m and a diameter of 150 cm, with an estimated production of 200 kg/tree/year. Candlenut produces 10 tons/ha/year of crude oil compared to palm oil, which only produces around 4.4 tons/ha/year of crude oil in 2020 [12]. The conversion efficiency of candlenuts into oil reaches 30% - 60% [13] compared to palm oil conversion, which is only 22% - 23% [14]. Oil palm plantations consume a lot of water, so they cannot coexist with many other plants [15]. Candlenut is an annual plant that does not consume much water and can coexist with many other annual plants. It can grow even in relatively dry areas [16]. In contrast to oil palm plantations, candlenut plantations have the potential to help reforestation [17, 18].

All the information above shows that candlenut has greater potential than palm oil and is worthy of exploration as a biodiesel raw material. The price is currently still relatively high, ranging from 40,000 to 65,000 rupiah per kilogram. However, as candlenut production increases, the price also decreases. Political will is needed from decision-makers regarding energy self-sufficiency. A blueprint and roadmap for the development of candlenut oil-based biodiesel must be established nationally. A pilot project to develop candlenut oil-based biodiesel should be carried out to find the most efficient technique for producing candlenut oil-based biodiesel. Candlenut plantations should be planned in various places close to designated biodiesel plants, which may include the plasma of communities living around the area of the biodiesel plant that grows candlenuts.

There are eight advantages to establishing a biodiesel factory made from candlenut oil. First, it will open many job opportunities in the fields of fabrication, transportation, and plantations. Second, it will aid reforestation [18], help achieve net-zero carbon emissions, reduce global warming, and contribute to supplying more oxygen. Third, this will reduce government spending on importing oil and reduce dependence on energy imports. Fourth, Indonesia will become the exclusive producer and pioneer in the development of candlenut oil-based biodiesel technology. Fifth, mass production of candlenuts ensures the sustainability of raw materials for many cosmetic industries [19]. Sixth, the drop in candlenut prices due to mass planting of candlenuts will help all households reduce their spending on buying candlenuts as an important ingredient in many traditional foods. Seventh, falling prices and the abundant availability of candlenuts have opened great opportunities for many researchers to develop candlenuts as antimicrobials that will help the pharmaceutical industry [20]. Eighth, candlenut oil is much healthier than palm oil because candlenut oil contains high levels of unsaturated oils [21]. In contrast, palm oil contains high levels of saturated oil [22]. Saturated oils increase LDL levels in the blood, which is dangerous for human heart health. With so many benefits to many people and industries, there is no reason for the government to miss this opportunity. It is our responsibility to convey this message to the decision-makers in this country at any level.

The content of candlenut oil is quite different from palm oil. Palm oil contains about 44% palmitic acid and 38% oleic acid. Meanwhile, candlenut oil consists of linoleic acid ($C_{18}H_{32}O_2$), oleic acid ($C_{18}H_{34}O_2$), and linolenic acid ($C_{18}H_{30}O_2$), which are included in unsaturated fatty acids. These unsaturated fatty acids contribute almost 85% of candlenut oil [23]. Linoleic acid contributes 31.1%, oleic acid contributes 27.85%, and linolenic acid contributes 25.19% [23] . Biodiesel is produced during a transesterification reaction when methanol is added to one of these acids. This endothermic reaction requires a certain amount of energy to take place, which is usually in the form of heat. To speed up the reaction, a homogeneous catalyst such as KOH or NaOH is needed [24]. The three reactions between these three acids and methanol are given by:

$$17C_{18}H_{32}O_2 + 4CH_3OH \leftrightarrow 2C_3H_8O_3 + 16C_{19}H_{34}O_2 \quad (1)$$

(17 linoleic acid + 4 methanol ↔ 2 glycerol + 16 methyl 8, 11-octadecadienoate,)

$$30C_{18}H_{34}O_2 + 43CH_3OH \leftrightarrow 13C_3H_8O_3 + 32C_{17}H_{34}O_2 \quad (2)$$

(30 oleic acid + 4 methanol ↔ 13 glycerol + 32 methyl hexadecanoate,)

$$34C_{18}H_{30}O_2 + 11CH_3OH \leftrightarrow 5C_3H_8O_3 + 32C_{19}H_{34}O_2 \quad (3)$$

(34 inolenic acid + 11 methanol ↔ 5 glycerol + 32 methyl 8, 11-octadecadienoate.)

The reaction in Equation 1 produces methyl 8,11-octadecadienoate and glycerol. The reaction in Equation 2 produces methyl hexadecanoate and glycerol, while the reaction in Equation 3 produces methyl 8,11-octadecanoate and glycerol. Methyl 8,11-octadecadienoate and methyl hexadecanoate constitute biodiesel [25]. It is important to note that there is a glycerol byproduct in each reaction that must be removed. Wasted glycerol is not just discarded because it has relatively high economic value. Therefore, at the industrial level, the glycerol byproduct in the production of biodiesel based on candlenut oil can reduce some of the production costs.

This paper reports the development and characterization of candlenut oil-based biodiesel. Materials and techniques will be explained clearly so that anyone can reproduce our work. Characterization was carried out to determine the effect of catalyst mass on density, viscosity, pour point, and flash point of B30 biodiesel made from candlenut oil. These values were then compared with the standard values set by the Indonesian government.

2. Material and Method

2.1. B100 Biodiesel Synthesis

Biodiesel B100 was made by mixing 200 ml of candlenut oil and 100 ml of methanol in a 500 ml beaker on a magnetic stirrer with relatively slow stirring. Seven milligrams of potassium hydroxide (KOH) were added as a catalyst, and the temperature was controlled at 60-65°C. Mixing was carried out for 30 minutes and was indicated as Sample 1. The procedure was repeated four more times by replacing 7 g KOH with 8 g, 8.5 g, 9 g, and 10 g KOH to obtain Sample 2, Sample 3, Sample 4, and Sample 5, respectively. These samples were then used to produce B30 biodiesel containing 7-10 grams of catalyst mass.

These five samples underwent glycerol removal using a separating funnel [26]. The procedure for removing glycerol using a separating funnel is as follows: First, ensure the stopcock is closed so that the biodiesel does not flow into the beaker under the separating funnel. Second, pour the biodiesel sample into the separating funnel. Third, leave the top cover of the separating funnel open. Fourth, let it sit for 12 hours so that the glycerol separates from the biodiesel [27]. Fifth, open the stopper so that the glycerol flows into the beaker. Sixth, stop the flow by closing the stopper when all the glycerol visible in the separating funnel has been removed. Glycerol is separated into the bottom of the separating funnel because it has a much higher density than biodiesel. The density of glycerol is 1260 kg/m³, and the density of biodiesel ranges from 815-880 kg/m³. If there is water content in biodiesel, it should also be separated because its density is higher (1000 kg/m³). Figure 1 depicts the glycerol removal process.

It should be noted that at this stage, the washing process using water to remove the catalyst and other contaminants is not carried out because we are investigating the effect of the catalyst on the physical characteristics of biodiesel. Washing biodiesel using water will remove most of the catalyst, so the effect of the catalyst on the physical properties of biodiesel cannot be determined.

Due to the limitations of separating funnels in the laboratory, glycerol removal using this technique takes a long time. With five samples in hand, it took 60 hours to complete the removal. Therefore, it is recommended to use other techniques that are faster than this technique.

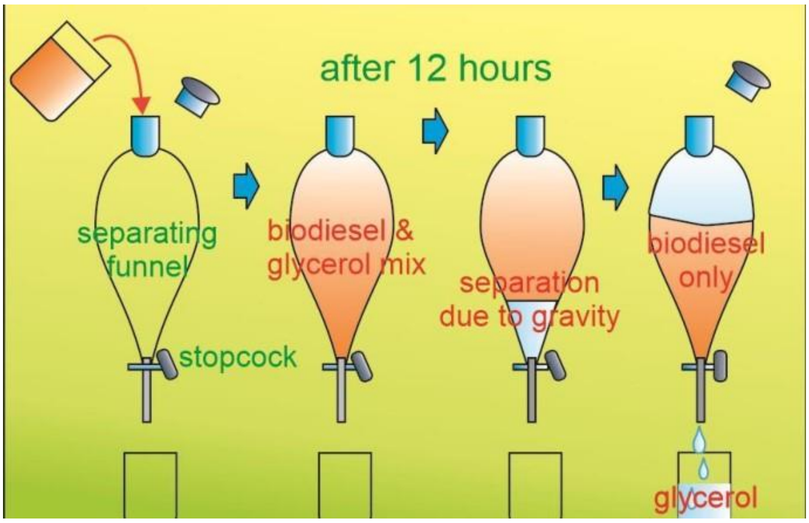

Figure 1.
Removing glycerol as a byproduct of transesterification during biodiesel production.

2.2. B30 Biodiesel Synthesis

Biodiesel B30 was made by mixing 60 ml of Sample 1 containing 7 g of KOH with 140 ml of diesel oil on a magnetic stirrer with relatively slow stirring. This mixture was also heated to a temperature of 60-65°C for 30 minutes while stirring. The same procedure was repeated four times for all samples that had been prepared, namely Sample 2, Sample 3, Sample 4, and Sample 5, and the results were identified as B30-Sample 1, B30-Sample 2, B30-Sample 3, B30-Sample 4, and B30-Sample 5, respectively. The effect of catalyst mass on the physical characteristics of each sample was observed and recorded. All data are presented in this paper, discussed, and analyzed thoroughly. Figure 2 shows five samples of B30 biodiesel made from candlenut oil that are being investigated.

Figure 2.
Five samples of candlenut oil-based B30 biodiesel.

2.3. Biodiesel B30 Characterization

2.3.1. Determination of B30 Density

The density of B30 was determined using a 10 ml volumetric flask. First, weigh an empty 10 ml volumetric flask and record it as m_o units. Second, fill the volumetric flask with the sample up to the line indicating the maximum capacity (10 ml) and record it as m_1. Third, determine the sample mass m by subtracting m_o from m1, which means $m = m_1 - m_o$. Finally, calculate the mass density using Equation 4.

$$\boldsymbol{\rho} = \frac{\boldsymbol{m}}{\boldsymbol{v}}, \qquad (4)$$

Here v represents the volume of sample, which is 10 ml. The results are presented in SI unit which kg/m3.

2.3.2. Determination of B30 Viscosity

There are many techniques available to determine the viscosity of solutions. However, most require large amounts of sample, except for the Oswald viscometer. Therefore, the viscosity of the B30 biodiesel sample was determined using an Oswald viscometer [28]. The measurement is based on a comparison between the viscosity of the water standard and the sample. First, ensure that the temperature of the water and the sample at the time of measurement is the same, 25°C. Second, measure the time it takes for the water to flow from the top mark (start mark) to the bottom mark (stop mark) using a stopwatch and record it as tw. Third, take the same time measurement for B30-sample 1 and record it as ts. Calculate the viscosity value of the sample using Equation 5.

$$\eta_s = \frac{t_s x \rho_s}{t_w \rho_w} \eta_w \qquad (5)$$

Where ηs represents the viscosity of the sample, ηw represents the viscosity of water, ρs denotes the density of the sample, ρw denotes the density of water, ts is the measured time of the sample, and tw is the measured time of water. Repeat the same measurement and calculation for the other samples. All the results are presented in SI units, which are N·s/m².

2.3.3. Determination of B30 Pour Point

The pour point tester is used to determine the pour point of biodiesel using the ASTM D 97 standard method [29, 30]. First, 50 ml of biodiesel is placed into a test jar and heated to a temperature of 45°C. Second, move the test tube into a beaker containing cold water to reduce the temperature of the biodiesel to 27°C-30°C. Next, place the test tube in a jacket in the cooling bath and observe the flow of biodiesel with every 3°C decrease. The pour point of biodiesel is reached when the flow stops, and the pour point value is recorded as this temperature plus 3°C.

2.3.4. Determination of B30 Flash Point

Flash point determination was carried out using a PMCC (Pensky-Martens Closed Cup) flash point tester following the ASTM D 93 method [31]. The measurement begins by filling the cup with 70 ml of biodiesel and tightening the cup lid. Next, the cup is heated at a temperature increase rate of around 4-5 °C per minute, and the temperature increase is monitored using a thermometer. The sample is stirred at a speed of 90-120 rpm, and the stirring is stopped while a flash test is conducted every 2 °C temperature increase. The flash point of biodiesel is recorded (in degrees Celsius) when a flame is visible.

3. Results and Discussion

The results of measurements of density, viscosity, pour point, and flash point of biodiesel made from B30 candlenut oil are presented in Table 1. The data is broken down into five categories, and each category is discussed in more detail under the following subheadings. All these results are then compared with the relevant values issued by the Indonesian Government in the Director General of Oil and Gas Decree number 146.K/10/DJM/2020.

Table 1.
Physical characteristics of B30 biodiesel made from candlenut oil.

KOH mass (g)	Density (kg/m3)	Viscosity (N.s/m2)	Pour Point (º C)	Flash Point (º C)
7	0.845	3.02	6	132.0
8	0.846	3.06	-	-
8.5	0.848	2.97	9	138.5
9	0.859	3.34	-	-
10	0.865	5.63	12	135.5

3.1. B30 Biodiesel Density Dependence on Catalyst Mass

Catalysts are used to speed up the reaction process in B100 biodiesel production. Therefore, the catalyst has a direct impact on the amount of product on the right side of Equation 1, Equation 2, and Equation 3. This means that, in the same time interval, the mass and volume of the product increase as the catalyst increases. The density of biodiesel depends on its mass and volume. The byproduct glycerol is removed, leaving biodiesel in the form of methyl 8,11-octadecadienoate and methyl hexadecanoate. Since biodiesel production involves three different reactions, it is difficult to expect that the relationship between the catalyst and biodiesel density will be linear. Figure 3 shows the fit of the polynomial regression data on the effect of catalyst mass on the density of B30 biodiesel, with the regression coefficient $R^2 = 0.9094$ indicating a good fit.

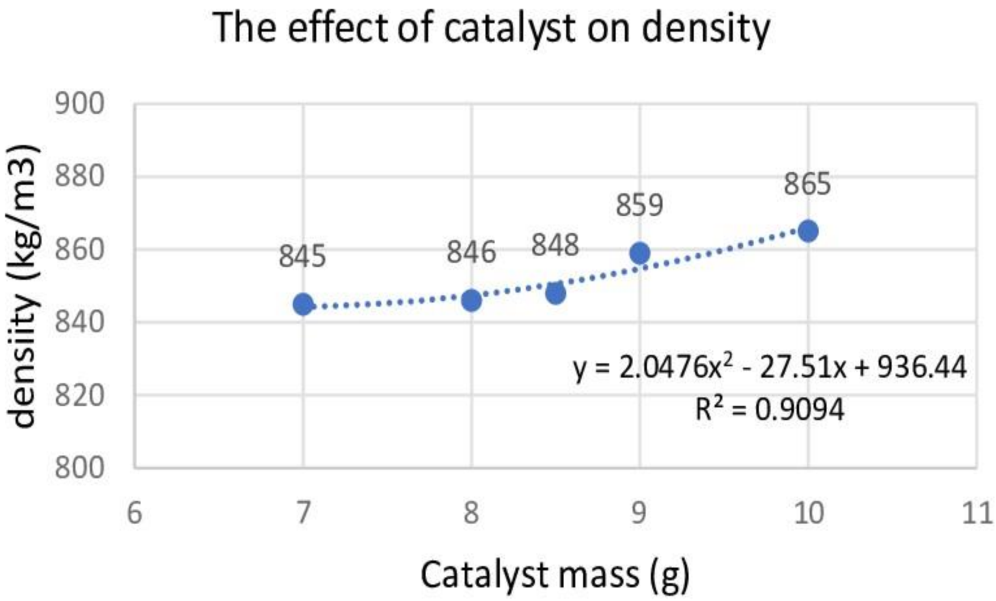

Figure 3.
The effect of the catalyst on B30 biodiesel density.

The density values of B30 biodiesel set by the government range from 815 to 880 kg/m³. Therefore, all measured density values between 845 and 865 kg/m³ meet the government requirements. The density of B30 biodiesel increases slowly with the addition of catalyst (KOH). This is likely due to the production of more products within the same time interval when using a greater amount of catalyst compared to using less [32].

3.2. B30 Biodiesel Viscosity Dependence on Catalyst Mass

The dependence of viscosity on the B30 biodiesel catalyst is shown in Figure 4, which indicates that the data is non-linear and fits the polynomial regression, yielding a regression coefficient $R^2 = 0.969$. The nonlinear dependence of viscosity on catalyst mass is understandable for two reasons. First, the viscosity of a liquid is highly dependent on the density of the liquid [33]. Second, the density of B30 biodiesel is demonstrated to depend on the catalyst mass in a non-linear manner. Therefore, polynomial regression provides a good fit for the data [34].

The viscosity value of B30 biodiesel set by the Indonesian government is in the range of (2.0-4.5) N·s/m². Consequently, all calculated density values, namely (2.97-5.65) N·s/m², meet the requirements except for the final measurement, which is 5.65 N·s/m². Essentially, the viscosity value of B30 biodiesel increases non-linearly with the addition of the KOH catalyst. This is most likely due to the addition of a catalyst producing more product, which causes the concentration and density of the product to increase, ultimately resulting in an increase in viscosity [33].

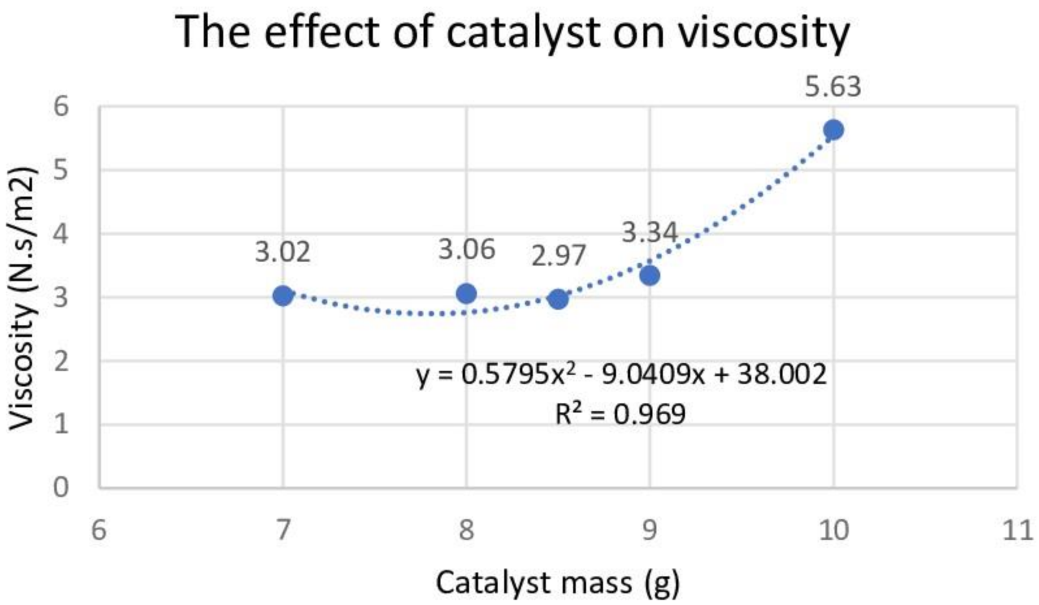

Figure 4.
The effect of the catalyst on the viscosity of B30 biodiesel.

3.3. B30 Biodiesel Pour Point Dependence on Catalyst Mass

There are only three data points regarding the dependence of the pour point on the catalyst and the dependence of the flash point on the catalyst. Our laboratory does not have a pour point tester or a flash point tester, so we must send the data to another university laboratory. As a result, a large amount of money had to be spent. In fact, this research received no funding. Therefore, private funds must be used wisely by reducing the data from five points to three points without omitting substantial related information.

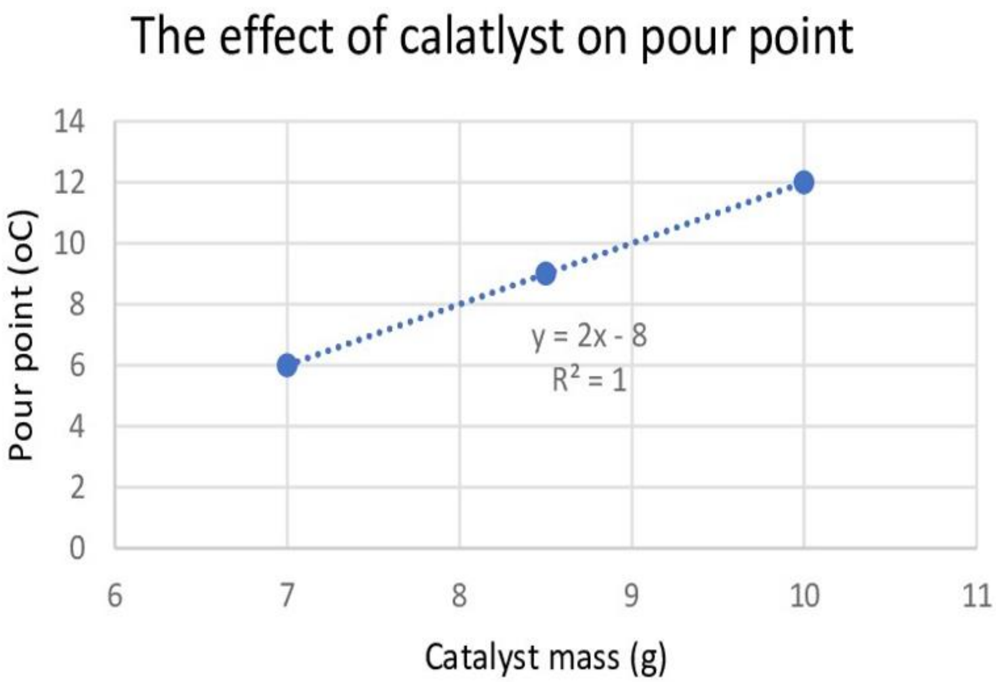

Figure 5.
The effect of the catalyst on the pour point of B30 biodiesel.

The maximum pour point for B30 biodiesel set by the government is 18 degrees Celsius. Therefore, the measurement results of three pour points, namely 6, 9, and 12 degrees Celsius, meet these requirements. The data in Figure 5 show that the pour point of B30 biodiesel made from candlenut oil increases linearly with the increasing catalyst mass (KOH) added from 7 mg to 10 mg during B100 biodiesel production. This is understandable because the pour point is a macroscopic characteristic of biodiesel, and the effect of adding a catalyst is only at the level of macroscopic physical characteristics. In addition, Chen and colleagues showed that the higher the viscosity of cooking oil-based biodiesel, the higher the pour point [35]. This behavior is similar to that of biodiesel made from candlenut oil.

3.4. B30 Biodiesel Flash Point Dependence on Catalyst Mass

The flash point values obtained from this research were 132.0°C, 138.5°C, and 135.5°C (see Figure 6). These values satisfy the minimum flash point standard for B30 biodiesel set by the Indonesian government, which is 55°C. The high flash point value guarantees the safety of biodiesel from fire when it is stored for a relatively long time. This candlenut-based biodiesel is a mixture of two components: methyl 8,11-octadecadienoate (Equation 1 and Equation 3) and methyl hexadecanoate (Equation 2). The flash point of the first component, methyl 8,11-octadecadienoate, is (96.90 ± 20.4) °C, and the flash point of the second component, methyl hexadecanoate, is (152.6 ± 7.5) °C. Therefore, it is understandable that the measured biodiesel flash points were found to be between the flash points of its two components.

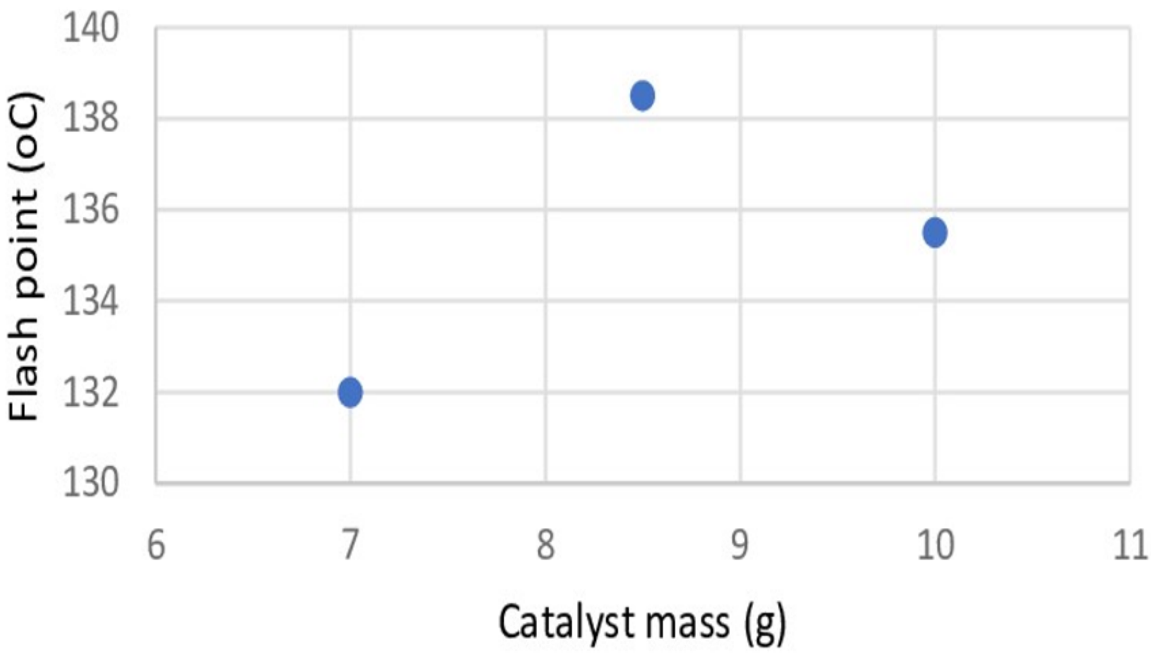

Figure 6.
The effect of the catalyst on the flash point.

4. Conclusion

In summary, B30 biodiesel made from candlenut oil has been successfully developed with physical characteristics, namely density, viscosity, and pour point, that satisfy the values set by the Indonesian government. The density of candlenut oil-based biodiesel samples was found to be (845-865) kg/m³, all of which met the government-set value of (815-880) kg/m³. The viscosity of the candlenut oil-based biodiesel sample was found to be (2.97-5.63) N·s/m², which 80% meets the government value of (2.0-4.5) N·s/m². Only one sample containing the highest catalyst mass (10 g) did not meet government regulations. This negative result is positive for the development of candlenut oil-based biodiesel because, with this data, we understand the mass limit of catalyst that can be added to develop biodiesel. Less catalyst mass must be used to develop candlenut oil-based biodiesel. The satisfactory characterization results of B30 biodiesel made from candlenut oil show the promising potential of candlenut oil as an alternative to palm oil for the biodiesel industry.

All pour point measurements show very good results because all values (6°C, 9°C, and 12°C) are below the maximum value set by the government, namely 18°C. This means that the candlenut oil-based biodiesel being developed is still flowing during operation before the temperature reaches 9°C (on average). The flash point values were found to be 132.0°C, 138.5°C, and 135.5°C, which are higher than the minimum value set by the government, namely 55°C. These high flash point values guarantee the safety of biodiesel for long-term storage. The candlenut oil-based biodiesel can be produced as a complement to the palm oil-based biodiesel. Larger-scale research needs to be carried out to understand the characteristics of candlenut oil-based biodiesel to convince the Indonesian government that candlenuts, as a raw material for the biodiesel industry, are better than palm oil.

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