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Study of Viscosity and Density Changes of Waste Cooking Oil Biodiesel Due to Gradual Heat Treatment

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Abstract

Biodiesel from used cooking oil is a renewable fuel for diesel engines that has the potential to be developed as a substitute for fossil fuels. However, the physical properties of biodiesel such as viscosity and density are affected by heat treatment. This will certainly affect engine performance, combustion quality and diesel engine efficiency. This study aims to analyze the heat treatment of used cooking oil biodiesel in stages with temperature values of 40°C, 50°C, 60°C, 70°C, and 80°C. Biodiesel is obtained from used cooking oil by a synthesis process using transesterification with ethanol and KOH catalyst. The results of the study were the viscosity and density values of used cooking oil biodiesel. The results showed that heat treatment of biodiesel reduced the viscosity and density values. The viscosity value continued to decrease along with the increase in the heating value from 4.52 cSt to 2.84 cSt. For the density value also decreased from 867 kg/m³ to 827 kg/m³. This study shows that heat treatment on biodiesel before use has the potential to improve atomization characteristics and fuel flow rates, so that combustion efficiency and diesel engine performance can be optimal.
Keywords: Waste Cooking Oil Biodiesel, Viscosity, Density, Heat Treatment

1. Introduction

The need for energy continues to increase and is not balanced with the discovery of new mining sources, causing turmoil such as an energy crisis in the future [1]. Currently, petroleum is still the mainstay to meet energy needs [2].

However, petroleum is a non-renewable energy source, thus causing an energy crisis problem in the future [3]. Problems caused by the use of petroleum include environmental pollution, environmental damage due to the mining process and climate change due to exhaust emissions produced and price fluctuations that continue to increase [4-6]. In this case, the use of renewable energy is a solution to overcome current problems [7,8]. One of the renewable energies that has the potential to support petroleum needs is biodiesel [9-13]. The environmentally friendly nature of biodiesel, its minimal carbon footprint and its sustainable nature are the basis for its selection as a substitute fuel for petroleum [14], [15].

In general, biodiesel synthesis can be done by transesterification process using vegetable raw materials or vegetable waste [16-18]. One of the popular raw materials currently as a biodiesel raw material is used cooking oil [19], [20]. The advantages of using used cooking oil as a biodiesel raw material include reducing domestic waste that can pollute the environment and reducing biodiesel production costs through the use of raw materials with low economic value [21]. In addition, the principle of using used cooking oil as biodiesel supports sustainable resource management [22].

However, the use of biodiesel as fuel has problems. The problems that occur are the viscosity and density values of biodiesel are higher compared to fossil fuels [23]. High viscosity affects engine performance so that the engine is not optimal in working due to imperfect atomization. In addition, high density also affects the equivalence ratio between fuel and air. An unbalanced air and fuel ratio has an impact on combustion efficiency and exhaust emissions. These two parameters are sensitive to diesel engine performance and temperature changes so that it is necessary to understand changes in biodiesel temperature at various operating temperature conditions.

Previous studies have discussed the effect of heat treatment on fuel. Haryanto et al. (2020) also conducted research on the synthesis of biodiesel from used cooking oil using the microwave method. The results showed that power intensity did not affect the viscosity and density values, but affected the biodiesel yield [24]. Barokah et al. (2022) conducted a study on the effect of heating on biodiesel on viscosity and density values. The results showed that increasing the temperature in B20 reduced the density, viscosity and surface tension values, thereby improving the quality of the combustion reaction in the combustion chamber [24]. Azharuddin et al. (2021) also conducted research on used oil waste into liquid fuel using a constant heat treatment method through the pyrolysis process. The results showed that increasing temperature affected the volume of fuel produced, but the viscosity value produced still exceeded the established standard [25]. From the research that has been carried out, it becomes a basis for continuing research on the effect of heat treatment on the physical properties of biodiesel from used cooking oil.

This study aims to analyze the effect of gradual heat treatment with temperatures of 40°C, 50°C, 60°C, 70°C, and 80°C on biodiesel. In addition, this study also evaluates and examines the impact on the performance of biodiesel use. The results of the study are expected to provide information on the effect of heat treatment on biodiesel from used cooking oil and support the development of renewable energy and the processing of used cooking oil waste into biodiesel and sustainable in the future.

2. Methods

The research method uses an experimental method through direct observation of the object being studied, namely biodiesel from used cooking oil. The raw materials in this study consist of two, namely the main raw material and synthetic raw materials. The main raw material is used cooking oil. The synthetic raw materials consist of Phosphoric Acid (H_3PO_4) which is used during the degumming process, Anhydrous Ethanol (≥99%) is used as a reactant during the transesterification process, Potassium hydroxide (KOH) as a base catalyst during the transesterification process, and Aquades as a biodiesel washing medium. In general, the raw material scheme can be observed in **Figure 1**.

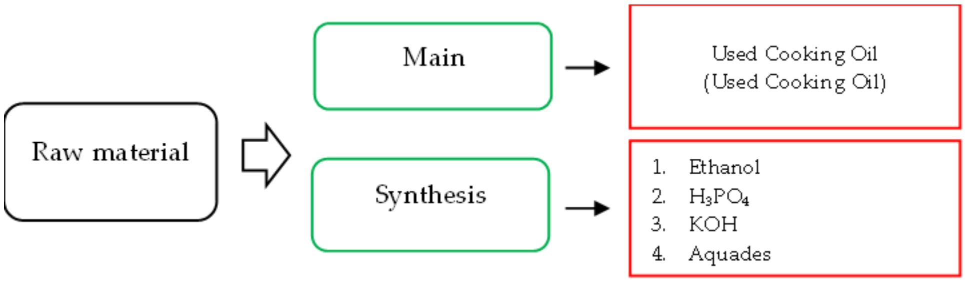

Figure 1. Raw Materials for Biodiesel Synthesis

The degumming process aims to remove phosphatides, gums and impurities from used cooking oil so that they do not interfere with the transesterification reaction [17]. The degumming process aims to remove gum, phosphatides and impurities in used cooking oil. The degumming process allows used cooking oil to coagulate so that it separates from used cooking oil. The degumming process is carried out by adding phosphoric acid (H_3PO_4) as much as one percent (1%) of the total mass of used cooking oil. Then, the results of mixing used cooking oil and H_3PO_4 are stirred using a magnetic stirrer at a temperature of 50^0C for thirty minutes. The results of the degumming process are precipitated for eight hours so that the oil and impurities are separated. The degumming oil is continued to the transesterification process. The degumming process scheme can be seen in **Figure 2**.

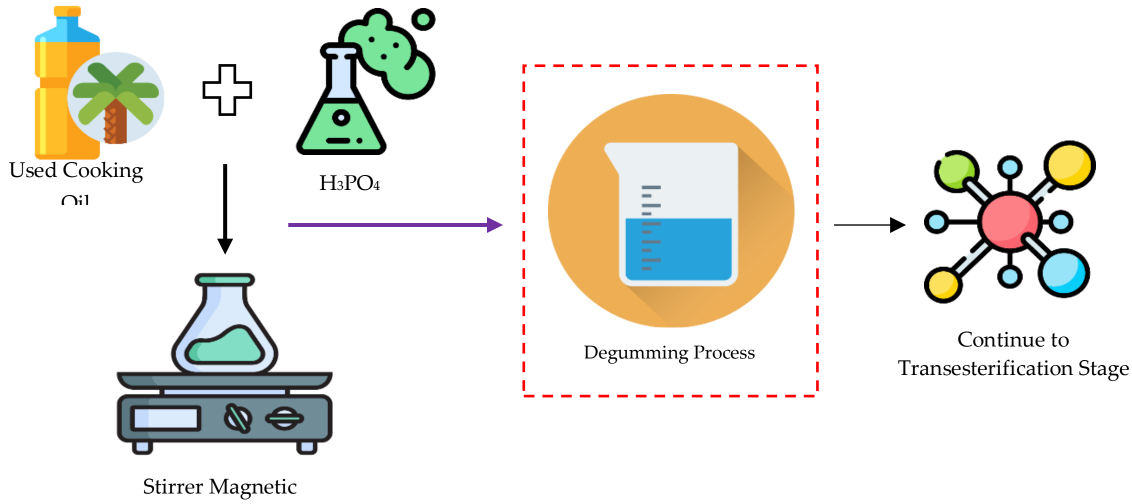

Figure 2. Degumming Process Scheme

Transesterification is a reaction between triglycerides and alcohol (in this case ethanol) and assisted by a base catalyst such as KOH to produce esters (biodiesel) and glycerol. This process is the most common and efficient method in biodiesel production [19]. The transesterification process is carried out to convert free fatty acids into ethyl esters with the help of alcohol (ethanol) and a catalyst. The ethanol used during the transesterification process is 1:8 (mol/mol) to the raw oil material, using a mole ratio. Meanwhile, the catalyst used is potassium hydroxide (KOH). The equation for determining the mole value can be seen in equation 1. The KOH used is one percent (1%) of the total mass of oil. The composition of used cooking oil, ethanol and catalyst is stirred using a magnetic stirrer at a temperature of 50^{0}C for sixty minutes (60 minutes) until homogeneous. The results of the transesterification process are ethyl ester and glycerol. Ethyl ester is continued to the washing stage while glycerol is discarded. The transesterification process scheme can be seen in **Figure 3**.

$$\text{Number of moles of ethanol} = \text{Mole ratio x } \left(\frac{\text{mass of oil x 1000}}{\text{molar mass of oil}}\right) \tag{1}$$

Description:

- Mass of oil in grams (g),
- Molar mass of oil is the molar mass of used cooking oil (g/mol)
- The mole ratio according to plan is 1:8.

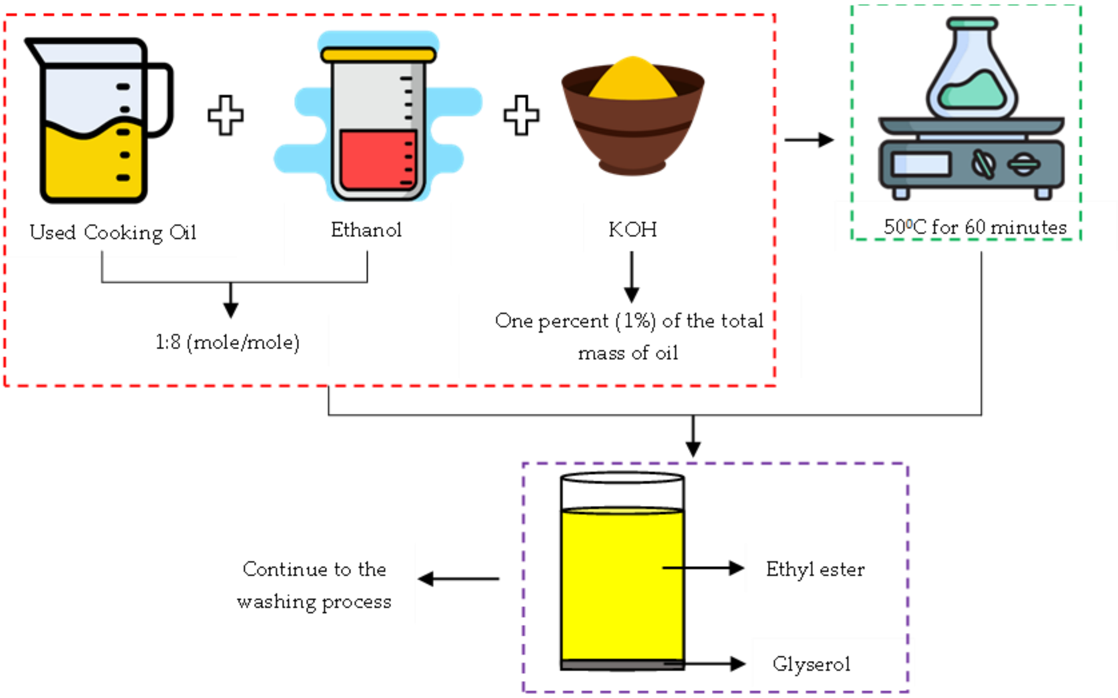

Figure 3. Transesterification Process Scheme

After the transesterification process, the washing process is continued. The washing process is carried out with the help of distilled water. The purpose of the washing process is to remove the remaining catalyst and ethanol in biodiesel. The ratio of biodiesel to distilled water used is 1:1. Then after the washing process, the process of removing the remaining water in the biodiesel is carried out. To remove water, the biodiesel is heated at a temperature of 100⁰C for 2-3 minutes. The washing and drying scheme can be seen in **Figure 4**.

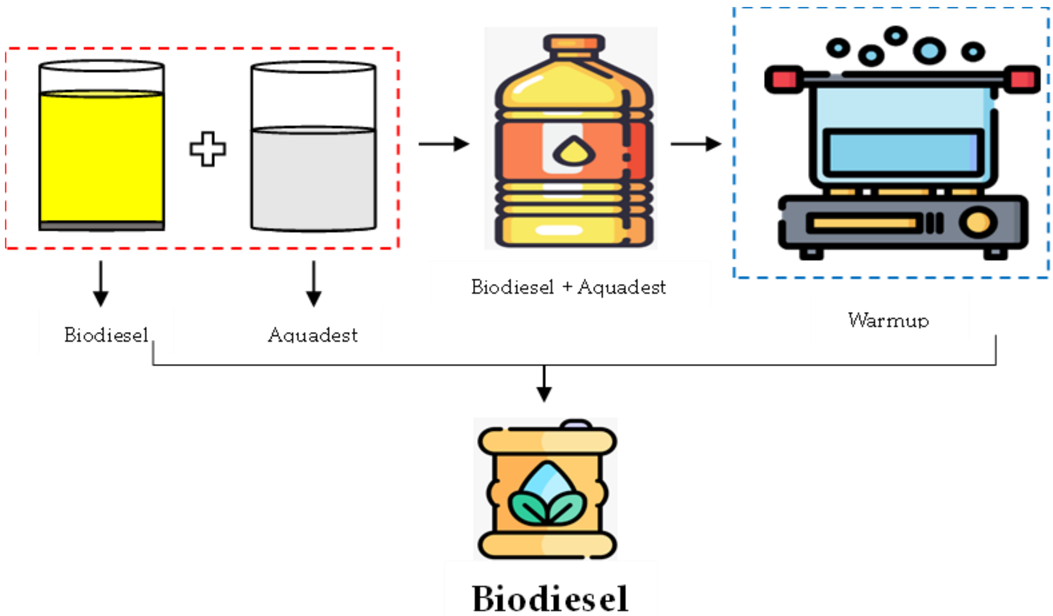

Figure 4. Biodiesel Washing and Drying Scheme

After the biodiesel is finished being produced, it is continued to the testing stage. The testing begins with heat treatment of the biodiesel. Heat treatment of the biodiesel is carried out at temperatures of 40°C, 50°C, 60°C, 70°C, and 80°C and each sample is kept at a temperature of five minutes to achieve thermal equilibrium. Then the viscometer is measured according to the ASTM D445 standard and the density with the ASTM D1298 standard. The testing was carried out in a controlled laboratory. The heat treatment test scheme can be seen in **Figure 5**. After the biodiesel is obtained, the testing is continued with gradual heat treatment. Before the heat treatment, one biodiesel sample is set aside without being heat treated and used as a control sample or base sample. This sample is used as a reference to compare changes in viscosity and density due to heat treatment.

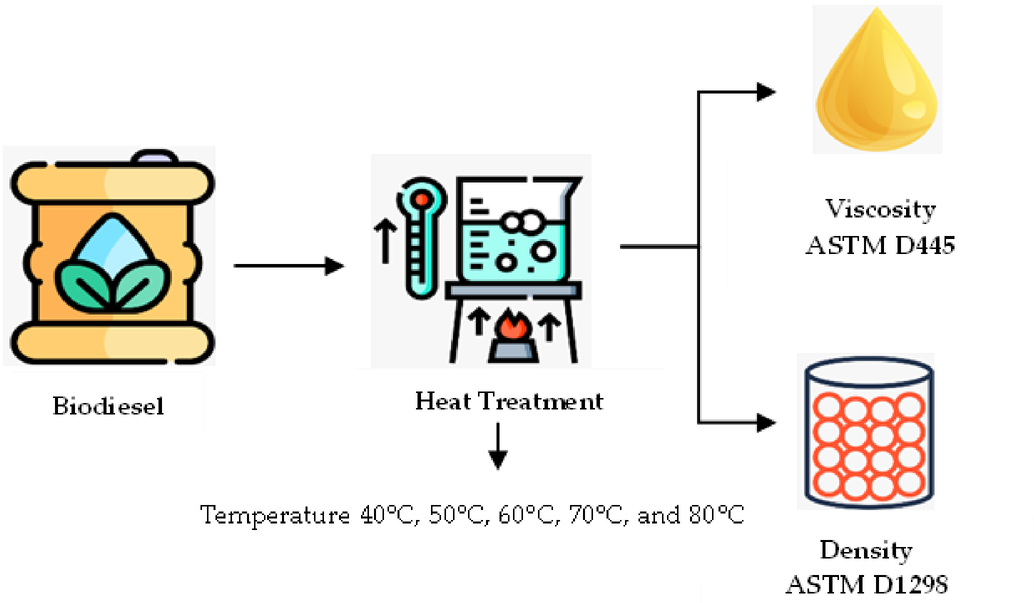

Figure 5. Stepwise Heat Treatment Scheme

3.Results and Discussion

The results of the study on the change in viscosity and density of used cooking oil biodiesel due to gradual heat treatment resulted in four sub-chapters of discussion. The sub-chapters of discussion are discussed in sub-chapters 3.1 to 3.4 as follows.

3.1 Changes in Biodiesel Viscosity due to Heat Treatment

Changes in the viscosity value of biodiesel to heat treatment indicate that there is a change in the viscosity value. The viscosity value of biodiesel decreases consistently with increasing heat treatment. The viscosity value without heat treatment is 4.52 cSt, then the viscosity value decreases by 4 cSt; 3.88 cSt; 3.56 cSt; 3.11 cSt and 2.84 cSt along with the gradual heat treatment of 40°C to 80°C. In molecular kinetic theory, an increase in thermal energy causes an attractive force between molecules so that the fluid flow is easier. This also has implications for a decrease in the viscosity value along with increasing thermal energy. The viscosity value against heat treatment can be observed in **Figure 6**.

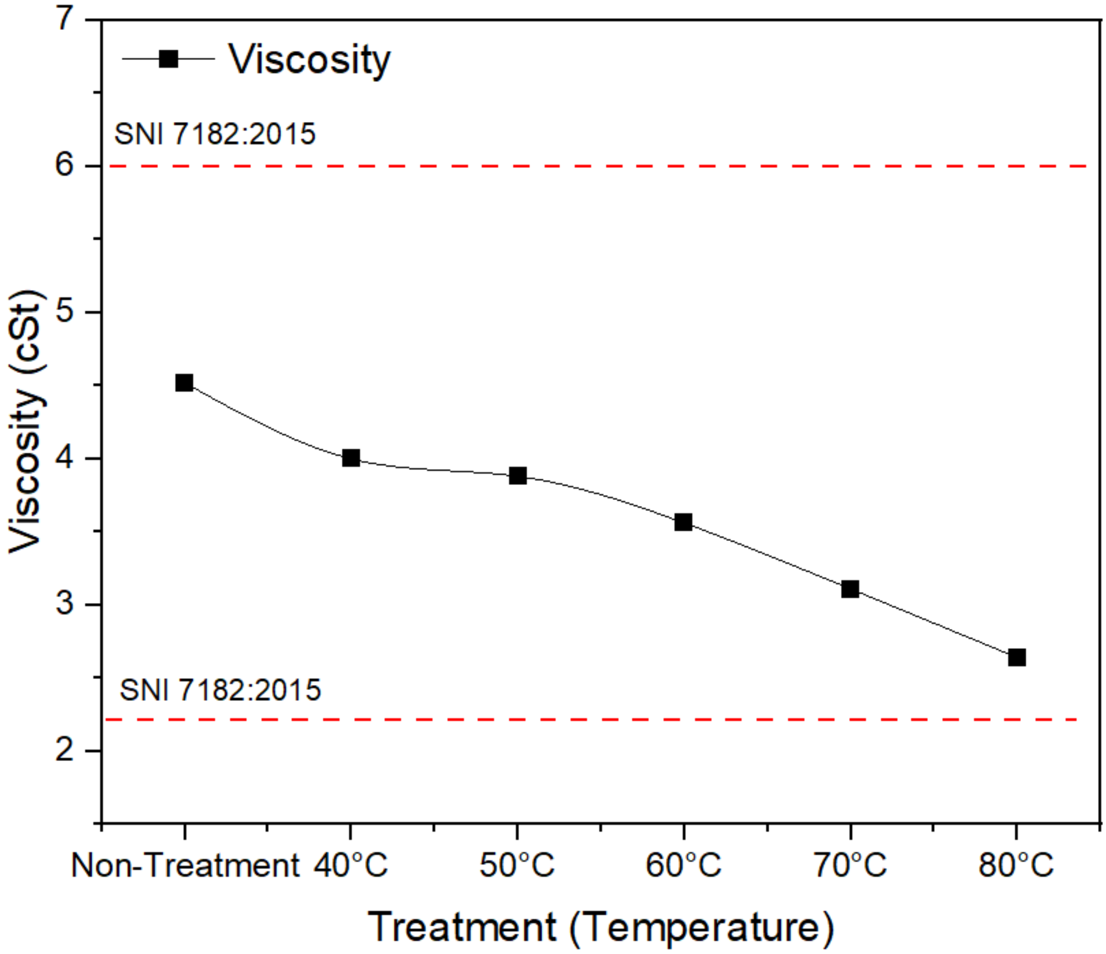

Figure 6. Viscosity Value Against Heat Treatment

The viscosity value of fuel is an important parameter in fuel. This is because fuel supplies energy to vehicle engines. Viscosity is a critical parameter because viscosity plays a role in the injection and atomization process in diesel engines. High viscosity values cause the combustion process in the combustion chamber to be imperfect due to the less than optimal fuel injection process. In addition, droplet sizes that are too large cause the combustion reaction process to be inefficient. Conversely, low viscosity values in fuel can cause optimal fuel injection so that the surface area of the fuel can burn completely. In addition, the perfect combustion reaction process also increases the thermal efficiency of the engine.

The results of the experiment show that providing heat to used cooking oil biodiesel can reduce the viscosity value. This is part of a strategy for a biodiesel problem that has a high viscosity value and is considered less efficient when used in engines. Of course, this is part of a strategy to reduce the general problems of using biodiesel. Common problems include nozzle clogging and higher fuel consumption rates. The decrease in biodiesel viscosity with increasing temperature can be explained by the molecular kinetic theory, where increasing thermal energy reduces the intermolecular attraction [23]. This is in line with research by Goga et al. (2018) which shows that biodiesel viscosity is greatly affected by temperature, and decreasing viscosity improves fuel atomization in diesel engines [10].

3.2 Changes in Biodiesel Density due to Heat Treatment

The test of heat addition to biodiesel from used cooking oil also affects the density value of biodiesel. The density value decreases with increasing calorific value. The density value of biodiesel without heat treatment is 867 kg/m³. The density value with heat treatment of 40°C to 80°C is 858 kg/m³; 847 kg/m³; 838 kg/m³; 831 kg/m³ and 827 kg/m³.

From the observation of the density value through the test that has been carried out, it appears that heat treatment affects the resulting density value. This is in line with the principle of thermal fluid, namely the higher the temperature, the greater the distance between molecules so that the density value decreases. The results of the test of the effect of heat on biodiesel from used cooking oil can be observed in **Figure 6**.

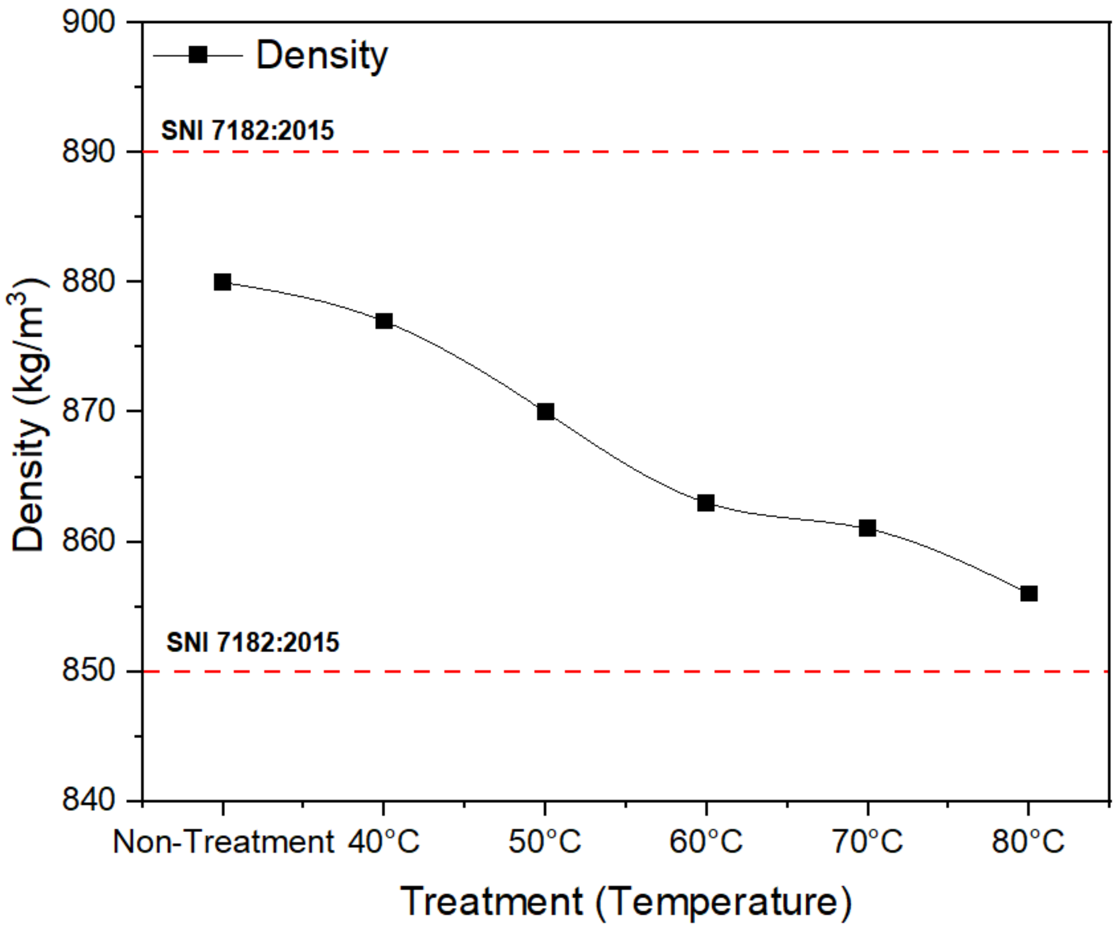

Figure 6. Density Value Against Heat Treatment

The decreasing density value as in **Figure 6** has implications for the amount of fuel mass with a fixed volume injected into the combustion chamber. This certainly affects the output produced by the engine. The output produced is in the form of performance and power on the engine. The lower the density value, the lower the mass of fuel injected into the combustion chamber with the assumption of a fixed volume. Therefore, compensation steps are needed through adjusting the injection system so that the amount of energy supply remains optimal.

Density also affects the combustion reaction, this is because density affects when the mixture is formed between air and fuel. Low density usually has a lower particle size. If injected into the combustion chamber, it can increase combustion efficiency and the homogeneity of the mixture will mix optimally. A decrease in density by a certain limit can be beneficial for the combustion reaction so that the fuel becomes perfect. However, it is necessary to be a basis that the density value has a threshold that is the standard as a fuel for diesel engines. The density value threshold becomes control information regarding changes in density value due to the provision of heat to the fuel. The decrease in density due to heating of biodiesel is in line with the principle of thermal expansion of fluids, where increasing temperature causes the distance between molecules to increase [3]. In addition, research by Ayetor et al. (2015) also shows that lower density supports more homogeneous mixing of air and fuel in the combustion chamber of a diesel engine [13].

3.3 Analysis of Viscosity and Density Relationship

The relationship between viscosity and density shows a phenomenon of decreasing values with the addition of heat (heating) to biodiesel. Heat treatment from 40°C to 80°C shows a phenomenon of decreasing viscosity and density values. Viscosity shows a greater sensitivity to changes in value when compared to viscosity values. The density and viscosity values that change due to heat treatment indicate that the changes are influenced by physical mechanisms, namely changes in molecular kinetics in biodiesel due to heat treatment.

In addition to viscosity, the density of biodiesel also decreases due to heat treatment, from 867 kg/m^3 (without treatment) to 827 kg/m^3 at 80°C. This decrease in density is closely related to the thermal expansion of the fluid where the volume increases faster than the mass as the temperature increases. Fuel density affects the mass of fuel injected into the combustion chamber at a certain volume, so changes in density due to heating need to be taken into account in the combustion system. A slightly lower density at high temperatures can improve fuel injection speed, but in the long term, its balance with combustion characteristics and fuel efficiency needs to be studied. The application of biodiesel as a diesel engine fuel with a heat treatment method is quite promising. This is because heat treatment on biodiesel can improve engine performance and also reduce exhaust emissions produced by vehicle engines. The heat treatment method on biodiesel from used cooking oil can be a simple idea to apply so that it can change the physical properties of biodiesel, especially in terms of density and viscosity. However, excessive heat treatment can increase thermal degradation so that degradation compounds are formed that have the potential to reduce performance in diesel engines. Therefore, heat treatment must be given appropriately so that it does not affect physical properties and tends to maintain chemical stability.

3.4 Implications of Physical Changes on Biodiesel Applications

The physical properties that change in biodiesel have an important impact on biodiesel applications. The decreased density and viscosity values of biodiesel due to heat treatment have the potential to reduce carbon deposits, increase combustion efficiency and improve fuel atomization. This opens up opportunities for biodiesel fuel preheating methods before being injected into the combustion chamber. However, viscosity values that are too low can cause leakage in the injection system, and can cause wear on vehicle engine elements such as pumps and injectors. Likewise, density values that are too low have an impact on increasing peroxide compound content, thermal decomposition and polymer formation. This will certainly cause fuel degradation. Therefore, heat treatment on biodiesel needs to have a maximum limit so that engine performance remains optimal and chemical stability is maintained. In general, the research method of heat treatment on biodiesel is limited in supporting increased engine performance. However, the heat treatment given to biodiesel is carried out strictly and precisely. A study by Elnajjar et al. (2022) showed that low viscosity biodiesel increases fuel injection efficiency and improves combustion response in CI engines [20]. However, too low viscosity and density values can also cause wear on engine components [15].

4. Conclusion

The study on the changes in viscosity and density of used cooking oil biodiesel due to gradual heat treatment led to the following conclusions. Heat treatment of biodiesel from used cooking oil at temperatures ranging from 40°C to 80°C resulted in a decrease in both viscosity and density. Specifically, the viscosity decreased from 4.52 cSt at 40°C to 2.84 cSt at 80°C, while the density reduced from 867 kg/m³ to 827 kg/m³ over the same temperature range. The reduction in both viscosity and density values has a direct impact on engine performance and the fuel supply system. A lower viscosity improves atomization, while the decrease in density influences the quantity of fuel injected during the combustion process. Based on these findings, further research is recommended to examine the chemical stability and long-term performance of heat-treated biodiesel when directly used in diesel engines.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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