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Physical property analysis of biodiesel from *nyamplung* and used cooking oil: density, viscosity, calorific value, and flash point

Wahyudi[*], Muhammad Nadjib, Achmad Faizi
Department of Mechanical Engineering, Universitas Muhammadiyah Yogyakarta, Yogyakarta, 55183, Indonesia
*Corresponding author: wahyudi@ft.umy.ac.id

Abstract

The increasing dem and for energy and the depletion of fossil fuel shas led to the exploration of alternative fuels like biodiesel, which require sref inement tomatch diesel oil properties. This study investigates the combination of *nyamplung* oil, a non-edible potential source, with waste cooking oil for biodiesel production, aiming to improve its physical properties. Through a method ological approachin volving degumming, esterification, and transesterification, biodiesel was produce dfrom these oils in 11 different blend compositions. The physical properties of these blends, including density, viscosity, flashpoint, and calorific value, were rigorously tested. Results indicate that incorporating waste cooking oil into *nyamplung* biodiesel significantly reduces viscosity, density, and flashpoint while increasing the calorific value. Specifically, the addition of waste cooking oil altered the density from 912.74 kg/m^3 in pure *nyamplung* biodiesel to 857.27 kg/m^3, decreased the viscosity from 28.02 cStto 4.58 cSt, reduced the flash point from 223°C to 197°C, and increased the heating value from 7,626.59 cal/g to 8,348.94 cal/g.

Keywords:
Nyamplung, used cooking oil, biodiesel, physical properties.

1 Introduction

The growth of industries worldwide has experienced remarkable acceleration over the past few decades. With this development, the energy demand has surged rapidly[1]. Energy has become the backbone of every industrial sector, ranging from manufacturing to transportation. However, a heavy reliance on fossil fuels, such as petroleum, coal, and natural gas, has posed serious challenges. These resources are depleting, and projections suggest that in the coming decades, the availability of fossil fuels could become increasingly limited. Besides resource constraints, the use of fossil fuels also significantly contributes to environmental pollution issues[2]. The combustion of fossil fuels produces greenhouse gas emissions, like carbon dioxide, which are the primary drivers of global climate change. Moreover, other pollutants resulting from this combustion, such as particulates and sulfur compounds, can lead to acid rain, smog, and other health issues for humans.

Biodiesel, derived from vegetable oil, offers several advantages over fossil fuels. Besides being renewable, biodiesel also produces lower emissions, including greenhouse gas emissions[3]. However, biodiesel also has several drawbacks, including relatively high production costs and the potential for competition with food sources if the raw materials used come from plants that are also used as food sources[4]. Therefore, it is crucial for researchers and the industry to seek alternative, more sustainable biodiesel raw materials that do not compete with food requirements.

Nyamplung, also known by its scientific name Calophyllum inophyllum, is a tropical tree that thrives in coastal areas and islands in Southeast Asia, the Pacific, and certain regions in Africa. This tree has specialized adaptations that allow it to grow in sandy soils with high salt content, commonly found in coastal areas. The *nyamplung* fruit contains seeds that are rich in oil, which has been researched as a potential source for biodiesel production. One of the unique features of the oil from *nyamplung* seeds is its diverse fatty acid content, making it promising as an alternative fuel source. *Nyamplung* oil, derived from the seeds of the *nyamplung* tree, represents a potential raw material for biodiesel production. The primary advantage of *nyamplung* oil is its abundant availability in several tropical regions and the fact that the *nyamplung* tree can grow in less fertile soils. In Indonesia, especially in the coastal areas of Java, Bali, and Nusa Tenggara, *nyamplung* is widely found and is an integral part of the coastal ecosystem, with economic potential as a renewable energy source[5]. However, this oil also has drawbacks, one of which is its relatively high viscosity. The viscosityof *nyamplung* oil is 49.22 cSt, and after it is processed into biodiesel, its viscosity decreases to 28.02 cSt[6]. However, its viscosity is still considered too high to use as fuel. High viscosity can cause issues in fuel injection and circulation within engines[7].

On the other hand, used cooking oil, often regarded as waste, has emerged as an attractive alternative raw material for biodiesel. Its advantages include recycling waste, reducing disposal issues, and the potential for lower production costs compared to fresh vegetable oil[8]. However, used cooking oil also has its downsides. For instance, its quality and possibly high free fatty acid content require special treatment in the biodiesel production process[1]. Based on the research, the free fatty acid value in waste cooking oil is very high, ranging between 14.25% to 18% [1].

Raw materials like waste cooking oil require two key steps in the biodiesel production process, namely esterification and transesterification. Esterification is the process of converting free fatty acids in oils to esters. This step is crucial for oils with high free fatty acid content. Following this, transesterification is applied, a crucial reaction where triglycerides in the oil are converted into biodiesel through a reaction with alcohol[9].

Each vegetable oil raw material has a unique fatty acid composition. The molecular structure and the ratio of saturated to unsaturated fatty acids ultimately determine the oil's physical properties, including density, viscosity, and flash point[10]. Therefore, the physical properties of the resulting biodiesel will heavily depend on the vegetable oil raw material used[11]. In efforts to optimize biodiesel properties, it is possible to blend oils from various sources[12]. By combining *nyamplung* oil with used cooking oil, for example, there's potential to create biodiesel with enhanced characteristics. This combination can leverage the strengths of each oil while simultaneously minimizing their weaknesses.

The physical properties of fuel are critical in terms of performance, efficiency, and safety when used in various engines. Viscosity, for example, affects the fuel's ability to flow smoothly within an engine's fuel system. Density is directly related to the amount of energy that can be produced per unit volume, while the calorific value determines how much energy can be generated from the combustion of that fuel. The flash point, on the other hand, is a safety indicator, indicating the temperature at which the fuel starts to evaporate and ignites. In the context of biodiesel, optimizing these properties is crucial to ensure that the fuel can be used efficiently and safely.

Although the unique fatty acid composition of each vegetable oil influences its physical properties such as density, viscosity, and flash point, there is a gap in understanding how specific blends of these oils, such as *nyamplung* and used cooking oil, affect the overall characteristics of biodiesel. Optimizing these properties is critical to the performance, efficiency, and safety of biodiesel in a wide range of engines. Therefore, this research aims to fill this gap by systematically studying the impact of mixing *nyamplung* oil with used cooking oil on the physical properties of the biodiesel produced.

2 Research methodology

2.1 Materials

In this research, the materials used included: *nyamplung* oil, used cooking oil, methanol, phosphoric acid (H_3PO_4), sulfuric acid (H_2SO_4), potassium hydroxide (KOH), and water. The properties of each oil are listed in Table 1.

Table 1. Propertiesof *nyamplung* oilandusedcookingoil

Properties	*Nyamplung*oil	Used cookingoil
Density (40ºC) kg/m³	912.74	857.27
Viscosity (40ºC) cSt	28.02	4.58
Flash point (ºC)	223	197.2
Calorificvalue(cal/g)	7628.6	8348.94

Each vegetable oil has a different fatty acid content. The fatty acid content of both oils is presented in Table 2.

Table 2. Fatty acid contents of *nyamplung* oil and used cooking oil

Fatty Acid	*Nyamplung*oil	Used cookingoil
Methyl Butyrate	6.24	14.74
Methyl Palmitate	11.67	35.9
Methyl Octadecanoate	14.3	3.18
Cis-9-Oleic Methyl Ester	36.59	36.51
Methyl Linoleate	16.3	7.28
Linolelaidic Acid Methyl Ester	0.52	-
Gamma-linolenic acid methyl ester	1.99	-
Methyl Lenolenate	2.27	-
Methyl Arachidate	-	0.39
M Cis-5,8,11,14- Eicosatetraenoic	10.12	-

2.2 Biodiesel Production

The raw materials from *nyamplung* oil and used cooking oil still contained gum and impurities, which needed to be cleaned through the degumming process. The degumming process began by heating the oil to a temperature of 80ºC. Phosphoric acid (H_3PO_4) was then added at a volume of 0.2% (v/w) of the oil weight and stirred for 15 minutes. Both *nyamplung* oil and used cooking oil also contained a relatively high amount of free fatty acids, necessitating the esterification process[13], [14].The esterification reaction was carried out by reacting the oil with methanol (22.5% of the oil volume). The reaction was conducted for 60 minutes at a temperature of 60°C using H_2SO_4 as the catalyst (0.5% of the oil volume).

The subsequent process was the transesterificationof each oil. The transesterification process began by dissolving methanol (15% of the oil volume) and KOH (1% of the oil volume), and then reacting it with the oil at a temperature of 60°C for 60 minutes. At the end of each process (degumming, esterification, and transesterification), washing and drying were carried out. All these parameters have become the standard for methanol-based transesterification[15].

2.3 Biodiesel Mixing Process

After the production of biodiesel, the next step was to create a blend of *nyamplung* oil biodiesel and waste cooking oil biodiesel. The biodiesel blends were made with varying compositions of 10:0, 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, 1:9, 0:10. Mixing was conducted at a temperature of 90°C for a duration of 60 minutes.

2.4 Physical Properties Testing of the Biodiesel Blend

Subsequent testing of the biodiesel characteristics included assessments of density, viscosity, flash point, and calorific value. The density of all biodiesel samples was measured at a temperature of 40°C. The mass of a 50 ml sample was weighed using a digital scale, and the density was then calculated by dividing the sample mass by its volume. The dynamic viscosity measurement was also conducted at a temperature of 40°C for all biodiesel samples using an NDJ-8S viscometer. The kinematic viscosity was calculated by dividing the dynamic viscosity by its density. The calorific value testing was conducted according to the ASTM D 240 - 02 method, using a Parr 6050 Bomb Calorimeter. The flash point was measured using the Cleveland Open Cup method.

To provide a clear and visual representation of the research methodology, we have included a comprehensive flowchart in Fig. 1. This flowchart outlines each stage of the biodiesel production process, from raw material preparation to the final testing of physical properties.

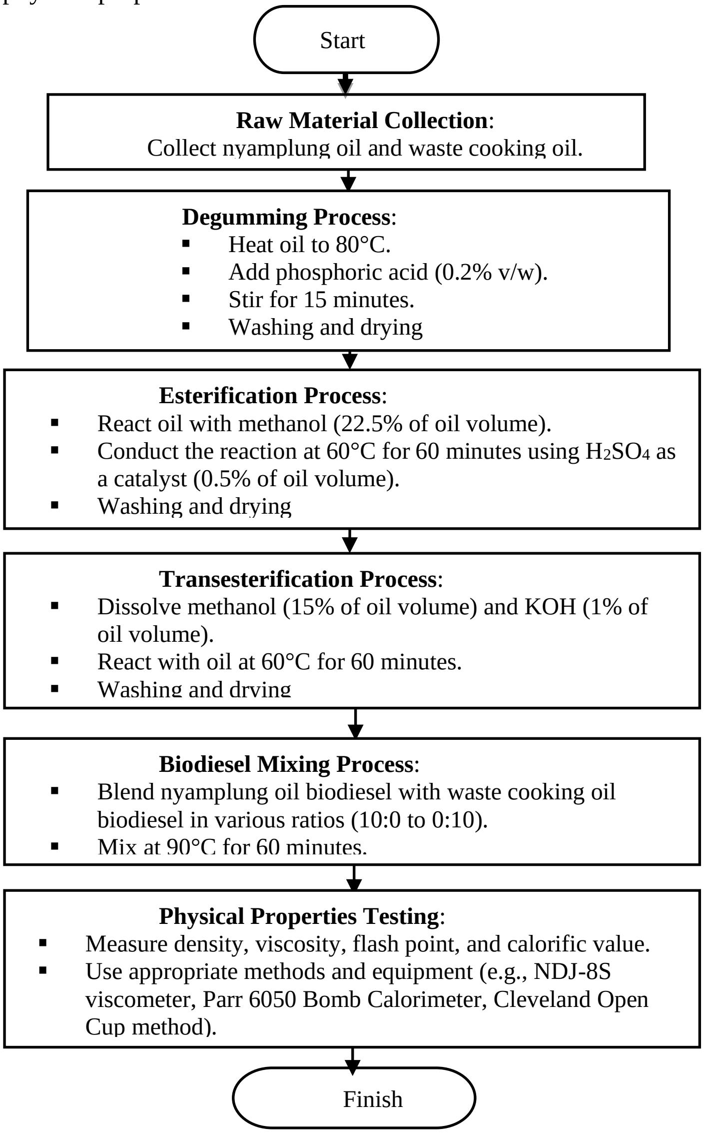

Fig. 1. Research methods.

3 Results and Discussion

Based on the physical properties data presented in Table 1, *nyamplung* oil has a higher flash point and density compared to waste cooking oil, but it also has a higher viscosity and a lower calorific value.

From the fatty acid content data of *nyamplung* oil (Table 2), it can be seen that the fatty acid with the highest content is Cis-9-Oleic Methyl Ester. This indicates that *nyamplung* oil is dominated by monounsaturated fatty acids. In addition, other fatty acids such as Methyl Octadecanoate and Methyl Linoleate also have significant contents. The presence of M Cis-5,8,11,14-Eicosatetraenoic also indicates the presence of polyunsaturated fatty acids in *nyamplung* oil.

On the other hand, for waste cooking oil, the dominant fatty acid was Methyl Palmitate. This fatty acid is a saturated fatty acid, showing distinct characteristics when compared to *nyamplung* oil. Nevertheless, waste cooking oil also contained Cis-9-Oleic Methyl Ester at a percentage almost similar to *nyamplung* oil, which was 36.51%, indicating the presence of monounsaturated fatty acids in its composition. From both types of oils, the dominant fatty acid structure was Cis-9-Oleic Methyl Ester, a monounsaturated fatty acid.

3.1 Density

The density of fuel is one of the crucial quality parameters and is defined as the mass of fuel per unit volume at a specific temperature. Density influences many aspects of engine performance[16], including fuel injection rate and combustion. Fuels with a higher density typically contain more energy per unit volume[17], which can enhance combustion efficiency.

Fig. 2 demonstrates that the density of the *nyamplung*-waste cooking oil biodiesel blends increases with a higher proportion of *nyamplung* in the mix. Specifically, the density of pure *nyamplung* biodiesel was recorded at 912.74 kg/m³, while pure waste cooking oil biodiesel shows a density of 857.27 kg/m³. The observed increase in density from mixtures with a higher proportion of *nyamplung* can be linked to the fatty acid content of each oil. As previously discussed, the fatty acid composition in vegetable oils affects the physical properties of the resulting biodiesel, including its density [18]. Fatty acids with longer carbon chains and an increasing number of double bonds tend to enhance the biodiesel's density. The degree of unsaturation in waste cooking oil was lower than that in *nyamplung* oil. This caused the density of waste cooking oil biodiesel to be lower, so adding waste cooking oil biodiesel composition to the blend with *nyamplung* biodiesel will decrease the mixture's density [19]. These findings are consistent with previous research on jatropha-waste cooking oil blends[18]. The fatty acid composition of *nyamplung* oil and waste cooking oil played a crucial role in determining the density of the blended biodiesel.

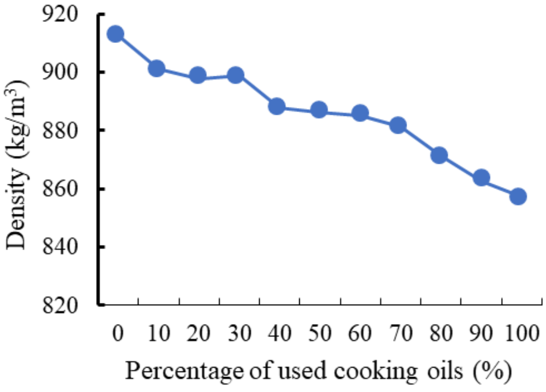

Fig. 2. Densityof *nyamplung*-used cooking oil biodiesel blends.

3.2 Viscosity

Viscosity is a measure of a fluid's resistance to flow and is defined as the internal resistance against movement. In the context of fuels, viscosity plays a pivotal role in determining how easily fuel flows in an engine's injection system[19]. Fuels with high viscosity might be challenging to spray efficiently[20], whereas fuels with low viscosity might not provide adequate lubrication for specific engine components.

The data shown in Fig. 3 clearly indicates that the viscosity of the blended *nyamplung*-waste cooking oil biodiesel decreases as the proportion of waste cooking oil biodiesel in the blend increases. Pure *nyamplung* biodiesel exhibits the highest viscosity at 28.02 cSt, while pure waste cooking oil biodiesel has the lowest viscosity, recorded at 4.58 cSt. This decrease in viscosity can be associated with the fatty acid composition of each oil. As is known, the fatty acid composition impacts the physical properties of biodiesel, including its viscosity[21]. Fatty acids with longer carbon chains tend to increase the biodiesel's viscosity. The carbon chains of fatty acids constituting waste cooking oil biodiesel are shorter on average than those in *nyamplung* biodiesel, resulting in a lower viscosity for waste cooking oil biodiesel and reducing the blend's viscosity when added to *nyamplung* biodiesel. This trend aligns with previous findings on jatropha-waste cooking oil blends[18], emphasizing that the composition and structure of fatty acids play a significant role in determining the viscosity of the blended *nyamplung*-used cooking oil biodiesel.

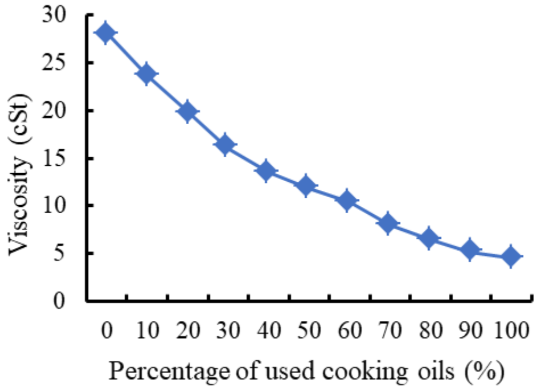

Fig. 3. Viscosityof *nyamplung*-usedcooking oil biodiesel blends.

3.3 Calorific Value

The calorific value of fuel refers to the amount of energy that can be released from the fuel when burned. It is defined in units of calories per gram or Joules per gram and indicates the energy capacity of the fuel. A high calorific value suggests that the fuel has the potential to provide more energy when burned, which can enhance engine efficiency and reduce fuel consumption.

Fig. 4 shows that the calorific value of the *nyamplung*-waste cooking oil biodiesel blend increases as the proportion of waste cooking oil biodiesel in the mixture rises. The calorific value of pure *nyamplung* biodiesel is 8,348.94 cal/g, while pure waste cooking oil biodiesel has a calorific value of 7,626.59 cal/g. The increase in calorific value with the rising proportion of waste cooking oil biodiesel in the blend relates to the fatty acid composition in that oil. The calorific value is influenced by the structure of the vegetable oil's fatty acids[22]. One structural feature of fatty acids that affects the fuel's calorific value is the degree of unsaturation. The higher the degree of unsaturation of the fatty acid, the lower the calorific value[12]. The calorific value increases with the increasing composition of waste cooking oil biodiesel due to the lower degree of unsaturation in its fatty acids compared to *nyamplung* biodiesel. These findings are consistent with the literature on jatropha-waste cooking oil blends[18], further validating our results.

3.4 Flash Point

The flash point is the minimum temperature at which fuel vapors can form a mixture with air that is combustible when approached by an ignition source[23]. The importance of the flash point lies in safety aspects; fuels with a lower flash point are more easily ignited and therefore pose greater risks under certain conditions.

Based on the data presented in Fig. 5, it is observed that the flash point of the *nyamplung*-waste cooking oil biodiesel blend tends to increase as the proportion of *nyamplung* in the mixture rises. The flash point of pure *nyamplung* biodiesel is the highest at 223°C, while pure waste cooking oil biodiesel has the lowest flash point, at 197°C. This indicates a strong influence of *nyamplung's* fatty acid composition on the flash point of the blend. The increase in flash point with the increasing proportion of *nyamplung* might be related to the fatty acid composition in the oil. Fatty acid components with longer carbon chains have higher flash points[24].These observations are in line with previous research, including studies on jatropha-waste cooking oilb lends[18], which further validate the consisten cyo four findings.

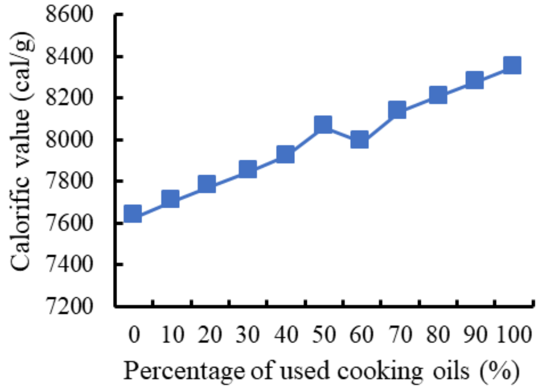

Fig. 4. Calorific value of *nyamplung*-used cooking oil biodiesel blends.

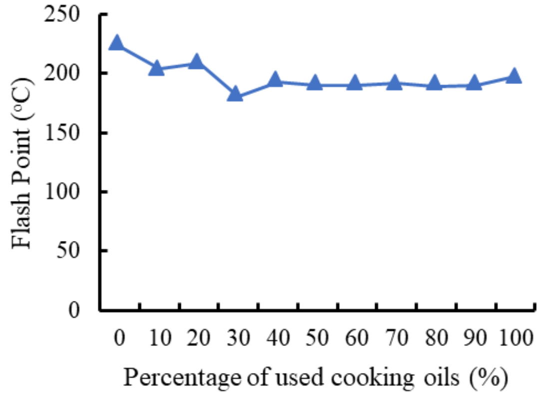

Fig. 5. The flashpoint of *nyamplung*-used cooking oil biodiesel blends

In summary, the main finding soft hisresearchshow a clear relationship between the proportion of *nyamplung* and waste cooking oil in the biodiesel blend and its physical properties. Increasing the proportion of waste cooking oil consistently reduce sviscosity and increase scalorific value, aligning with the aim of this research tooptimize biodiesel characteristics.

4 Conclusion

The composition and fatty acid content of the blended nyamplung-used cooking oil biodiesel have a significant influence on its physical properties. With the increasing percentage of waste cooking oil biodiesel in the mixture, the density and viscosity of the biodiesel tended to decrease, while the calorific value increased, closely relating to the fatty acid composition in the waste cooking oil. The flash point decreased with an increasing percentage of waste cooking oil biodiesel, indicating that fatty acid composition plays a key role in determining biodiesel's physical properties. These findings not only offer the potential for developing an optimal *nyamplung*-used cooking oil blended biodiesel formulation but also strengthen the results of similar research studies on biodiesel blends. Future research can focus on exploring different blend compositions and evaluating engine performance using the blended biodiesel.

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