Engineering and Technology Journal e-ISSN: 2456-3358

Volume 10 Issue 05 May-2025, Page No.- 5141-5148

DOI: 10.47191/etj/v10i05.43, I.F. – 8.482

Production of Biodiesel from Candlenut Oil Using Catalyst Variations (KOH and ZnO) Through the Transesterification Method

Kiagus Ahmad Roni[1], Muhammad Arief Karim[2], Arientieno Alip Aji Wahakil[3], Nico Syahputra Sebayang[4]

[1,2,3]Chemical Engineering Study Program, Faculty of Engineering, Muhammadiyah University of Palembang

[4]Food Technology Departnent, Faculty of Agricultural, Muhammadiyah University of Palembang

ABSTRACT: The global reliance on fossil-based energy sources such as petroleum, natural gas, and coal— characterized as non-renewable—is leading to their rapid depletion. In response, renewable fuels have emerged as sustainable alternatives, primarily derived from biological sources such as plants and animals. Catalysts play a vital role in both fossil and renewable fuel production by accelerating chemical reactions.

This study investigates the production of biodiesel (methyl ester) from candlenut oil using potassium hydroxide (KOH) and zinc oxide (ZnO) as catalysts via a transesterification process conducted for one hour. A total of 16 biodiesel samples were synthesized with varying catalyst types and concentrations. The samples were characterized based on density, viscosity, calorific value, flash point, and compound identification via gas chromatography– mass spectrometry (GC-MS). The optimal result was achieved using a combination of 1% KOH and 1% ZnO catalysts with a methanol-to-oil molar ratio of 1:6. The biodiesel produced exhibited a flash point of 188°C and a calorific value of 9000.60 cal/g for the KOH-based sample, and a flash point of 181°C with a calorific value of 8223.60 cal/g for the ZnO-based sample. GC-MS analysis indicated a methyl ester content of 93.23% in the ZnO-catalyzed biodiesel, confirming its high purity and potential suitability as a diesel substitute.

KEYWORDS: Biodiesel, Transesterification, Candlenut Oil, Catalyst Variation, KOH, ZnO

INTRODUCTION

Energy resources commonly utilized and managed today primarily originate from fossil based fuels such as petroleum, natural gas, and coal. These sources are non-renewable in nature and are progressively depleting over time. To address this growing concern, renewable energy sources have been increasingly considered as a viable and sustainable solution. One such renewable alternative is biodiesel, a biofuel derived from plant or animal-based raw materials. Both fossil and non-fossil fuel production processes require an abundant supply of catalysts, which play a pivotal role in accelerating product formation (Agustina, 1996).

Among the renewable energy products, methyl esters derived from vegetable oils are of particular significance. Biodiesel, also known as methyl ester, is a type of fuel synthesized from vegetable oils and exhibits properties closely resembling conventional diesel fuel (Prihandana & Nuramin, 2006).

In several countries, biodiesel derived from vegetable oil has been produced and consumed on a large scale. With petroleum classified as a non-renewable energy resource, the continuous rise in fuel consumption has led to a rapid depletion of reserves. Without the development of alternative energy sources, petroleum will eventually need to be imported in significant volumes (Roni, 2012). Among the various available feedstocks, candlenut oil is considered a highly promising option due to its abundance and accessibility. The candlenut producing plant (*Reutealis trisperma* Blanco), originally native to the Philippines, is now being cultivated in Indonesia, particularly in West Java (Handoyo et al., 2007).

The *Reutealis trisperma* Blanco tree, commonly known as kemiri sunan, is capable of producing approximately 300–500 kg of dry seeds per tree per year, with an oil content ranging from 50–56%. This high production potential translates into approximately 50 tons of dry seeds or 15–25 tons of oil per hectare, which exceeds the yield of palm oil. The fatty acid composition of candlenut oil includes 10% palmitic acid, 9% stearic acid, 12% oleic acid, 19% linoleic acid, and 51% eleostearic acid (Anonymous, 2013; Pronowo, 2014). The oil also contains a high iodine value, ranging from 133 to 160 g-I_2/100 g, attributed to the presence of three double bonds in eleostearic acid, its primary component. When used directly as a feedstock for biodiesel production, candlenut oil tends to yield biodiesel with iodine values exceeding the limits defined by the Indonesian National Standard SNI 7182:2012. This represents a key technical challenge in the utilization of kemiri sunan oil for biodiesel production (Agarwal & Das, 2001).

Biodiesel production from vegetable oils typically involves a transesterification reaction between oil and alcohol, facilitated by a homogeneous catalyst. Although homogeneous catalysts are effective in producing biodiesel, they present several drawbacks, including the formation of soap as a by-product, which can reduce biodiesel yield, complicate catalyst separation, and pose environmental risks (Budiawan et al., 2013). In response to these challenges, the use of heterogeneous catalysts is being developed as a more sustainable alternative. Unlike homogeneous catalysts, heterogeneous catalysts can be more easily separated from the reaction mixture and reused. Potassium hydroxide (KOH) is one such heterogeneous catalyst that can be applied effectively in transesterification processes (Carlo et al., 1997).

Candlenut Seed Composition

Candlenut seeds contain a variety of chemical components, including glycerides, linoleic acid, palmitic acid, stearic acid, myristic acid, fatty acids, proteins, and vitamin B1. These compounds collectively contribute to what is internationally recognized as candlenut oil. The candlenut plant belongs to the *Aleurites* genus, specifically the species *Aleurites moluccana*. Morphologically, the plant is a large tree with a height ranging from 25 to 40 meters. It has numerous branches, and its buds are covered with grayish-black or brownish hairs. The young leaves are lobed (three to five segments), and the stem is characterized by lenticel filled surfaces, sympodial branching, and a light brown color. The flowers are compound, monoecious, and white with short stalks. The fruit is encased in a hard shell with a diameter of approximately 5 cm and contains one or two seeds surrounded by a coarse outer layer.

These fruits are toxic when raw due to the presence of a compound called toxalbumin (Handoyo et al., 2007).

Figure 1. Candlenut Seeds

Candlenut oil is commonly used as a substitute for linseed oil. While linseed oil is traditionally utilized in the production of varnishes and paints, candlenut oil is considered a superior alternative due to its favorable properties. It has a higher evaporation rate, classifying it as a volatile oil. Candlenut seeds contain 55–65% oil, with the shell comprising about 60% of the seed mass. The palmitic and stearic acids in the oil are classified as saturated fatty acids, whereas oleic, linoleic, and linolenic acids are unsaturated fatty acids.

Table 1. Fatty Acid Composition in Candlenut Oil

Fatty Acid	Systematic Name	Analytical Result (%)
Capric	Decanoic Acid	0.202
Palmitic	Hexadecanoic Acid	6.32
Stearic	Octadecanoic Acid	2.31
Oleic	cis-9-Octadecenoic Acid	26.93
Linoleic	cis-9, cis-12-Octadecadienoic Acid	38.52
Linolenic	cis-9, cis-12, cis-15-Octadecatrienoic Acid	25.25

Sources: *(Yulianti, 2006)*

The extraction of candlenut oil involves separating the seed from its hard shell. Refinement can be carried out either by heating the fruit over an open flame followed by soaking in cold water, or by boiling the seeds for 5–6 hours and then crushing and grinding them.

Table 2. Physicochemical Properties of Crude and Refined Candlenut Oil

Property	Crude Oil	Refined Oil
Physical Form	Liquid	Liquid
Color	Dark Yellow	Clear Yellow
Specific Gravity	0.9523	0.9191
Refractive Index at 25°C	1.545	1.479
Melting Point (°C)	13–14	13–14
Acid Value (mg KOH/g)	5.72	0.56
Saponification Value	207.06	190.04
Unsaponifiable Matter (%)	6.51	0.10
Peroxide Value (meq/kg)	12.96	4.87
Iodine Value	152.93	147.96

Sources: *(Ketaren, 1986)*

Biodiesel

Biodiesel is a renewable alternative fuel that can be synthesized from vegetable oils (Roni & Martini, 2021). It is considered a viable substitute for conventional diesel fuel and is derived from organic sources such as palm oil, soybean oil, jatropha oil, and other biologically sourced feedstocks. The production of biodiesel involves a transesterification reaction, in which organic oil reacts with alcohol (typically methanol or ethanol) in the presence of a catalyst such as *sodium hydroxide* (NaOH) or *potassium hydroxide* (KOH).

Biodiesel is often used directly as a substitute for diesel fuel without requiring major engine modifications. Its environmental benefits are considerable, as it produces lower emissions compared to petroleum diesel. The key distinguishing component in biodiesel is *Fatty Acid Methyl Ester* (FAME), which is derived from plant oils and contributes to its biodegradability and reduced environmental footprint (Hikmah et al., 2014).

Another distinguishing characteristic is that biodiesel feedstocks often contain monoglycerides, which act as natural emulsifiers and stabilizers when blended with fossil diesel. However, biodiesel may also contain sulfate compounds that can cause corrosion in engine components if not properly treated. These chemical constituents must be carefully managed to ensure high-quality biodiesel and minimize operational issues during usage and storage (Agarwal & Das, 2001).

Catalysts

Catalysts are substances that are added to a chemical reaction to accelerate its reaction rate. Although they participate in the reaction mechanism, catalysts do not undergo permanent chemical changes and are regenerated upon completion of the reaction. They function as facilitators by enabling the reaction to proceed at a faster rate or at lower temperatures without being consumed as reactants or products. The presence of a catalyst can reduce the activation energy required, thereby enhancing the overall reaction kinetics. Furthermore, catalysts may introduce additional steps in the reaction pathway, such as intermediate binding and release (Jairul and Kasa, 2007).

Catalysts exhibit specific characteristics, meaning they are effective only under certain reaction conditions. Their primary function is to lower the activation energy, which results in an increased rate of product formation. Generally, catalysts are classified into two main types:

· **Homogeneous catalysts**, which exist in the same phase as the reactants and products. · **Heterogeneous catalysts**, which exist in a different phase than the reactants and products.

The most important process utilizing solid catalysts is **cracking**, in which long-chain hydrocarbons in crude oil are broken into shorter chains. The catalysts used in such operations are often discarded after a single use, contributing to hazardous solid waste (classified as B3 waste in Indonesia). A sustainable approach proposed by BAPEDA involves repurposing spent catalysts from Pertamina's UP III cracking units to produce biodiesel from rubber seed oil. This method not only enhances the economic value of the feedstock by converting it into esters and glycerol but also reduces environmental pollution. Through alcoholysis, rubber seed oil can be reacted with alcohol using spent catalysts to produce biodiesel and glycerol (Roni et al., 2020).

Table 3. Comparison of Homogeneous and Heterogeneous Catalysts

Homogeneous Catalysts	Heterogeneous Catalysts
Liquid or gas phase	Solid phase
Each molecule is catalytically active	Contains a fixed number of active sites
High activity and selectivity	Moderate to high activity and selectivity
Less susceptible to poisoning	Easily deactivated by impurities

A. Potassium Hydroxide (KOH) Catalyst

Potassium hydroxide (KOH) is a strong base widely used across industrial applications, available in solid or aqueous form. Chemically, it is a white, hygroscopic crystalline substance made from the alkali metal potassium, with atomic number 19. KOH solutions are typically prepared at concentrations of 10% for reactivity. Due to its highly corrosive nature, it can cause severe chemical burns and even blindness upon contact; therefore, appropriate personal protective equipment (PPE), especially eye protection, is strongly recommended during handling (Kamarudin, 2006).

KOH is frequently used as a catalyst in transesterification reactions due to its high basicity, affordability, and availability. It facilitates the conversion of triglycerides into methyl esters and glycerol, making it suitable for biodiesel production (Pranowo et al., 2014).

Figure 2. KOH Material

B. Zinc Oxide (ZnO) Catalyst

Zinc oxide (ZnO) is a type of heterogeneous catalyst, meaning its physical phase differs from that of the reactants and products. This property allows for easy separation and potential reusability after the reaction. ZnO is an inorganic compound derived from zinc metal, usually synthesized by reacting metallic zinc with oxygen at elevated temperatures.

ZnO offers several advantages as a catalyst, including non-corrosive behavior and environmental friendliness. It also minimizes the formation of soap, a common side product in biodiesel synthesis using homogeneous catalysts. ZnO can be engineered into nanoparticles, with its catalytic properties strongly influenced by particle size, surface morphology, crystal facets, and dispersion. These characteristics enhance the availability of reactive surface atoms for interaction with reactants (Pakpahan, 2009).

Methanol

Methanol, also known as methyl alcohol (CH_3OH), is the simplest form of alcohol. It is a light, volatile, colorless, flammable liquid with a distinctive odor. Methanol is naturally produced through fermentation and decomposition processes (Perry and Green, 1984). In biodiesel synthesis, alcohols such as methanol, ethanol, propanol, and butanol serve as reactants in the transesterification reaction.

Methanol is the most widely used alcohol in biodiesel production due to its low cost, low molecular weight, and favorable chemical properties. It ensures greater reaction efficiency and stability compared to other alcohols. In transesterification, methanol reacts with triglycerides to form methyl esters (biodiesel) and glycerol, facilitated by either homogeneous or heterogeneous catalysts (Highina et al., 2011).

Table 4. Physical and Chemical Properties of Methanol

Property	Value
Molar mass	32.04 g/mol
Physical form	Colorless liquid
Specific gravity	0.7918
Melting point	−97°C
Boiling point	64.7°C
Water solubility	Completely miscible
Acidity (pKa)	15.5

*(**Source**: Perry, 1984)*

RESEARCH METHODOLOGY

This study utilized candlenut oil as the primary feedstock, while the chemicals used included methanol, aquadest (distilled water), KOH, and ZnO. The experimental design consisted of fixed and independent variables. To determine the percentage of free fatty acids (FFA), 5 grams (5.43 mL) of candlenut oil was weighed using an analytical balance and placed into an Erlenmeyer flask. A volume of 25 mL of methanol was added, along with three drops of phenolphthalein indicator. The mixture was titrated using 0.1 N KOH solution until a stable pink color appeared. The volume of KOH used during the titration was recorded.

If the FFA content exceeded 2%, the sample required pretreatment via adsorption. Otherwise, the sample proceeded directly to the transesterification process. The FFA percentage was calculated using the formula:

(N KOH × Titrant Volume × Equivalent Weight of Fatty Acid) / Sample Mass × 100%.

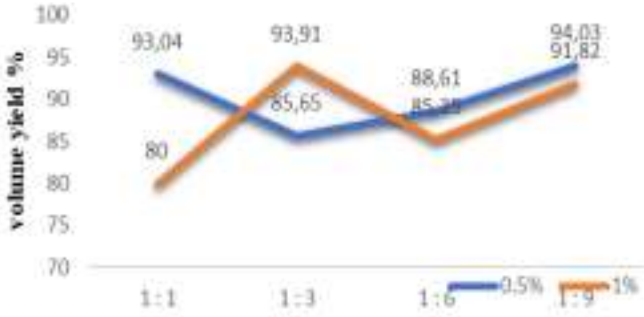
RESULTS AND DISCUSSION

The titration of free fatty acids (FFA) showed a value of 0.3584%, which qualified the sample for direct transesterification without pretreatment. According to Hadrah et al. (2018), oils with FFA content above 1%—such as waste cooking oil—may form soap emulsions that complicate biodiesel separation. Thus, candlenut oil with FFA content below 1% is considered ideal for transesterification.

Operating conditions of temperature and biodiesel yield.

Reaction time: 1 hour

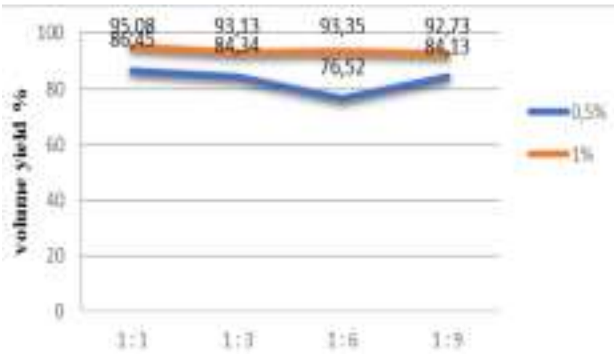
A. KOH Catalyst.



Molar Mass

Oil Methanol

B. ZnO Catalyst.



Molar Mass

Oil Methanol

Figure 4. Effect of Oil-to-Methanol Ratio on %Biodiesel Yield at Various Catalyst Amounts: A. KOH and B. ZnO.

The optimum reaction conditions were as follows: 1-hour reaction time, 60°C temperature, methanol-to-oil ratio of 1:6, and catalyst concentration of 1%. The yield of biodiesel using ZnO was 93.35%, while KOH achieved 85.25% under the same conditions. Despite a higher yield at a 1:9 ratio, soap formation made the separation process difficult, confirming 1:6 as optimal. Oil : Methanol (mol/mol)

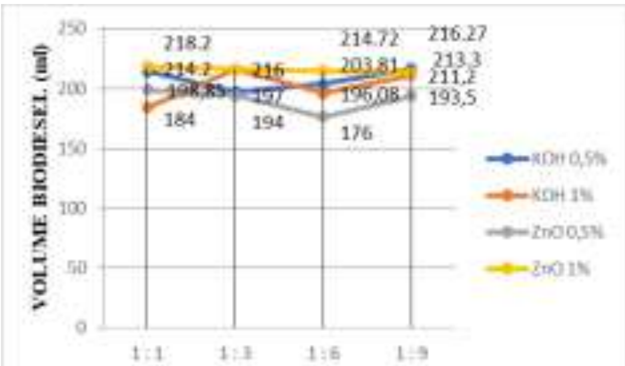


Figure 5. Effect of KOH and ZnO Catalysts on Biodiesel Product Volume at Various Oil-to-Methanol Ratios

1,00

densitas gr/ml **minyak:metanol mol/mol**

0,95 0,90 0,85 0,80

0,97

0,90 0,88 0,90 0,90 0,90 0,88 0,90 1 : 1 1 : 3 1 : 6 1 : 9

0,5% 0,97 0,90 0,88 0,90

1% 0,90 0,90 0,88 0,90

Figure 6. Effect of Oil-to-Methanol Ratio on Density

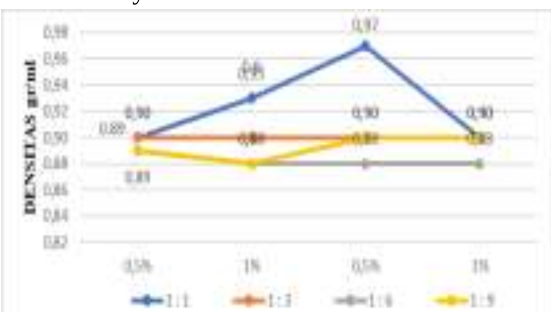


Figure 7. Effect of KOH and ZnO Catalysts on Biodiesel Product Density at Various Oil-to-Methanol Ratios.

Viscositas

Viscosity analysis indicated that ZnO-based biodiesel at a 1:6 ratio yielded 4.13 cSt, within the national biodiesel standard. KOH-based biodiesel showed a lower viscosity of 2.07 cSt. A high viscosity enhances fuel injection performance but should remain within acceptable limits to prevent atomization delays (Syamsidar, 2010).

Flash point results showed that KOH-based biodiesel had a flash point of 188°C and ZnO based biodiesel 181°C, both above the 130°C threshold set by EBTKE No.189.K/10/DJE/2019. The calorific values were 9000.5987 cal/g for KOH and 8223.5953 cal/g for ZnO, approaching the calorific value of commercial diesel at 9536.8 cal/g.

GC-MS analysis of the biodiesel sample (methanol-to-oil ratio of 1:6, 1% catalyst) showed that KOH-based biodiesel contained 59.36% methyl esters, while ZnO-based biodiesel exhibited higher purity with 93.23%, dominated by methyl palmitate (23.58%) and methyl oleate (69.62%).

GC-MS Analysis at an Oil-to-Methanol Ratio of 1:6 Using 1% KOH and ZnO Catalysts

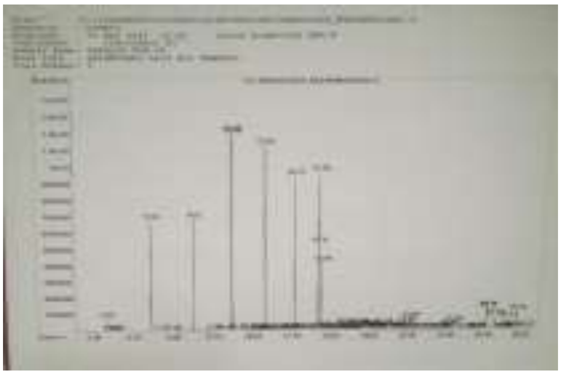


Figure 8. GC-MS Analysis with KOH Catalyst

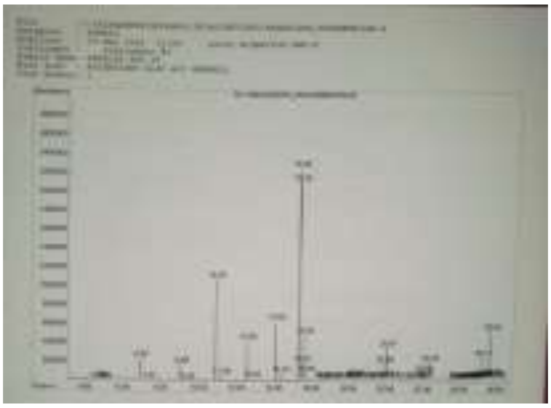


Figure 9. GC-MS Analysis with ZnO Catalyst

CONCLUSION

Based on the experimental study using various methanol-to-oil ratios (1:1, 1:3, 1:6, 1:9) and catalyst concentrations (0.5% and 1% for KOH and ZnO), and under reaction conditions of 60°C, 300 rpm, and 1-hour duration, the optimum condition was identified as a 1:6 ratio with 1% ZnO catalyst. This configuration produced a biodiesel yield of 93.35%, density of 0.88 g/mL, viscosity of 4.13 cSt, calorific value of 8223.60 cal/g, and flash point of 181°C. In contrast, KOH-based biodiesel yielded 85.25% with similar density, 2.07 cSt viscosity, calorific value of 9000.60 cal/g, and flash point of 188°C. All results complied with the national standard EBTKE No.189.K/10/DJE/2019.

GC-MS analysis confirmed that ZnO-based biodiesel had the highest methyl ester purity at 93.23%, making it the more suitable catalyst compared to KOH. Thus, ZnO is recommended for producing high-quality biodiesel from candlenut oil based on its superior performance across yield, density, viscosity, calorific value, flash point, and chemical composition.

REFERENCES

1. Agarwal, A. K., & Das, L. M. (2001). *Biodiesel development and characterization for use as a fuel in compression ignition engines*. Madison: University of Wisconsin.
2. Augustine, R. L. (1996). *Heterogeneous catalysis for the synthetic chemist* (1st ed.). New York: Marcel Dekker Inc.
3. Budiawan, Zulfansyah, R., Fatra, W., & Helwani, Z. (2013). Off-grade palm oil environmental implication in Indonesia. In *Proceedings of the International Biodiesel Workshop: Enhancing Biodiesel Development and Use*. Ministry of Agriculture, Indonesia.
4. Handoyo, R., Ananta, A. A., & Anwar, S. (2007). *Biodiesel from kapok seed oil*. Faculty of Agricultural Technology, Universitas Gadjah Mada.

5. Highina, B. K., Bugaje, I. M., & Umar, B. (2011). Biodiesel production from *Jatropha curcas* oil in a batch reactor using zinc oxide as catalyst. *Journal of University of Maiduguri*.
6. Hikmah, M. N., & Zuliyana. (2010). Production of methyl ester (biodiesel) from rice bran oil and methanol via esterification-transesterification process. *Diponegoro University*, Semarang.
7. Joelianingsih, Tambunan, A. H., Nabetani, H., Sagara, Y., & Abdullah, K. (2006). Development of biodiesel production processes. *Volume 5*, 342–346.
8. Mittelbach, M., & Remschmidt, C. (2004). *The biodiesel comprehensive handbook*. Vienna: Boersedruck Ges.m.b.H.
9. Pakpahan, A. (2009). *Palm biodiesel: Its potential, technology, and business prospects*. Bogor: Institut Pertanian Bogor.
10. Perego, C., & Villa, P. (1997). Catalyst preparation methods. *Department of Industrial Chemistry and Chemical Engineering*.
11. Pranowo, D., Syakir, M., Prastowo, W., Herman, M., Aunillah, A., & Sumanto. (2014). Biodiesel production from *Reutealis trisperma* and utilization of by-products. Jakarta: Indonesian Agency for Agricultural Research and Development (IAARD) Press, pp. 12–18.
12. Prihandana, R., Hendroko, R., & Nuramin, M. (2006). *Producing affordable biodiesel to overcome pollution and fuel shortages*. Jakarta: Agromedia Pustaka.
13. Prihanto, A., & Irawan, T. A. B. (2017). Effect of temperature, catalyst concentration and methanol-to-oil molar ratio on biodiesel yield from used cooking oil via neutralization transesterification. *Journal of Chemical Engineering*.
14. Roni, K. A. (2012). Biodiesel production from *Sterculia foetida L* via alcoholysis using waste catalyst from petroleum cracking (Pertamina Unit II, Palembang). *Jurnal Dinamika Penelitian Industri*, 23(1), 22.
15. Roni, K. A., & Martini, S. (2021). Biodiesel production from rubber seed oil by alcoholysis as an alternative economic fuel source. *Journal of Chemical Process Engineering*, 6(2), 90.
16. Roni, K. A., et al. (2020). Utilization of rubber seed and spent catalyst from petroleum cracking (Pertamina Refinery Unit III) for biodiesel production. *Jurnal Ilmiah Pengabdian Pada Masyarakat*, 2(1), 15

.