

EFFECT OF MICROWAVES POWER FOR BIODIESEL PRODUCTION FROM PALM OIL

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Abstract- Palm oil is the raw material for biodiesel that has the greatest potential based on the amount of supply and price when compared to other vegetable oils. The use of microwave heating technology in the transesterification process offers opportunities for optimizing production by accelerating the reaction and reducing energy consumption. The combination of microwave heating with NaOH catalyst can increase biodiesel yields, both in terms of quantity and quality. The aim of this study was to assess the impact of microwave power and NaOH catalyst concentration on biodiesel quality, as well as to determine the best microwave power and NaOH catalyst concentration for biodiesel quality. The synthesis of biodiesel from palm oil through the use of microwave method begins by mixing palm oil and methanol (1:9) and NaOH catalyst. The mixture is heated in a microwave at the specified power for 2.5 minutes. After the heating process, the mixture is divided into biodiesel and glycerol. The biodiesel is subsequently washed with distilled water and heated again to eliminate any remaining water. This method accelerates the transesterification process by adjusting the microwave power and catalyst concentration, which affect the quality of the biodiesel produced. Microwave power has a significant effect on the quality of biodiesel produced from palm oil with NaOH catalyst. Optimal conditions were achieved at 400 watts of power with a NaOH catalyst concentration of 0.5%, producing the highest yield of 99.6%. Under these conditions, the biodiesel produced had a density of 0.853 g/cm³, a viscosity of 4.689 cSt, and an acid number of 0.118 mg KOH/g. All of these parameters meet the SNI 7182:2015 standard.

Keywords: Biodiesel Production, Microwave, Palm Oil, Transesterification, Renewable Energy.

1. INTRODUCTION

Energy is a vital resource for humanity and sustainable development. At present, the global energy crisis remains a major challenge. Fuel plays a key role as it can be burned to generate substantial energy. Many aspects of daily life rely on fuel, particularly for the transportation of goods and

people. The majority of the world's energy supply, approximately 80%, comes from fossil fuels such as petroleum, coal, and natural gas. Diesel engines are widely used in industrial production, while in transportation, private vehicles, buses, and ships consume significant amounts of diesel and gasoline. This results in a heavy dependence on fossil fuels in everyday life [1]. Total greenhouse gas (GHG) emissions in 2018 resulting from global transportation activities reached around 8.5 GtCO₂eq, or equivalent to 14% of total global emissions. Of this amount, road transportation contributed significantly, namely 73% of the total emissions produced by the transportation sector [2].

Road transportation also contributes a large proportion of emissions in this sector, the application of environmentally friendly fuels in this sector has the potential to significantly reduce emissions in the transportation industry. Consequently, research on alternative fuels for motor vehicles, including cars and motorcycles, remains a key area of development. Additionally, the unequal distribution of fossil fuel reserves across different regions of the world poses a significant challenge, leading to energy insecurity in countries that lack these resources. Based on the latest data in 2022, the ten countries with the largest oil reserves in the world control more than 85% of the total global oil reserves. One of the alternative energy sources that can be utilized is biodiesel [3].

Biodiesel is a sustainable fuel sourced from organic materials such as recycled cooking oil, animal lipids, and agricultural by-products, offering a practical substitute for traditional fossil fuels. It generates substantially lower greenhouse gas emissions, commonly lessening them by 50% to 85%, and seamlessly integrates with current diesel engines. Produced from both consumable and non-consumable vegetable oils along with certain animal fats, biodiesel is globally acknowledged as an environmentally friendly fuel due to its biodegradability, elevated flash point, and minimal sulfur content. The use of biodiesel and other biofuels helps decrease reliance on fossil fuels while contributing to climate change mitigation [4].

The development of biodiesel production has gained momentum due to its relatively simple process, lower production costs, and renewable sources. As a sustainable fuel, biodiesel offers several benefits, including environmental friendliness, biodegradability, and lower emissions compared to fossil fuels. Comprised of fatty acid alkyl esters, biodiesel is a diesel alternative derived from renewable resources and can be produced using vegetable oils, animal fats, used cooking oils, or recycled oils. Various vegetable oils, such as palm oil, castor oil, and *Calophyllum inophyllum* oil, serve as potential raw materials for biodiesel, helping to reduce reliance on fossil fuels that contribute to high greenhouse gas emissions [5].

When it comes to accessibility and expense, palm oil emerges as the most advantageous feedstock for biodiesel compared to alternative vegetable oils. Indonesia holds the title of the largest palm oil producer globally. In 2020, the country produced around 45 million tons of palm oil from a total plantation area of 14 million hectares, comprising 6 million hectares of community plantations, 7 million hectares of private company owned plantations, and 565 thousand hectares of state owned plantations. Almost 50% of Indonesia's crude palm oil (CPO) output is sent abroad, whereas the rest is allocated for local food use. Data indicates a significant upward trend in Indonesia's CPO export volume. In 2016, Indonesia accounted for 57% of global CPO exports, with India being its largest importer. Apart from exports, CPO is widely used in food products such as cooking oil and margarine. More recently, its applications have expanded, including as a component in diesel fuel, known as biodiesel. This makes palm oil a highly viable option for biodiesel production. Palm-based biodiesel is well-suited for diesel engines, as it shares similar properties with petroleum-based diesel and meets the SNI 7182:2015, ASTM D6751, and EN 14214 standards [6].

Biodiesel can be produced through various methods, such as thermal cracking (pyrolysis), micro emulsion (micro emulsifying), and transesterification processes. Without a catalyst, the transesterification process is very slow, but with the addition of a catalyst, the reaction becomes very fast [7]. Microwaves heat materials internally by causing polar molecules, such as those in oils and alcohol, to oscillate. This results in rapid heating throughout the substance, leading to uniform temperature distribution and reduced heating duration. Alternative technologies developed in the chemical reaction of transesterification to produce biodiesel currently include the use of microwave radiation. Microwave radiation is very promising compared to conventional methods, which generally use conventional heating [8]. Conventional heating causes a relatively slow and less efficient reaction the response is influenced by the movement of energy to the specimen, which relies on the convection currents and the thermal conductivity of the reaction blend. The transesterification method using microwave heating can also provide high yields and pure FAME (Fatty Acid Methyl Ester) [9].

Transesterification reaction is a reaction between triglycerides and alcohols that produces free glycerol and fatty acid alkyl esters. This process takes place with the help of a catalyst, either a base catalyst or an acid catalyst. Base catalysts are more often used than acid catalysts, because at the same temperature and concentration, the transesterification reaction with a base catalyst takes place faster than with an acid catalyst [10]. The concentration of free fatty acids (FFAs) in the raw ingredients significantly influences the appropriateness of the catalyst employed for producing biodiesel. In substrates that possess elevated FFA levels, traditional homogeneous acid catalysts are utilized for their capability to concurrently esterify FFAs while transesterifying triglycerides into biodiesel [11]. The NaOH base catalyst is often chosen in the transesterification process for several reasons. First, its price is relatively cheap, thus reducing the cost of biodiesel production. Second, its availability is easily found in the market. Ultimately, the NaOH alkaline catalyst is recognized for its significant efficacy in speeding up the transesterification process of triglycerides derived from plant oils and animal fats into fatty acid methyl esters [12].

This study aims to determine the efficiency of the microwave heating method in making biodiesel from palm oil using NaOH catalyst. In addition, this study will also explore the effect of variations in catalyst power and concentration on the yield of biodiesel produced. Thus, it is hoped that this study can contribute to the development of more efficient, environmentally friendly, and sustainable biodiesel production technology.

The quest for sustainable and renewable energy sources has gained immense momentum in recent years, driven by the urgent need to mitigate climate change and reduce reliance on fossil fuels. Among various alternative fuels, biodiesel has emerged as a promising contender, particularly due to its potential for reducing greenhouse gas emissions and its compatibility with existing diesel engines. As one of the leading feedstocks for biodiesel production, palm oil has garnered attention for its high oil yield and favorable properties. However, traditional biodiesel production methods often face challenges related to efficiency, reaction time, and energy consumption. In this context, microwave-assisted transesterification has surfaced as a groundbreaking approach poised to revolutionize biodiesel synthesis.

The application of microwave energy in biochemical processes presents unique advantages by providing rapid and uniform heating, which is critical for enhancing reaction kinetics. Conventional transesterification methods typically require prolonged heating to achieve satisfactory conversion rates, resulting in increased energy costs and prolonged production times. In contrast, microwave assisted techniques have demonstrated the ability to significantly accelerate the reaction by generating localized heating effects that enhance molecular interactions. As the power levels of microwave irradiation are finely tuned, researchers have observed dramatic improvements in the yield of fatty acid methyl esters (FAMEs), leading to more efficient biodiesel production.

Energy efficiency remains a cornerstone of the sustainability narrative surrounding biodiesel production. Traditional methods often entail substantial energy expenditures to maintain reaction temperatures, contributing to the overall carbon footprint of the biodiesel lifecycle. Microwave irradiation addresses this issue by minimizing energy consumption through rapid thermal processing. By adjusting the microwave power, it becomes possible to optimize reaction conditions, thereby achieving higher yields in shorter timeframes and with reduced energy inputs. This not only leads to cost savings but also promotes a more environmentally friendly approach to biodiesel manufacturing.

Furthermore, scalability is a crucial aspect that determines the commercial viability of any production technology. The versatility of microwave-assisted transesterification allows for its adaptation to various scales of biodiesel production, from small laboratory setups to large industrial applications. Advanced designs for continuous microwave reactors can facilitate efficient processing of large volumes of feedstock while ensuring consistent biodiesel quality. As industries increasingly seek to implement more sustainable practices, the integration of microwave technology into biodiesel production lines represents a potent strategy for enhancing productivity and meeting growing energy demands.

In summary, the exploration of microwave power's effect on biodiesel production from palm oil encapsulates a transformative approach to energy sustainability. By harnessing the benefits of improved reaction kinetics, enhanced energy efficiency, and scalable production processes, microwave-assisted transesterification stands poised to play a pivotal role in the future of biodiesel technology. This research aims to contribute valuable insights into optimizing microwave-assisted biodiesel production, ultimately advancing the development of efficient and sustainable energy solutions.

Microwave assisted biodiesel production from palm oil shows considerable promise at the laboratory scale, with enhanced reaction speeds and improved energy efficiency. However, to upscale this method for industrial applications, significant advancements in reactor design, energy distribution, and process integration are required. With continued research and the development of tailored industrial-scale microwave reactors potentially in hybrid configurations the method could ultimately contribute to more sustainable and economically viable biodiesel production processes.

2. MATERIAL AND METHODS

2.1. Materials and Chemicals

The materials used are Palm Oil (Bimoli Oil) as the main ingredient for making Biodiesel, Sodium Hydroxide (NaOH) catalyst with concentrations of 0.1; 0.2; 0.3; 0.4; and 0.5 (%) Methanol and Aquadest using microwave power 100, 264, 400 and 600 (watts).

2.2. Equipment Design

The design of the biodiesel manufacturing process equipment is as shown in Figure 1. All material on all

pages should fit within an area of A4 (21×29.7 cm), 2.8 cm from the top of the page and ending with 2.4 cm from the bottom.

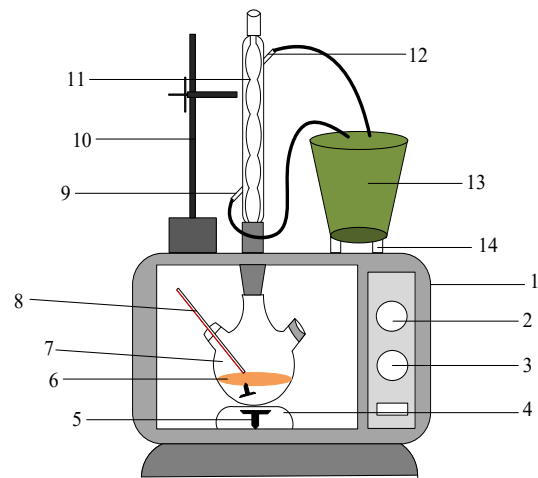


Figure 1. Schematic illustration of microwave reactor for in situ transesterification: 1. Microwave, 2. Power control, 3. Temperature control, 4. Flask holder, 5. Stirring bar, 6. Stirrer, 7. Distiller, 8. Thermometer, 9. Water inlet, 10. Stand, 11. Condenser, 12. Water outlet, 13. Collection Bucket, 14. Support stand

2.3. Preliminary Treatment and Transesterification

Calculate the ratio of palm oil and methanol volume (1:9) according to the specified operating conditions to be reacted, then weigh the catalyst according to the specified variables. Next, mix and stir the catalyst with methanol according to the specified ratio on the stirrer without heating process.

Mixing palm oil into a previously mixed methanol and catalyst solution, then stir until homogeneous. After that, the microwave power is adjusted according to the required variables. The next step is to heat the mixture in the microwave for 2.5 minutes. After the transesterification process is complete, the results of the reaction process are transferred into a separating funnel. The mixture is allowed to sit and cool for 2 hours until two layers are created, with the upper layer being biodiesel and the lower layer consisting of glycerol [13]. This observation is critical for the scalability of microwave-assisted biodiesel production. The optimized reaction time not only improves energy efficiency by reducing processing duration but also ensures product quality by preventing excessive thermal exposure. Hence, from both a kinetic and an economic standpoint, a reaction time of 2.5 minutes under microwave irradiation is considered optimal for biodiesel synthesis from palm oil.

Next, the upper layer (biodiesel) and the lower layer (glycerol) are separated using a separating funnel. Afterward, the biodiesel is rinsed with distilled water at 40 °C to remove any impurities left from the separation process with a volume of 40% of the total volume of the solution approximately 3 times, and left for approximately 2 hours until two more layers are formed that is, the top layer (biodiesel) and the bottom layer (distilled water mixed with impurities). Then, the biodiesel is poured into a sample bottle and heated for 1 hour in an oven at a

temperature of 100 °C. Finally, the biodiesel is cooled to room temperature, weighed to calculate the yield, and its viscosity and density are measured.

Similarly, ZnO has been investigated as a heterogeneous catalyst owing to its unique physicochemical properties. While ZnO may require further modifications or specific reaction conditions to match the catalytic performance of CaO, its stability and potential for surface functionalization make it an attractive alternative. The inherent benefits of these heterogeneous catalysts namely improved catalyst separation, recyclability, and reduced environmental impact present a compelling case for their use in industrial biodiesel production.

In summary, the shift from homogeneous catalysts like NaOH to heterogeneous alternatives such as CaO and ZnO is driven by the need for more sustainable, cost-effective, and environmentally friendly biodiesel production processes. The enhanced ease of recovery and reuse, combined with their effective catalytic properties, underscores the potential of these solid catalysts for scaling up biodiesel production in industrial applications.

2.4. Analysis of Results

2.4.1. Density

Density testing (mass density) was conducted using the pycnometer measurement method. Initially, the empty pycnometer was weighed and its weight recorded. Subsequently, biodiesel was inserted into the pycnometer, and its mass was measured using a digital balance. The sample mass was then calculated using the following formula:

$$\rho = \frac{\text{Mass (pycnomass and sample) - Pycnomass}}{\text{Sample volume}} \quad (1)$$

2.4.2. Viscosity

Viscosity testing is conducted with an Oswald viscometer, which is used to assess the viscosity of the sample. The procedure involves measuring the time it takes for the liquid to flow from point a to point b within the capillary tube. The liquid being tested is placed into the Oswald viscometer, which is positioned on a thermostat, and then drawn into the tube using a pump until it reaches above the a mark. In this study, we employed the Hagen-Poiseuille equation to calculate the dynamic viscosity of the fluid:

$$\eta_D = \frac{\pi P R^4 t}{8 v L} \quad (2)$$

where,

η_D : dynamic viscosity (g/cm.s)

π : mathematical constant (φ)

P : applied pressure (g/cm.s)

R : radius of the capillary tube (cm)

t : time (s)

v : velocity (cm/s)

L : length of the capillary tube (cm)

This equation was then related to the kinematic viscosity and fluid density through Equation (3):

$$\eta_k = \frac{\eta_D}{\rho} \quad (3)$$

where,

η_k : kinematic viscosity (cm²/s)

ρ : density (g/cm³)

This approach enabled us to investigate the relationship between dynamic viscosity, kinematic viscosity, and fluid density, providing valuable insights into the fluid's behavior under various conditions.

2.4.3. Free Fatty Acids

American Oil Chemists Society, FFA concentrations were assessed using the titration technique described by the American Oil Chemists Society, AOCs (1990) by weighing 10 grams of sample into a 250 mL Erlenmeyer flask then adding 50 mL of Neutral Propyl Alcohol. Add 3 drops of phenolphthalein indicator solution to the alcohol, then titrate the solution using 0.1 N KOH in a burette until the sample solution changes to a constant pink color. Record the titration volume reading on the burette and calculate the free fatty acid content (%). The percentage of free fatty acids (FFA) was calculated using Equation (4):

$$\text{Free Fatty Acid} = \frac{V \times T \times M}{w \times 1000} \times 100\% \quad (4)$$

where, V is the volume of KOH (in milliliters), T is the normality of KOH, M is the molecular weight of the fatty acid or methyl ester (in g/mol), and w is the weight of the sample (in grams).

2.4.4. Biodiesel Yield

The biodiesel yield is determined by measuring the volume of biodiesel produced using a measuring cup, followed by division by the volume of raw material utilized (50 mL), and subsequent multiplication by 100% to obtain the resulting percentage yield.

$$\text{Yield} = \frac{\text{Volume of pure biodiesel}}{\text{Volume of feedstock used}} \times 100\% \quad (5)$$

To ensure optimal biodiesel quality, a thermal process is employed to remove excess water and methanol content. Heating the biodiesel to 100 °C enables the evaporation of unwanted water and methanol, thereby ensuring stable and durable biodiesel quality.

3. RESULTS AND DISCUSSION

3.1. The Effect of Power and Concentration On Yield

The power of the microwave used in the production process can affect the yield of biodiesel. Research has shown that increasing the microwave power can increase the yield of biodiesel. This is because higher microwave power can more effectively break down the oil molecules, resulting in a higher yield of biodiesel. However, it is important to note that increasing the microwave power can also increase the reaction temperature, which can affect the stability of the catalyst and the quality of the biodiesel produced. The figure 1. it shows that as the microwave power increases, the yield produced also increases.

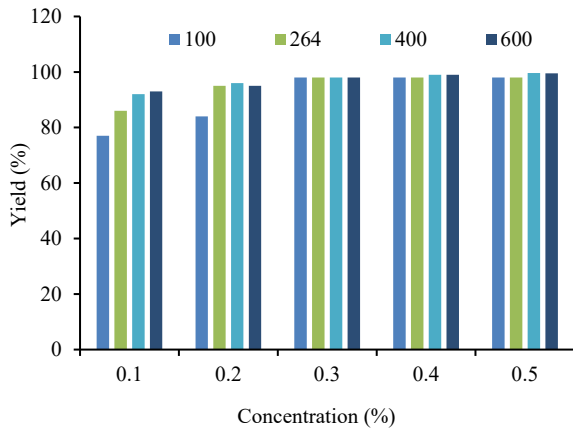


Figure 1. Effect of power on yield of palm oil biodiesel

The increase in yield value is due to the greater power used, where the greater the power, the more triglycerides in palm oil react with methanol and produce more biodiesel. The yield values produced at a catalyst concentration of 0.1% with a power of 100, 264, 400 and 600 watts are 77% and 98%. While the yield values produced at a catalyst concentration of 0.2% with a power of 100, 264, 400 and 600 watts are 98%, and the yield values produced at a catalyst concentration of 0.5 are 98%, 98%, and 99.6% respectively. From these data, it can be seen that the best yield is at a power of 400 watts with a concentration of 0.5% of 99.6%. This is in accordance with the theory that states that increasing the power of microwave waves emitted will increase the biodiesel yield to a certain limit and after reaching that limit, the biodiesel yield will decrease [9]. High concentrations of FFA can react with alkaline catalysts to produce soap rather than biodiesel, which may complicate the separation and purification steps. The formation of soap can result in a reduced biodiesel yield [14]. Microwaves activate the movement of polar molecules and ions, like alcohol, through changes in the magnetic field. This interaction causes rapid rotation of molecules or ions, generating heat and speeding up chemical reactions, leading to higher product yields in less time [15].

3.2. Effect of Power and Concentration on Viscosity

Based on the Figure 2, regarding the impact of power and catalyst concentration on the viscosity of biodiesel, it shows that the NaOH catalyst concentration of 0.1; 0.2; 0.3; 0.4 and 0.5 (%) at 100, 264, 400 and 600 watts of power produced has met SNI 7182-2015 where the kinematic viscosity at a temperature of 40 °C is in the range of 2.3-6.0 cSt.

The viscosity value produced is inversely proportional to the concentration of the catalyst used, meaning that the higher the concentration of the NaOH catalyst, the lower the viscosity value of the biodiesel. This is because the higher the catalyst concentration, the more efficient the transesterification reaction will be, resulting in biodiesel with a lower viscosity value. Using too small a catalyst ratio can negatively impact the reaction, slowing it down and resulting in lower product viscosity. On the other hand, adding too much of a base catalyst is also undesirable, as it can lead to unwanted side reactions during the transesterification process

[16]. The data shows that the biodiesel viscosity is within the SNI range, as expected. This supports the theory that a longer transesterification process lowers viscosity, and increasing catalyst concentration further reduces the viscosity of the resulting biodiesel [17]. Lower viscosity improves fuel flow, atomization, and combustion efficiency, enhancing engine performance [18].

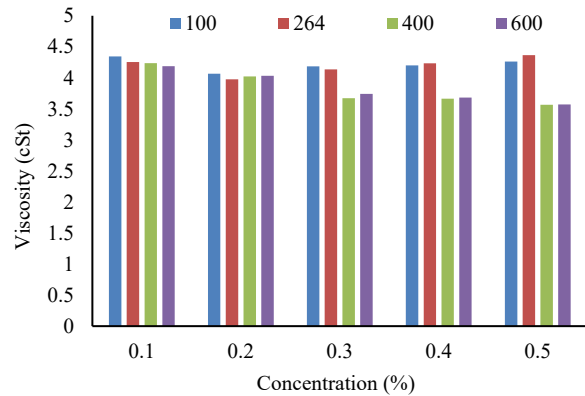


Figure 2. Effect of power on viscosity of palm oil biodiesel

3.3. Effect of Power and Concentration on Density

The density of biodiesel produced from palm oil is significantly affected by the microwave power and catalyst concentration used in the production process. Research has shown that increasing microwave power and catalyst concentration can increase the density of biodiesel, resulting in a higher-quality fuel. However, the optimal combination of microwave power and catalyst concentration must be carefully determined to achieve the desired density and quality of biodiesel.

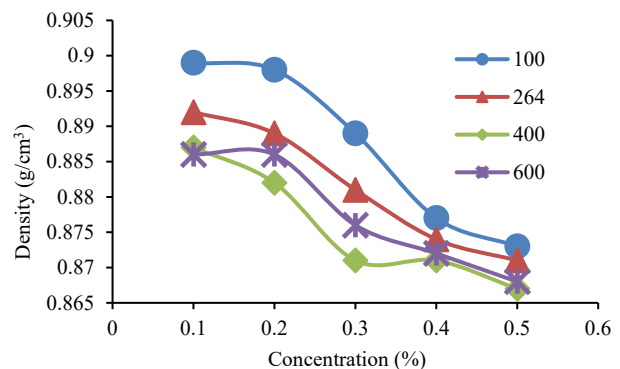


Figure 3. Effect of power on density of palm oil biodiesel

Based on the figure 3, it shows that the density value of palm oil has met SNI 7182:2015 where the density at 40 °C has a range of 0.850-0.890 g/cm3. From the data obtained at 100, 264, 400 and 600 watts of power, the catalyst concentration of 0.1; 0.2; 0.3; 0.4 and 0.5% tends to decrease with increasing microwave power used. The smallest density value obtained was at 400 watts of power of 0.853 g/cm3 and the largest density was 0.881 g/cm3 at 264 watts, meaning that the higher power, the smaller the density value. During the transesterification process, the density of methyl esters decreased as a consequence of transforming triglycerides into methyl esters.

This aligns with the theory that increasing the conversion rate of triglycerides to methyl esters reduces the density of biodiesel, considering that the density of methyl esters is lower when compared to triglycerides [19]. Catalysts play a role in accelerating the reaction rate [20]. An optimal reaction speed will bind glycerol, a byproduct, more quickly. Additionally, the higher the mass percentage of the catalyst (NaOH), the greater the efficiency of the synthesis process from oil to ethyl ester. The fuel composition is a key factor in determining the resulting density. The density value is influenced by the fatty acid content, with saturated fatty acids contributing more to higher density [18].

3.4. Effect of Power Acid Number

The acid number of biodiesel is a critical parameter that affects its quality and stability. Research has shown that the microwave power used in the production process can significantly impact the acid number of biodiesel. Increasing microwave power can lead to a decrease in acid number, resulting in a higher-quality fuel. This is because higher microwave power can more effectively break down the oil molecules, reducing the formation of acidic compounds. However, excessive microwave power can also lead to the formation of unwanted byproducts, which can negatively impact the acid number of biodiesel.

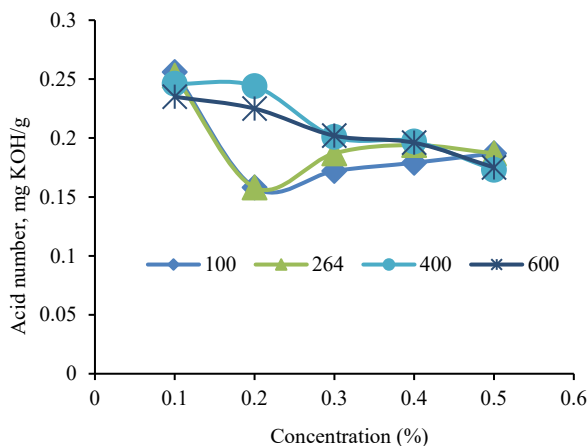


Figure 4. Effect of power on acid number of palm oil biodiesel

Based on Figure 4, it shows that the acid number of biodiesel from palm oil has met SNI 7182:2015 where the acid number has a range of 0.118-0.239 mg KOH/g max or less than 0.5 mg KOH/g. From the data obtained at 100, 264, 400 and 600 watts of power, the catalyst concentration of 0.3%, and 0.5% tends to experience a decrease in acid number with increasing microwave power used. This shows that the higher the power used, the smaller the acid number in biodiesel. While at 100, 264, 400 and 600 watts of power, the catalyst concentration of 0.2% tends to experience an increase in acid number with increasing microwave power used.

This is because if the power used is greater with a low catalyst, the transesterification reaction does not run optimally, and free fatty acids are not sufficiently converted into methyl esters. The smallest acid number value obtained was at 400 watts of power with a

concentration of 0.5% of 0.118 mg KOH/g and the largest acid number was 0.239 at 100 watts of power with a concentration of 0.5%, meaning that the higher the power, the lower the acid number value. Higher microwave power can increase the temperature during the transesterification process, which can accelerate the reaction rate and increase the frequency of collisions between reactant molecules. With increasing temperature, the chance of methyl ester formation becomes greater, which contributes to reducing the amount of free fatty acids in biodiesel [21].

3.5. Gas Chromatography Mass Spectroscopy (GCMS) Analysis of Methyl Ester Products

Methyl ester products from palm oil with methanol through a transesterification reaction with the help of a NaOH catalyst, identification of saturated and unsaturated fatty acids which successfully formed ester bonds can be seen in the chromatogram as in Figure 5. To identify and confirm the formation of methyl ester products from the results of the transesterification reaction, gas chromatography analysis. The test results show the methyl ester composition of various fatty acids contained in palm oil [10].

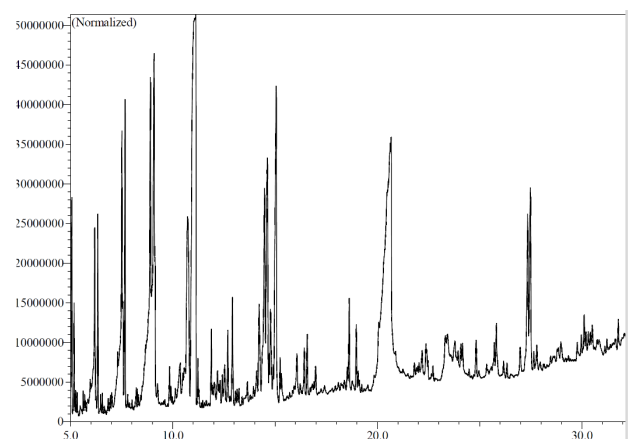


Figure 5. Results of gas chromatography analysis of methyl ester products

Figure 5 shows the results of Gas Chromatography-Mass Spectrometry (GC-MS) analysis show that the synthesis of biodiesel from palm oil successfully produces methyl esters from various fatty acids. The chromatogram obtained under optimal conditions, namely 400 watts of power and 2.5 minutes of reaction time with a catalyst concentration of 0.5%, shows seven methyl ester peaks. The GC-MS analysis revealed 7 significant peaks corresponding to methyl ester products, indicating the successful conversion of palm oil into biodiesel. The chromatogram showed that the methyl esters formed as biodiesel products comprised saturated fatty acids, including caproic acid (C6:0) with a retention time of 6.18 min, capric acid (C10:0) of 7.51 min, lauric acid (C12:0) of 8.71 min, myristic acid (C14:0) of 9.08 min, palmitic acid (C16:0) of 10.77 min, and stearic acid (C18:0) of 15.05 min. Furthermore, unsaturated fatty acids were also detected, including oleic acid (C18:1) with a retention time of 20.07 min, linoleic acid (C18:2) 25.08 min, and linolenic acid (C18:3) of 27.48 min.

The results demonstrate that palm oil can be efficiently converted into biodiesel with microwave heating, which accelerates the reaction process and reduces catalyst usage [10, 21], resulting in a purity of over 99%. This finding has significant implications for the development of sustainable and efficient methods for biodiesel production, particularly in reducing greenhouse gas emissions and mitigating climate change. The biodiesel content was determined based on the area of methyl esters detected as biodiesel products relative to the total area analyzed in the GC test. Notably, the power used in the biodiesel synthesis process significantly impacted the yield of methyl esters. A higher power input resulted in a greater conversion of triglycerides to methyl esters, as reflected in the yield values obtained, with the highest yield achieved at 400 watts.

4. CONCLUSION

This study shows that microwave power and NaOH catalyst concentration have a significant effect on the quality of biodiesel from palm oil. At lower power (100 watts) with a catalyst concentration of 0.2%, the yield produced is lower (84%) with a density of 0.880 g/cm³ and a viscosity of 5.01 mm²/s, approaching the upper limit of the SNI viscosity standard. An increase in power of 264 watts and a catalyst concentration of 0.5% increases the yield to 98%, with a density of 0.877 g/cm³ and a viscosity of 4.12 cSt, which is more optimal. These results prove that the combination of higher power and catalyst concentration produces a more efficient reaction and better quality biodiesel at 2.5 minutes. The best condition for biodiesel production from palm oil was achieved at 400 watts of microwave power with a NaOH catalyst concentration of 0.5%, producing the highest yield of 99.6%.

The resulting biodiesel had a density of 0.853 g/cm³, a viscosity of 4.689 cSt, and an acid number of 0.118 mg KOH/g, the SNI 7182:2015 standard. Therefore, 400 watts of microwave power and 0.5% catalyst concentration are the optimal combination for producing biodiesel with quality that meets national standards.

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REFERENCES

- [1] D. Huang, H. Zhou, L. Lin, "Biodiesel: An Alternative to Conventional Fuel", *Energy Procedia*, Vol. 16, No. 3, pp. 1874-1885, 2012.
- [2] A.T. Hoang, V.V. Pham, X.P. Nguyen, "Integrating Renewable Sources into Energy System for Smart City as a Sagacious Strategy Towards Clean and Sustainable Process", *J. Clean. Prod.*, Vol. 305, p. 127161, 2021.
- [3] V.G. Nguyen, M.T. Pham, N.V.L. Le, H.C. Le, T.H. Truong, D.N. Cao, "A Comprehensive Review on The Use of Biodiesel for Diesel Engines", *Int. J. Renew. Energy Dev.*, Vol. 12, No. 4, pp. 720-740, 2023.
- [4] M.M. Rana, M.M. Al Mueed, M.N. Islam, M.H. Ali, "Production and Analysis of Biodiesel from Mango Seed Kernels and Tamarind Seeds Using Hybrid Approach of Solvent Extraction and Transesterification", *Results Eng.*, Vol. 25, No. 2, p. 103983, 2025.
- [5] A. Suryanto, H.W. Zakir Sabara, H. Ismail, A. Artiningsih, U. Zainuddin, A. Almukmin, U. Nurichsan, F.W. Niswah, "Production Biodiesel from Kapok Seed Oil Using Ultrasonic", *IOP Conf. Ser. Earth Environ. Sci.*, Vol. 175, No. 1, 2018, "Production Biodiesel from Kapok Seed Oil Using Ultrasonic", *IOP Conf. Ser. Earth Environ. Sci.*, Vol. 175, No. 1, 2018.
- [6] Z. Mayandi, Suharjito, "Palm Oil-Based Biodiesel Industry Sustainability Model using Dynamic Systems to Balance Food, Energy, and Export Allocations", *Smart Agric. Technol.*, Vol. 7, p. 100421, 2024.
- [7] K.S. Chen, Y.C. Lin, K.H. Hsu, H.K. Wang, "Improving Biodiesel Yields from Waste Cooking Oil by Using Sodium Methoxide and a Microwave Heating Ystem", *Energy*, Vol. 38, No. 1, pp. 151-156, 2012.
- [8] H.S. Kusuma, M. Mahfud, "The extraction of Essential Oils from Patchouli Leaves (*Pogostemon Cablin Benth*) Using a Microwave Air-Hydrodistillation Method as a New Green Technique", *RSC Adv.*, Vol. 7, No. 3, pp. 1336-1347, 2017.
- [9] M. Mahfud, A. Suryanto, L. Qadariyah, S. Suprpto, H.S. Kusuma, "Production of Methyl Ester from Coconut Oil Using Microwave: Kinetic of Transesterification Reaction Using Heterogeneous CaO Catalyst", *Korean Chem. Eng. Res.*, Vol. 56, No. 2, pp. 275-280, 2018.
- [10] A. Suryanto, T. Arief, F. Firman, "Microwave-Assisted Transesterification For Biodiesel Production: Catalyst Activity Of Ca/Na/ γ -Al₂O₃ Derived From Egg Shells", *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, Issue 61, Vol. 16, No. 4, pp. 70-76, December 2024.
- [11] C. Victoria, K. Tochukwu, "Optimized Biodiesel Production From Palm Kernel And *Jatropha Curcas* Oil Blend Using KOH-Supported Calcined Animal Bone Catalyst : A Response Surface Methodology And Genetic Algorithm-Bayesian Hybridization", *Cleaner Chemical Engineering*, Vol. 11, 2024.
- [12] E.M. Shahid, Y. Jamal, "Production of Biodiesel: A Technical Review", *Renew. Sustain. Energy Rev.*, Vol. 15, No. 9, pp. 4732-4745, 2011.
- [13] N. Kapilan, B.D. Baykov, "A Review On New Methods Used For The Production Of Biodiesel", *Pet. Coal*, Vol. 56, No. 1, pp. 79-86, 2014.
- [14] M.D. Asfaw, A.T. Yadeta, B.G. Yewalie, Y.W. Negash, "Production And Characterization Of Biodiesel From Argemone Mexicana Seed Oil", *Results Chem.*, Vol. 13, 2024.
- [15] N. Azcan, A. Danisman, "Alkali Catalyzed Transesterification Of Cottonseed Oil By Microwave Irradiation", *Fuel*, Vol. 86, No. 1, pp. 2639-2644, 2007.
- [16] R. Hartono, W. Pamungkas, "The Effect of NaOH Catalyst Ratio on Biodiesel Manufacturing from Off Grade CPO", *World Chem. Eng. J.*, Vol. 4, No. 2, pp. 56-61, 2020.
- [17] J.B. Tarigan, et al., "Microwave-Intensified

Esterification Of High-Free Fatty Acid Feedstock Into Biodiesel Using Waste Chicken Eggshells As A Heterogeneous Catalyst”, Case Stud. Chem. Environ. Eng., Vol. 11, pp. 101-107, 2025.

[18] D. Hari, T. Prasetyo, N. Ilminnafik, M. Trifiananto, A. Sanata, “Study of the Effect of NaOH Type Alkaline Catalyst on The Physicochemical Characteristics of Used Cooking Oil Biodiesel”, Vol. 12, No. 3, 2024.

[19] A.S. Elgharbawy, A.I. Osman, A.G.M. El Demerdash, W.A. Sadik, M.A. Kasaby, S.E. Ali, “Enhancing Biodiesel Production Efficiency With Industrial Waste-Derived Catalysts: Techno-Economic Analysis Of Microwave And Ultrasonic Transesterification Methods,” Energy Convers. Manag., Vol. 321, No. 1, pp. 118-945, 2024.

[20] A. Suryanto, M. Munira, "Kinetic Isotherm Adsorption Modelling In Ammonium Removal Process”, International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 59, Vol. 16, No. 2, pp. 261-268, June 2024.

[21] A. Suryanto, S. Suprpto, M. Mahfud, “Production Biodiesel From Coconut Oil Using Microwave: Effect Of Some Parameters On Transesterification Reaction By NaOH Catalyst”, Bull. Chem. React. Eng. Catal., Vol. 10, No. 2, pp. 162-168, 2015.

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