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Production of Biodiesel from Sunflower Oil using Base Catalysts

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A B S T R A C T

The reduction of petroleum reserves is a severe problem faced by many countries. With the help of the rapid development of science and technology, vegetable oil can not only be consumed. Still, it can also be processed into something with more value, one of which is biodiesel. Biodiesel is a clean, renewable fuel and can be used as the best substitute for diesel fuel. This study aims to provide a comprehensive overview of the development of research related to the production of biodiesel from sunflower oil using base catalysts. This research was conducted using the transesterification reaction method with the help of catalysts. Then, the biodiesel yield from sunflower oil can be influenced by several factors, including the amount of catalyst, reaction temperature, reaction time, stirring speed, and molar ratio between methanol and oil. Based on the research, several tests were carried out. The first test was based on the influence of stirring speed, and the results showed that the faster the stirring, the more biodiesel yield. The second test was based on the effect of reaction time, and the results showed that the reaction time could not significantly increase the biodiesel yield. The third test was based on the impact of the molar ratio of methanol and oil, and the results showed that the optimum ratio could help drive the transesterification reaction towards the product. The fourth test was based on the effect of KOH solution concentration on biodiesel yield, and the results showed that using the optimum catalyst can increase the efficiency of the transesterification reaction. The fifth test was based on the effect of reaction temperature, and the results showed that at high temperatures (60°C) methanol mixes more easily with oil so that the biodiesel formation reaction takes place faster. From the results of this study, it can be concluded that sunflower oil can be used as one of the ingredients in making biodiesel.

Contribution to Sustainable Development Goals (SDGs):
SDG 7: Affordable and Clean Energy
SDG 9: Industry, Innovation, and Infrastructure
SDG 12: Responsible Consumption and Production
SDG 13: Climate Action

1. INTRODUCTION

The depletion of petroleum reserves is a severe problem faced by many countries, including Indonesia. In Indonesia, the production of fuel oil (BBM) is only 261 million barrels, with an installed oil refinery capacity of 1.17 million bpd (barrels per day) in 2022. Meanwhile, fuel consumption in Indonesia is 37 million tonnes of oil equivalent (TOE) [1].

Some of the government's efforts to overcome dependence on petroleum (non-renewable energy) are to utilize Renewable Energy and New Energy, such as ocean energy, geothermal, bioenergy, wind, hydro, and solar [1]. Below is the potential and utilization of renewable energy in Indonesia in 2022.

Bioenergy is energy derived from biological organisms or organic materials. In general, bioenergy produces three types of energy sources, namely, biofuels (biodiesel and bioethanol), biogas, and solid biomass (wood chips, briquettes, and agricultural residues) [2]. The potential of bioenergy in Indonesia

in 2022 reached 57 GWe, consisting of 52.1 GWe biomass, 1.3 GWe POME (Palm Oil Mill Effluent), 1.4 GWe waste, and 2.3 GWe biogas [1].

Table 1. Potential and Utilisation of Renewable Energy in Indonesia in 2022

Type of Renewable Energy	Potential (GW)	Utilization	% Utilization
Sea	63	-	-
Geothermal	23	2.4	10.3%
Bioenergy	57	3.1	5.4%
Wind	155	0.2	0.1%
Hydro	95	6.7	7%
Sun	3.294	0.3	0.01%
Total	3.687	12.6	0.3%

Source: Directorate General Renewable-New Energy and Conservation Energy 2023 cit. National Energy Council, 2023

Figure 1. Map of Bioenergy Distribution in Indonesia
Source: Directorate General Renewable-New Energy and Conservation Energy 2022 cit. National Energy Council, 2023

Biodiesel is an alkyl ester (FAME (Fatty Acid Methyl Ester)) of long-chain fatty acids (C14-C24) synthesized from plant or animal lipids, such as vegetable oils, animal fats, and even used cooking oil [3]. In Indonesia, most biodiesel comes from palm oil, amounting to 11.81 million kilolitres out of an installed plant capacity of 17.14 million in 2022 [4]. Meanwhile, biodiesel consumption in the second quarter of 2024 was 6.2 million kilolitres [5].

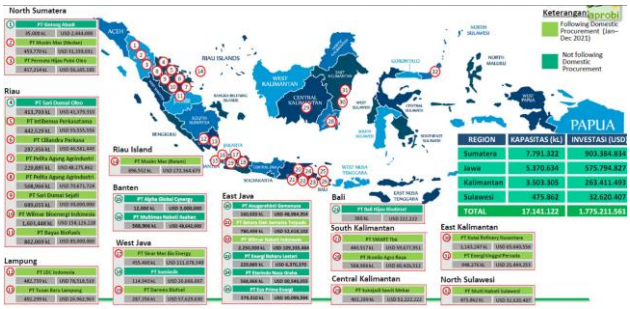

Figure 2. Distribusi Produsen Biodiesel di Indonesia
Source: Indonesian Biodiesel Producers Association cit. Palm Oil Agribusiness Strategic Policy Institute, 2024

Transesterification is the most widely used method to produce biodiesel. A transesterification reaction is a reaction between lipids and short-chain alcohol, such as methanol or ethanol, at a specific temperature with the help of a catalyst.

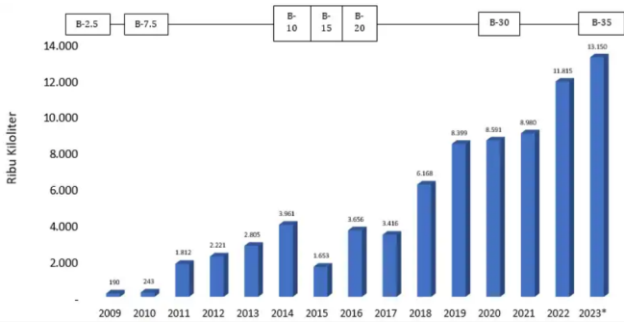

Figure 3. Development of Indonesia's Biodiesel Production
Source: Indonesian Biodiesel Producers Association cit. Palm Oil Agribusiness Strategic Policy Institute, 2024

Biodiesel is a clean, renewable fuel and has recently been considered the best substitute for diesel fuel as it can be used in diesel cycle engines with or without modification. Biodiesel is easy to use, biodegradable, non-toxic, and essentially free of sulphur and aromatic compounds. Biodiesel is commonly used as a diesel fuel oil additive to reduce the concentration of particulates, carbon monoxide, hydrocarbons, and pollutants in diesel vehicles [6] or can also be used as B100 (100% biodiesel) [7]. When used as an additive, the resulting diesel fuel can be referred to as B5, B10, B20, B30, B35, and B40. The number is the percentage of biodiesel mixed with diesel fuel oil. For example, B5 means that biodiesel and diesel fuel oil are combined in a ratio of 5:95 to produce a B5 biodiesel product [8].

Biodiesel is produced through a process in which oil is reacted with an alcohol (ethanol or methanol) assisted by catalysts (homogeneous (alkali and acid), heterogeneous (acid and base), and enzymatic (biocatalyst [10]) [9] to form ethyl or methyl esters. The resulting ethyl or methyl esters can be blended with conventional diesel fuel or used as a pure fuel (100% biodiesel) [6].

Biodiesel can be produced in several ways, namely [6,10]:

1. Direct transesterification of oils or fats catalyzed by alkali or heterogeneous catalysts (If free fatty acids (FFA) < 2.5%);
2. Acid-catalyzed esterification of oil or fat followed by transesterification (If FFA > 2.5%);
3. Conversion of oils and fats into their fatty acids and then into biodiesel;
4. Direct use and blending: direct use means that vegetable oil is used directly as diesel fuel without going through any process while blending means that vegetable oil is mixed directly with diesel fuel at a specific ratio;
5. Microemulsions, a technique of mixing vegetable oils or animal fats with solvents, surfactants, or co-surfactants to produce thermodynamically stable disperse fuels; and
6. Thermal cracking, or pyrolysis, is a process that uses high temperatures to break down triglycerides into smaller molecules.

Stoichiometrically, three moles of light-phase alcohol react with one mole of triglyceride to produce alkyl esters (biodiesel) and glycerol as a by-product. This reaction occurs at a temperature of 60-70℃, 1 atm, for 90 minutes [10]. The transesterification reaction can be seen in **Figure 4**.

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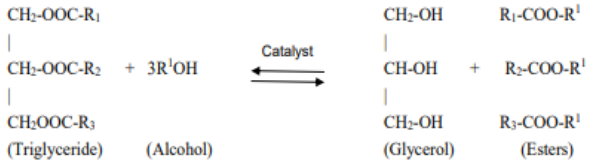

Figure 4. Transesterification Reaction
Source: [11]

Transesterification is a reversible reaction, hence, alcohol must be in excess so that the reaction can progress. After the reaction, the unreacted alcohol can be reused within certain limits, and the resulting glycerol must be separated to improve the quality of biodiesel and prevent the formation of harmful gases, namely acetaldehyde or formaldehyde when burning biodiesel [10]. Catalysts are essential in biodiesel production because they determine the reaction conditions, feedstock limitation conditions, and post-separation conditions [11].

The feedstocks for biodiesel production are vegetable oils and animal fats. In vegetable oils, the most common feedstocks used to produce biodiesel are soya oil, rapeseed oil, palm oil, coconut oil, jatropha, canola oil, corn oil, sunflower oil, mustard oil, hemp oil, flaxseed oil, rubber seed oil, neem seed oil, champagne seed oil, nyamplung seed oil, kepayang seed oil, kapok seed oil, microalgae, kemiri sunan oil, olive oil, safflower oil, and feun kase seed oil, animal fats, namely beef fat, pork fat, and fish oil [12, 13, 14, 15, 16, 17, 18, 19].

Sunflower (*Helianthus annuus L.*) belongs to the Asteraceae family. Sunflower oil contains unsaturated fatty acids, namely linoleic acid, as much as 44-72%, and oleic acid, as much as 14-43%. As for saturated fatty acids, palmitic acid is 4-9%, and stearic acid is 1-7%. The oil content in sunflower seeds is quite large, at around 48%-52%. On the other hand, the high oil content of sunflower seeds can be utilized as an alternative fuel to petroleum, namely biodiesel. Sunflower oil is a triglyceride composed of fatty acids and glycerol with a long carbon chain. Sunflower seeds also contain 45%-50% lipids, making it possible to be used as an alternative fuel [20].

Table 2. Sunflower oil composition

Fatty Acids	Chemical Formula	Metil Ester
Palmitic acid (C16:0)	$C_{16}H_{32}O_2$	Methyl palmitate
Stearic acid (C18:0)	$C_{18}H_{36}O_2$	Methyl stearate
Oleic acid (C18:1)	$C_{18}H_{34}O_2$	Methyl oleate
Linoleic acid (C18:2)	$C_{18}H_{32}O_2$	Methyl linoleate
Linolenic acid (C18:3)	$C_{18}H_{30}O_2$	Methyl linolenate

Source: [11]

Table 3. Physical Properties of Sunflower Oil

Properties	Value
Density @26℃ (kg/m^3)	918
Viscosity @26℃ (mm^2/s)	34
Flashpoint (℃)	220
Calorific value (kJ/kg)	39500
Acid value	0,15
Cetane number	36
Iodine value/100 grams	135

Source: [21,22]

A catalyst is a substance that can accelerate the rate of reaction. The catalyst is not permanently involved in the response, so at the end of the reaction, the catalyst does not join the reaction compound. The catalyst is obtained with the same mass when the reaction is complete. In the transesterification process, five types of catalysts are commonly used: homogeneous base catalysts, homogeneous acid catalysts, heterogeneous base catalysts, heterogeneous acid catalysts, and enzymatic catalysts [3].

Homogeneous base catalysts are most often used in the transesterification process because they are easy to obtain and low cost and can react 4000 times faster than homogeneous acid catalysts. Still, homogeneous base catalysts such as KOH and NaOH are less effective if the oil contains high moisture and FFA content. Homogeneous acid catalysts have several advantages, namely having higher effectiveness than homogeneous base catalysts if the FFA concentration is high (>6%) so that its performance is not affected by the presence of FFA in the raw material so it is suitable for used cooking oil raw materials (used cooking oil and animal fat), for example, HCl and H_2SO_4 [9].

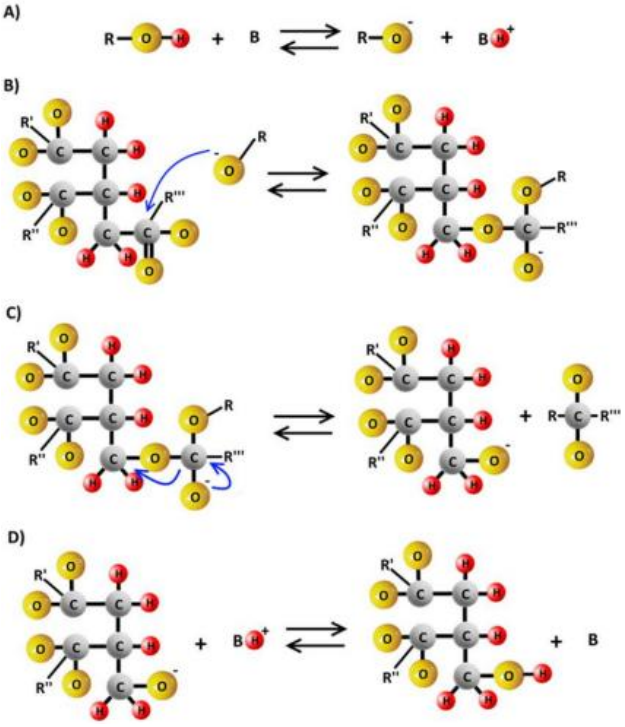

Figure 5. Schematic Steps of Base-catalyzed transesterification
Source: [10]

Figure 5 shows the schematic steps of the esterification reaction by base catalyst. The steps are: [10]

a. Alcohol activation
   - Bases (B) such as KOH and NaOH react with alcohol (R-OH) to produce alkoxide ions (R-O-) and H+ ions which combine with the base.
   - Reaction: R-OH + B ↔ R-O- + B-H+ (alkoxide ions are nucleophiles that will attack triglyceride molecules)

b. Nucleophilic substitution on triglycerides
   - Alkoxide ions (R-O-) attack carbonyl groups on triglycerides (R'-COOR"), forming tetrahedral intermediate compounds.
   - Reaction: R-O- + R'-COOR" → Intermediate (The intermediate compound is unstable, so it will decompose)

c. Ester formation and alcohol release
   - The tetrahedral intermediate will decompose into alkyl esters (biodiesel, R'-COOR'") and alcohol molecules (R-OH).
   - Reaction: Intermediate → R'-COOR'" + R"-OH

d. Base regeneration and end-product formation
   - The base (B) used at the beginning of the reaction is regenerated so that it can be reused in the following process.
   - The final products of this reaction are biodiesel (alkyl esters) and glycerol (by-product).

Heterogeneous catalysts are in a different phase or state from the reactants. Heterogeneous catalysts have advantages, including ease of purification and if reused will be superior to homogeneous catalysts while the disadvantages are increased temperature and a higher oil-to-alcohol ratio than homogeneous catalysts. Heterogeneous catalysts are also divided into two types, namely heterogeneous acids and bases. Heterogeneous catalysts in solid bases such as CaO, MgO, SrO, and BaO are often used, while heterogeneous acid catalysts commonly used are Tungsten oxide, Zn-Cr oxide, and silica [9].

Biocatalysts or enzymatic catalysts are obtained from living organisms that promote chemical reactions without affecting themselves chemically. The advantages of enzymatic catalysts, namely reducing energy consumption and unwanted by-products (soaps and polymer pigments) that can inhibit the separation of methyl esters and glycerol, can be used on a variety of triglyceride sources with a range of FFA 0.5-80%, moderate process temperatures (35-45 ℃), and catalysts can be reused, but the use of enzymes as catalysts requires high costs. Enzymatic catalysts are divided into two types, namely extracellular lipase and intracellular lipase [9].

Based on the explanation above, we will compare the use of NaOH and KOH catalysts in making biodiesel with sunflower oil.

2. MATERIALS AND METHODS

This study uses the literature review method, which is a research method that can provide an overview of the development of a particular topic, which includes collecting literature from research related to the focus of the study, analyzing and synthesizing data, interpreting data, and drawing conclusions. This method provides a comprehensive overview of research development related to Biodiesel Production from Sunflower Oil using CaO, KOH, K_2CO_3, K_2O/RGO, CH_3ONa, NaOH, and BaO catalysts.

Biodiesel production uses the transesterification reaction method, which generally requires the oil to be heated to a predetermined temperature before the reaction stage is carried out. Then, the methanol and catalyst are added simultaneously and stirred at a speed of 400 rpm with a predetermined reaction time duration. After the reaction time is reached, proceed to the deposition stage for 24 hours until the reactants are divided into two layers, namely methyl ester and glycerol. After the layers are formed, separate the methyl esters from the by-products, namely glycerol. The methyl ester obtained is then washed with hot water at 70°C, which aims to dissolve methanol and catalyst so that the main product, methyl ester, is obtained. The washed methyl ester is then continued to the purification stage in a set of distillation equipment to obtain biodiesel with high purity.

3. RESULT AND DISCUSSION

Based on research conducted by several researchers using several different catalysts and several variables obtained

Table 4. Biodiesel Yield from Sunflower Oil with Different Catalysts

Catalysts	Yield (%)	Catalyst Amount (wt%)	Temperature (°C)	Reaction Time (minute)	Stirring Speed (rpm)	Molar Ratio Methanol : Oil	Microwave Power (watt)	KOH Solution Concentration (%)	Reference
	76				200				
	82				400				
	88	1			600				
	94				800				
	100				1000				
	78				200				
	85				400				

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Catalysts	Yield (%)	Catalyst Amount (wt%)	Temperature (°C)	Reaction Time (minute)	Stirring Speed (rpm)	Molar Ratio Methanol : Oil	Microwave Power (watt)	KOH Solution Concentration (%)	Reference
CaO	90	2			600				32
	97				800				
	100				1000				
	74				200				
	81				400				
	87	3			600				
	92				800				
	99				1000				
	67				200				
	73				400				
	80	4			600				
	86				800				
	92				1000				
	55				200				
	62	5			400				
	68				600				
	73				800				
	80				1000				
KOH	93.67			10			300		28
	95.01						600		
	95.45						900		
	95.5			20			300		
	96.35						600		
	92.89						900		
	96.76			30			300		
	97.72						600		
	90.58						900		
K2CO3	62.1					3:1			27
	95.3					6:1			
	94.2					9:1			
	93.1					12:1			
K2O/RGO	30							0,5	29
	90							1	
	80							2	
	82							8	
	68							10	
CH3ONa	89.35	1							30
	93.9	2							
	94.33	3							
	92.17	4							
	80.4	5							
NaOH	70		50	70					20
	73.5		55						
	74.6		60						
	67.5		65						
	72		50	80					
	75		55						
	77.8		60						

Catalysts	Yield (%)	Catalyst Amount (wt%)	Temperature (°C)	Reaction Time (minute)	Stirring Speed (rpm)	Molar Ratio Methanol : Oil	Microwave Power (watt)	KOH Solution Concentration (%)	Reference
BaO	68.2		65	90					31
	73.4		50						
	76		55						
	80.1		60						
	69		65						
	55.8			60					
	58.12		60	120					
	62.5			180					
	56.26			240					
	57.8			60					
	63.24		65	120					
	68.81			180					
	71.36			240					
	61.3			60					
	66.8		70	120					
	72.53			180					
	78.38			240					

The yield content is a percentage that states the product produced from the amount of raw material fed. The yield obtained in biodiesel production is influenced by several factors: the amount of catalyst, reaction temperature, reaction time, stirring speed, and the molar ratio between methanol and oil.

Stirring speed is essential in biodiesel production because it affects the homogeneity of the mixing between oil and alcohol and the effectiveness of contact with the catalyst. If the stirring speed is too low, the oil and alcohol cannot mix well, and the contact between the reactants and the catalyst is less effective, so many triglycerides have not reacted, causing the yield of biodiesel produced to be lower. However, if the stirring is too fast, an emulsion will form, making it challenging to separate biodiesel and glycerol, and increasing by-products (soap) can reduce biodiesel quality.

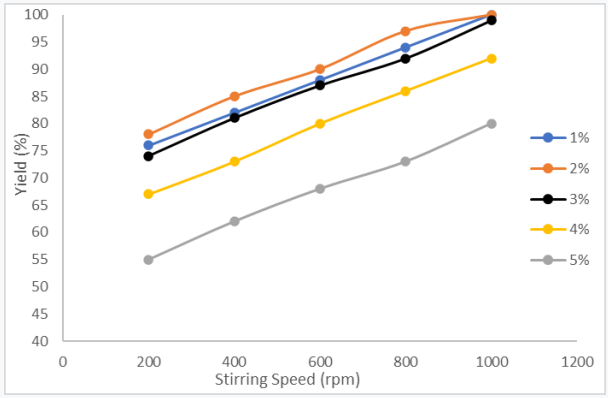

Figure 6. Effect of Catalyst Amount and Stirring Speed on Biodiesel Yield

In **Figure 6**, it can be seen that the faster the stirring, the higher the biodiesel yield. This is because, with optimal stirring speed, the contact between oil, alcohol, and catalyst will increase so that the reaction runs efficiently and produces a high biodiesel yield. In addition, emulsion formation between biodiesel and alcohol does not occur significantly, so the separation between biodiesel and glycerol is more straightforward, which increases biodiesel yield. The highest yield was obtained at 1 wt% and 2 wt% catalyst with a stirring speed of 1,000 rpm, which was 100%, while the lowest yield levels were obtained at 5% catalyst with a stirring speed of 200 rpm, 55%. The low yield at the 5 wt% catalyst amount, when compared to other catalyst amounts with the same stirring speed, may be due to the catalyst being used excessively, causing side reactions (saponification reactions) with free fatty acids in the oil.

To be able to reduce the use of solvents (methanol) and faster heating rates so that heating is more evenly distributed and quicker reaction times than using conventional heaters, microwaves can be used [28]. Microwave heating utilizes microwave radiation to generate heat that can extract various mixtures, including inert compounds, at high temperatures. The electrical power influences the heat and heating rate generated by the microwave. This power will determine how quickly and effectively the heat is absorbed by the reactants (oil and methanol), thus affecting the biodiesel yield.

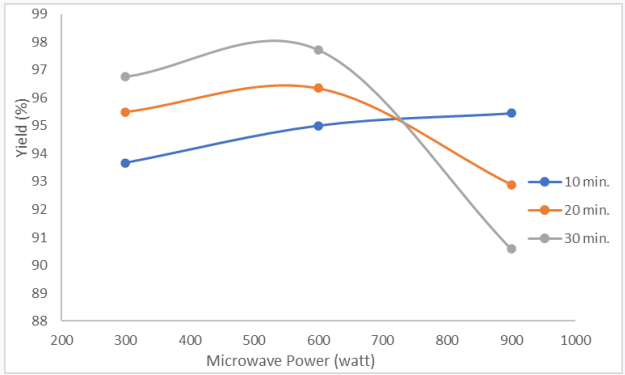

Figure 7. Effect of Microwave Power and Reaction Time on Biodiesel Yield

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In **Figure 7**, it can be seen that in each variation of reaction time, there was an increase in biodiesel yield from 300 watts to 600 watts, with the highest yield achieved in the 30-minute reaction time variation with 600 watts of power, which was 97.72%. The increase in yield can occur because giving time to absorb microwave energy in the extraction system can also trigger more extended thermal accumulation in the reactants (methanol and sunflower oil). Extending the reaction time in transesterification can affect the absorbed microwave exposure so that the heating becomes efficient (fast and evenly distributed) and accelerates the conversion of oil into biodiesel. However, the decrease in yield when the power is 900 watts occurs at a reaction time of 20 minutes and 30 minutes, with the lowest result obtained when the reaction time is 30 minutes, which is 90.58%. It can be concluded that extending the microwave reaction time cannot significantly increase the biodiesel yield from sunflower seed oil. This is because greater power will affect the absorption of microwaves to sunflower seed oil. Hence, the heating rate is high, and the results are inversely proportional, where the resulting yield levels will decrease. Too much power increases the heating rate, and the temperature rises too fast, so the triglycerides produced will increase in conversion. Still, the oil quality will be below standard and damaged (degraded), and it can even trigger side reactions (saponification). However, in the 10-minute reaction time variation, as the microwave power increased, the resulting yield levels also increased, which may be due to the reaction time being too short and the reaction not reaching optimal conditions so that there are still many triglycerides that have not been fully converted into biodiesel.

In biodiesel production, the molar ratio between methanol and oil is a key factor in the transesterification process, affecting reaction efficiency and biodiesel yield. Ideally, the transesterification reaction requires 3 moles of ethanol for every 1 mole of triglyceride, but in practice, higher ratios are often used to increase biodiesel conversion. An optimum molar ratio between methanol and oil (slightly over the stoichiometric ratio) helps to push the reaction towards the product so that the entire oil can react and increase biodiesel production. Also, it results in better phase separation between biodiesel and glycerol and improved product purity. However, if the molar ratio between methanol and oil is too low, causing the triglycerides to not fully react so that there is still a lot of oil left in the mixture, the biodiesel yield is less, and the reaction rate decreases, so the reaction time becomes longer.

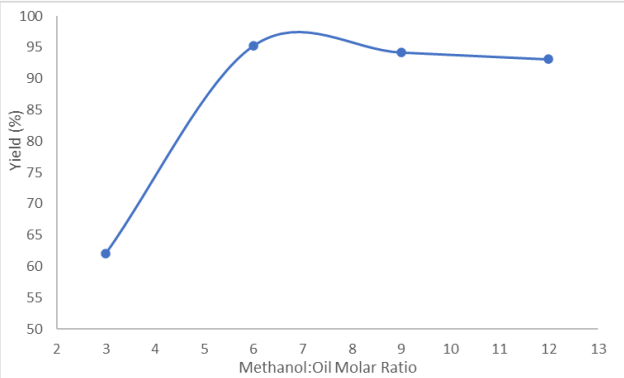

Figure 8. Effect of Methanol-to-Oil Molar Ratio on Biodiesel Yield

In **Figure 8**, it can be seen that there is an increase in yield from a 3:1 to a 6:1 molar ratio, and the 6:1 molar ratio produces the highest biodiesel yield of 95.3%. This means that the 6:1 molar ratio is the optimum methanol-to-oil molar ratio, so almost all the oil reacts and produces high yields. However, above the 6:1 ratio, the yield continues to decrease and reaches its lowest point at a molar ratio of 12:1 with a yield of 93.1%. This is due to the high molar ratio, which results in too much methanol in the biodiesel mixture. It can cause emulsions to form so that the glycerol cannot settle properly, making it difficult to purify the biodiesel.

Apart from being a catalyst, KOH can also be used to increase the activity of heterogeneous catalysts [29]. KOH was used in the synthesis of K_2O/RGO catalysts as a catalyst activator by increasing the surface area of RGO so that it has more active sites so that the efficiency of the transesterification reaction rises, helping to disperse (evenly distribute) K_2O on the surface of RGO (impregnation), creating a porous structure on RGO that can increase the active area of the catalyst so that the reaction is more effective, and improving the basic properties of the K_2O catalyst.

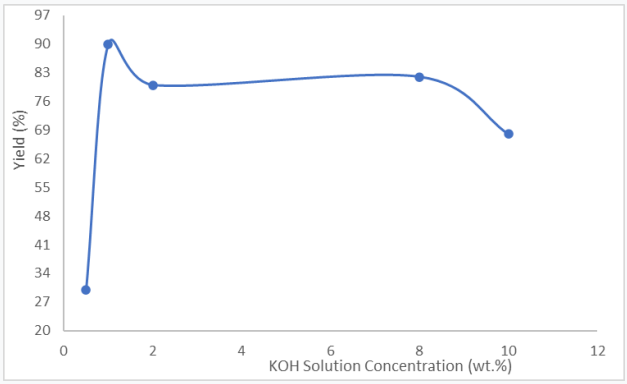

Figure 9. Effect of KOH Solution Concentration on Biodiesel Yield

Figure 9 shows an increase in biodiesel yield levels from 0.5% to 1% concentration, with 1% concentration giving the highest result, which is 90%, which means that the optimal concentration is at 1% concentration. At a concentration of 2%, there was a decrease in yield levels, but the yield levels increased again at 8%. This may be due to a less than optimal dispersion at 2% concentration or a change in catalyst structure that reduces the effectiveness of active sites, but at 8% concentration there is a possibility of reconstructing the catalyst structure (even though the amount of KOH is more) so as to reopen or increase the active sites or areas of the catalyst, at a concentration of 2% the catalyst is not strong enough to accelerate transesterification to the maximum but the saponification reaction has started so as to reduce the yield level, However, at a concentration of 8%, although the saponification reaction still occurs, the increase in the amount of active catalyst can offset the saponification reaction so that the yield level increases again, at a concentration of 2%, there is a possibility that the catalyst begins to experience initial aggregation so as to reduce the specific surface area and reduce the effectiveness of the catalyst, but at a concentration of 8%, an increase in the amount of KOH helps redistribute the catalyst or increase solvation so that more reactions take place. Further investigation using XRD, BET, and SEM/TEM can be done to find out the exact cause. Then, the yield level decreased again at a concentration of 10%, this was caused by too much base that

caused the catalyst clumping to be more dominant and reduced the active surface area, the saponification reaction increased and reduced the biodiesel yield level, and too high a concentration of KOH can change the porous structure of RGO and cause a reduction in the number of active sites, thus reducing the efficiency of the catalyst.

In biodiesel production, the amount of catalyst affects the biodiesel yield because catalysts play a role in accelerating the transesterification reaction. In optimum amounts, using catalysts can increase the efficiency of the transesterification reaction, thereby increasing the biodiesel yield. However, if the amount of catalyst is too small, the oil conversion into biodiesel becomes less optimal, so the biodiesel yield is lower, and the reaction time required is longer.

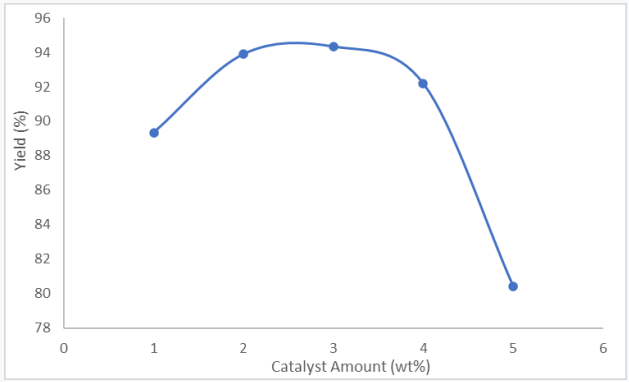

Figure 10. Effect of Catalyst Amount on Biodiesel Yield

In Figure 10, it can be seen that there is an increase in biodiesel yield as the amount of catalyst increases, with the highest yield obtained at 3 wt% catalyst with a yield of 94.33%. With more than 3 wt%, the yield level will decrease with the lowest yield level obtained when the amount of catalyst is 5 wt%, which is 80.4%. This is due to the excessive amount of catalyst, which causes side reactions, such as saponification (soap formation) with free fatty acids. The soap formed from this reaction will cause emulsification between biodiesel and glycerol, complicating purification and reducing biodiesel yield.

Reaction temperature is one of the parameters that affect biodiesel yield because reaction temperature affects the rate of biodiesel reaction and the mixing efficiency between reactants (methanol and oil). At the optimum temperature, the reaction rate increases because the reacting molecules have enough energy to pass the activation energy. The mixing of reactants becomes more homogeneous, so the transesterification reaction becomes more efficient and increases the biodiesel yield. The optimum reaction temperature is usually close to the boiling point of methanol (around 65°C). However, if the reaction temperature is too low, the kinetic energy of the reactant molecules is not high enough. Hence, the reaction rate is slow, and the mixing process between oil and alcohol is not optimal, resulting in lower biodiesel yield.

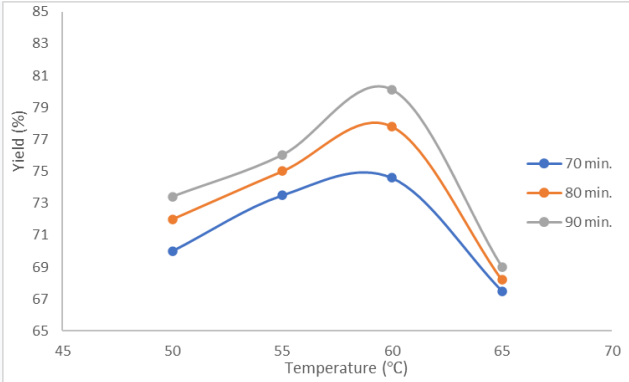

Figure 11. Effect of Reaction Temperature on Biodiesel Yield

In **Figure 11**, it can be seen that in the three variations of reaction time, there is an increase in biodiesel yield as the reaction time increases, and the variation of 90 minutes reaction time and 60°C reaction temperature gives the highest yield, which is 80.1%. This shows the effect of temperature on biodiesel because high temperatures can increase the rate of transesterification reactions. After all, the reactant molecules can react faster. With an increase in temperature, the oil's viscosity decreases, facilitating mixing between oil, methanol, and catalyst and increasing biodiesel yield. At high temperatures, methanol mixes more easily with oil, so the biodiesel formation reaction occurs faster. However, at too high a temperature (above the boiling point of methanol (64.7°C)), the methanol will evaporate before it can react with the oil, reducing the reaction efficiency and the biodiesel yield. As shown in Figure 11, there is a decrease in yield at 65°C. Excessively high temperatures can also cause soap formation (if an essential catalyst is used), decreasing biodiesel yield.

Another factor that affects biodiesel yield is reaction time. With an optimal reaction time, the transesterification reaction takes place effectively so that almost all of the oil is converted into biodiesel, and no side reactions occur. However, if the reaction time is too short, the reaction will not run optimally, and the oil will not fully react so the biodiesel yield will decrease.

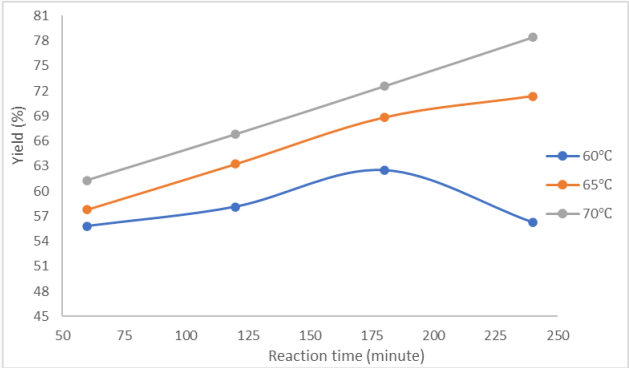

Figure 12. Effect of Reaction Time on Biodiesel Yield

In **Figure 12**, it can be seen that there is an increase in yield along with an increase in reaction time, with the highest yield obtained at a temperature variation of 70 °C and a reaction time of 240 minutes, which is 78.38%. However, suppose the reaction time is too long. In that case, a reverse reaction can occur, where biodiesel begins to break down back into triglycerides, thereby reducing the biodiesel yield and also the formation of by-products or oil; polymerization can occur if the reaction time is too long, as in the variation of 60 °C temperature and 240 minutes reaction

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time, the biodiesel yield decreased from 62.5% to 56.26%. But this did not happen in other temperature variations. This may be due to several reasons, namely at 60°C, the activation energy is not high enough to maintain the transesterification reaction optimally for a long time, and as time increases, with limited reaction energy, the possibility of reverse reaction (hydrolysis back to triglycerides) or the formation of by-products such as soap, which can reduce biodiesel yield. At 60 °C, the viscosity of oil and methanol remains relatively high, so the diffusion of reactants becomes slower. As a result, after a specific time, the reaction becomes less efficient, and precipitation or phase separation may occur, reducing biodiesel yield. At low temperatures (60°C) with a long reaction time, side reactions such as saponification (soap formation) or incomplete phase separation are more likely to occur, especially if alkaline catalysts such as NaOH or KOH are present. Soap formation causes biodiesel loss due to the formation of emulsions that are difficult to separate, so the measured yield decreases.

4. CONCLUSION

Based on the explanation above, it can be concluded that:

1. The yield obtained in biodiesel production is influenced by several factors: the amount of catalyst, reaction temperature, reaction time, stirring speed, and the molar ratio between methanol and oil.
2. The faster the stirring, the higher the biodiesel yield.
3. Extending the microwave reaction time could not significantly increase the biodiesel yield from sunflower oil.
4. The optimum molar ratio between methanol and oil (6:1) helps the reaction towards the product.
5. Using optimum catalyst concentration (1%) can increase the efficiency of the transesterification reaction.
6. At high temperatures (60°C), methanol mixes more easily with the oil, so the biodiesel formation reaction occurs faster.

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