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Analysis of Collision Theory in the Production of Candlenut Oil Biodiesel Using a Zeolite-KOH Catalyst

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ABSTRACT

The methanol-to-oil ratio is one of the most important factors affecting biodiesel production through transesterification. This study investigated the effect of different methanol-to-oil ratios (1:2, 1:4, 1:6, 1:8, and 1:10) on biodiesel production from candlenut oil (Aleurites moluccanus L.) using KOH-activated zeolite catalyst from a collision theory perspective. Biodiesel was produced through transesterification at 60–65 °C with a stirring speed of 300 rpm for 1 h. The resulting biodiesel was characterized based on yield, volume, and density. The results showed that increasing the methanol-to-oil ratio up to 1:6 increased biodiesel yield and improved product quality. The highest yield of 95.47% was obtained at a ratio of 1:6 with a density of 0.850 g/mL. Further increases in methanol concentration reduced biodiesel yield. Based on collision theory, the 1:6 ratio provided the optimum condition for effective molecular collisions during transesterification.

Keywords: biodiesel, candlenut oil, collision theory, methanol-to-oil ratio, KOH-activated zeolite

1. INTRODUCTION

The increasing depletion of fossil fuel reserves and growing environmental concerns have accelerated the search for renewable and sustainable energy sources. Biodiesel has emerged as one of the most promising alternatives to conventional diesel fuel due to its biodegradability, renewability, and lower emissions of sulfur compounds, particulate matter, and greenhouse gases. Biodiesel is commonly produced through the transesterification of vegetable oils or animal fats with short-chain alcohols, particularly methanol, resulting in fatty acid methyl esters (FAME) and glycerol as a by-product.[1]

Among various vegetable oil feedstocks, candlenut oil (*Aleurites moluccana* L.) has attracted attention due to its high oil content and widespread availability in Indonesia. The oil contains considerable amounts of unsaturated fatty acids, mainly oleic and linoleic acids, which are suitable precursors for biodiesel production. In addition, the utilization of non-edible oils such as candlenut oil avoids competition with food resources, making it a more sustainable feedstock for biofuel production Previous studies have demonstrated the feasibility of converting candlenut oil into biodiesel with favorable fuel properties and acceptable conversion efficiencies.[2]

The transesterification process is strongly influenced by several operational parameters, including catalyst type, reaction temperature, reaction time, mixing intensity, and methanol-to-oil ratio. Among these factors, the methanol-to-oil ratio is considered one of the most critical parameters because it directly affects the equilibrium and conversion of triglycerides into methyl esters. According to the stoichiometric reaction, one mole of triglyceride reacts with three moles of methanol to form three moles of methyl ester and one mole of glycerol. However, excess methanol is commonly employed to shift the equilibrium toward product formation and enhance biodiesel yield.[3] Previous studies have reported that increasing the methanol concentration generally improves biodiesel conversion up to an optimum level, beyond which excessive methanol may reduce process efficiency and complicate glycerol separation.

Catalysts play an essential role in accelerating transesterification reactions by reducing the activation energy required for the reaction to occur. Potassium hydroxide (KOH) is widely used as a homogeneous catalyst because of its high catalytic activity and ability to achieve high biodiesel conversion. On the other hand, zeolite is an attractive heterogeneous catalyst support due to its porous structure, large surface area, thermal stability, and abundance.[4] KOH activation can enhance the basicity and catalytic activity of zeolite by increasing the number of active sites available for the transesterification reaction. The combination of KOH and zeolite is therefore expected to improve biodiesel production efficiency while providing a catalyst system with enhanced catalytic performance.[5]

The effect of methanol concentration and catalyst activity can be explained through collision theory. According to this theory, chemical reactions occur only when reactant molecules undergo effective collisions with sufficient energy and proper orientation. Increasing the amount of methanol raises the frequency of collisions between methanol molecules and triglycerides, while catalysts lower the activation energy barrier and increase the proportion of effective collisions. Consequently, both factors are expected to promote biodiesel formation and improve reaction efficiency.[6]

Although numerous studies have investigated biodiesel production from various vegetable oils, limited studies have examined the influence of methanol-to-oil ratio on biodiesel production from candlenut oil using KOH-activated zeolite catalyst from a collision theory perspective. Most previous studies have focused primarily on biodiesel yield and physicochemical properties without relating the observed trends to molecular collision phenomena. Therefore, this study aims to evaluate the effect of different methanol-to-oil ratios (1:2, 1:4, 1:6, 1:8, and 1:10) on biodiesel yield, density, and volume produced from candlenut oil using a KOH-activated zeolite catalyst. It is hypothesized that increasing the methanol-to-oil ratio will increase the frequency of effective molecular collisions and enhance biodiesel production up to an optimum condition, beyond which additional methanol will no longer significantly improve reaction performance.

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

Candlenut oil (*Aleurites moluccana* L.) was used as the feedstock for biodiesel production. Methanol (CH_3OH, analytical grade) was used as the alcohol reagent in the transesterification process. Potassium hydroxide (KOH, analytical grade) was employed for zeolite activation and catalyst preparation. Natural

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zeolite was used as the heterogeneous catalyst support. Distilled water (H_2O) was used for preparing the KOH solution and washing purposes. The glassware used in this study included beakers, Erlenmeyer flasks, volumetric flasks (100 mL), graduated cylinders, watch glasses, porcelain crucibles, glass stirring rods, separatory funnels, and filter paper. The equipment employed consisted of a hot plate magnetic stirrer capable of maintaining temperatures between 60–65 °C and stirring speeds up to 300 rpm, an analytical balance (±0.001 g accuracy) for mass measurements, and laboratory support stands for the separation process. Biodiesel density was determined using mass-to-volume measurements obtained from the analytical balance and graduated cylinder.

2.2. Research Procedure

The research procedure consisted of catalyst preparation, Zeolite activation, and transesterification process.

2.2.1. Preparation of 2 M KOH Solution

Approximately 50 mL of distilled water was placed into a beaker. Subsequently, 11.2 g of potassium hydroxide (KOH) was weighed and gradually added to the distilled water while stirring continuously until completely dissolved. The resulting solution was transferred into a 100 mL volumetric flask, and distilled water was added until the total volume reached 100 mL. The solution was mixed thoroughly to ensure complete dissolution and then allowed to cool to room temperature before further use.

2.2.2. Zeolite Activation

The zeolite was first ground into a fine powder. A total of 10 g of zeolite was weighed and immersed in 100 mL of 2 M KOH solution. The mixture was stirred and soaked for 12–24 hours to facilitate the activation process. After activation, the zeolite was transferred into a porcelain crucible and placed on a hot plate. The material was heated at a medium temperature of approximately 100–120°C while being stirred gently. The activated zeolite was dried for 1–2 hours and subsequently allowed to cool to room temperature before storage and use as a catalyst.

2.2.3. Transesterification Process

A volume of 36 mL of candlenut oil was placed into an Erlenmeyer flask, followed by the addition of approximately 1.1 g of KOH-activated zeolite catalyst. A magnetic stir bar was inserted into the flask, and methanol was added according to the predetermined oil-to-methanol ratios of 1:2 (13 mL), 1:4 (25 mL), 1:6 (38 mL), 1:8 (50 mL), and 1:10 (63 mL). The Erlenmeyer flask was immediately covered with aluminum foil containing a small opening to allow the release of pressure and vapors generated during the reaction.

The reaction mixture was heated and stirred using a magnetic stirrer equipped with a hot plate at a temperature of 60–65°C and a stirring speed of 300 rpm for 1 hour. After the transesterification reaction was completed, the mixture was transferred into a separatory funnel and allowed to stand for 6–12 hours to promote phase separation. Two distinct layers were formed, consisting of biodiesel in the upper layer and glycerol along with catalyst residues in the lower layer. The upper biodiesel layer was carefully separated from the lower layer and collected. Finally, the biodiesel product was weighed to determine the yield and density obtained from the transesterification process.

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3. RESULTS AND DISCUSSION

3.1. Analysis of Characterization Results

The effect of methanol-to-oil ratio on biodiesel production from candlenut oil using KOH-activated zeolite catalyst was evaluated through measurements of biodiesel yield, volume, and density. The results obtained at different methanol-to-oil ratios are presented in Table 1.

Table 1. Effect of Methanol-to-Oil Ratio on Biodiesel Yield and Density

Ratio	Oil Volume (mL)	Methanol Volume (mL)	Biodiesel Mass (g)	Biodiesel Volume (mL)	Yield (%)	Density (g/mL)
01:10	36	63	25,26	30	74,64%	0,842
01:08	36	50	28,49	34	84,19%	0,837
01:06	36	38	32,31	38	95,47%	0,85
01:04	36	25	30,12	35	89,00%	0,86
01:02	36	13	28,92	32	85,46%	0,9

3.2. Reaction Equation

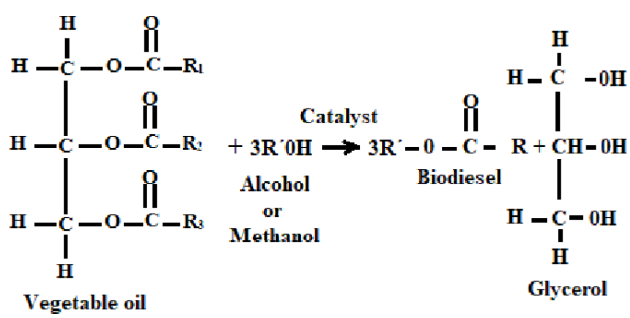

Figure 1. Transesterification Reaction of Candlenut Oil

3.3. Effect of Methanol-to-Oil Ratio on Biodiesel Density in Relation to Collision Theory

Density is one of the physical properties used to evaluate the quality of the biodiesel produced.[7] Based on collision theory, increasing the methanol-to-oil ratio increases the number of methanol molecules available to react with the triglycerides in candlenut oil, thereby increasing the frequency of interparticle collisions. With the presence of a KOH-activated zeolite catalyst, which serves to lower the activation energy, the number of effective collisions that yield products also increases.[8] Consequently, the conversion of triglycerides into methyl esters proceeds more completely and can affect the density of the resulting biodiesel. The relationship between the oil-to-methanol ratio and biodiesel density is shown in Figure 2.

As shown in Figure 1, the density of the biodiesel produced decreased as the oil-to-methanol ratio increased from 1:2 to 1:8, specifically from 0.900 g/mL to 0.837 g/mL. However, at a ratio of 1:10, the density increased to 0.842 g/mL. According to SNI 7182:2015, the density of biodiesel that meets the standard is in the range of 0.850–0.890 g/mL. Based on the results obtained, biodiesel at ratios of 1:4 and 1:6 meets the SNI standard with densities of 0.860 g/mL and 0.850 g/mL, respectively, while the 1:2 ratio exceeds the maximum standard limit. Meanwhile, the 1:8 and 1:10 ratios have densities below the established standard range.

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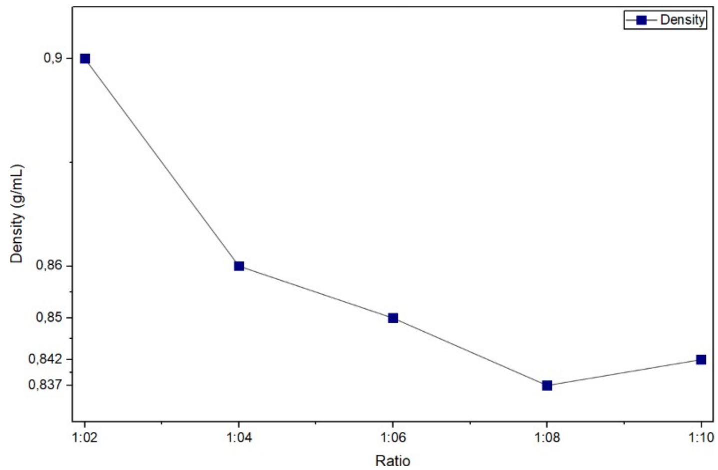

Figure 2. Effect of Methanol-to-Oil Ratio on Biodiesel Density: A Collision Theory Perspective

According to collision theory, increasing the amount of methanol to a 1:6 ratio increases the frequency of collisions between methanol molecules and triglycerides, thereby increasing the number of effective collisions that produce methyl esters.[9] With the aid of a KOH-activated zeolite catalyst, which lowers the activation energy, the transesterification reaction proceeds more effectively and produces biodiesel with a density that meets the standard. At a 1:6 ratio, a density of 0.850 g/mL was obtained, which falls precisely at the lower limit of the SNI standard and is supported by the highest yield of 95.47%, so this ratio can be considered the optimal condition. Further addition of methanol up to ratios of 1:8 and 1:10 no longer significantly increases reaction efficiency because the system has approached the optimal condition. Consequently, although the density continued to decrease and even fell below the SNI standard, the biodiesel yield actually decreased, indicating that the addition of excess methanol does not provide any benefit to the transesterification process.[10]

3.4. Effect of Methanol-to-Oil Ratio on Biodiesel Yield in Relation to Collision Theory

Biodiesel yield is a parameter used to indicate the effectiveness of the transesterification process.[11] Based on collision theory, increasing the methanol-to-oil ratio increases the number of methanol molecules available to react with the triglycerides in the candlenut oil, thereby increasing the collision frequency.[12] With the aid of a KOH-activated zeolite catalyst, which reduces the activation energy, the number of effective collisions increases and biodiesel formation proceeds more optimally. Therefore, the biodiesel yield tends to increase until the optimum effective collision conditions are reached. The relationship between the oil-to-methanol ratio and biodiesel yield is shown in Figure 2.

As shown in Figure 3, the biodiesel yield increased from 85,46% at a 1:2 ratio to 95.47% at a 1:6 ratio. However, at ratios of 1:8 and 1:10, the yield decreased to 89.00% and 85.46%, respectively. The increase in yield up to a 1:6 ratio indicates that the addition of methanol increases the collision frequency between methanol molecules and triglycerides, thereby increasing the number of effective collisions that produce methyl esters. With the presence of KOH-activated zeolite catalyst, the activation energy of the reaction becomes lower, allowing biodiesel formation to proceed more optimally.

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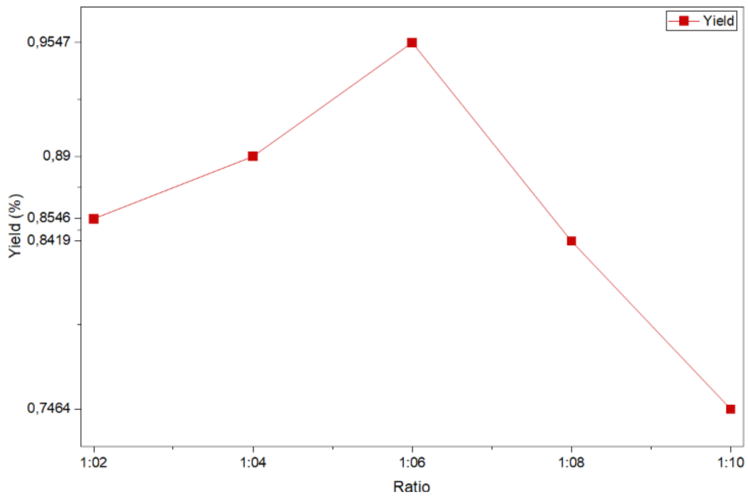

Figure 3. Effect of Methanol-to-Oil Ratio on Biodiesel Yield: A Collision Theory Perspective

The highest yield was obtained at a 1:6 ratio of 95.47%, indicating that the number of effective collisions had reached an optimal condition. Beyond this ratio, adding more methanol no longer significantly increases the number of effective collisions because most of the triglycerides have already reacted. Consequently, the biodiesel yield decreases at ratios of 1:8 and 1:10. Based on collision theory, the 1:6 ratio represents the most optimal condition because it yields the highest biodiesel yield and a product with a density that still meets SNI standards.

3.4.1. Influence of Methanol Volume on Biodiesel Production and Yield through Effective Molecular Collisions

Methanol volume is one of the factors that significantly affects biodiesel production during the transesterification process[13]. Based on collision theory, increasing the volume of methanol increases the concentration of reactant molecules in the reaction system, thereby enhancing the frequency of collisions between methanol and triglyceride molecules.[14] The use of KOH-activated zeolite catalyst further facilitates the reaction by lowering the activation energy and increasing the number of effective collisions.[5] Therefore, biodiesel production and yield are expected to increase with increasing methanol volume until an optimum condition is achieved, where the maximum number of effective molecular collisions occurs. The relationship between methanol volume, biodiesel production, and biodiesel yield is presented in Figures 4 and 5. Based on Figures 3 and 4, increasing the methanol volume from 13 mL to 38 mL caused the biodiesel yield to increase from 85.4% to 95.5%, while the biodiesel volume increased from 32 mL to 38 mL. According to collision theory, the addition of methanol increases the concentration of reactants in the mixture, thereby increasing the frequency of collisions between methanol molecules and triglycerides.[15] Consequently, the number of effective collisions that produce biodiesel also increases. With the presence of a catalyst, the activation energy of the transesterification reaction decreases, thereby increasing the likelihood of biodiesel formation.

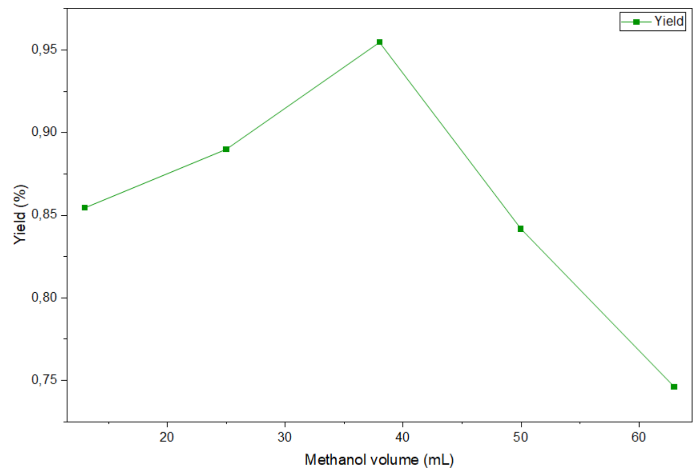

Figure 4. Effect of Methanol Volume on Biodiesel Yield: A Collision Theory Perspective

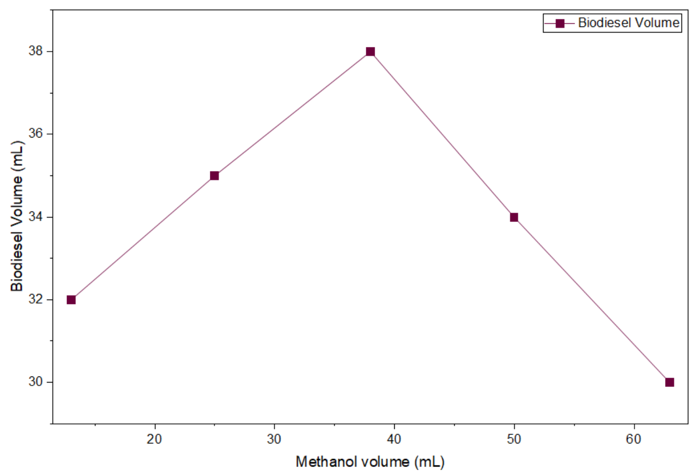

Figure 5. Effect of Methanol Volume on Biodiesel Volume: A Collision Theory Perspective

The yield and volume of biodiesel reached maximum values at 38 mL of methanol, indicating that the number of effective collisions had reached an optimal condition. Beyond this point, increasing the methanol volume to 50 mL and 63 mL actually reduced the yield to 84.2% and 74.6%, respectively, and decreased the biodiesel volume to 34 mL and 30 mL. Based on collision theory, the addition of excessive methanol no longer significantly increases the number of effective collisions because most of the triglycerides have already reacted. Therefore, a methanol volume of 38 mL represents the optimal condition that produces the highest number of effective collisions, resulting in maximum biodiesel yield and volume.

4. CONCLUSION

The methanol-to-oil ratio significantly affected biodiesel production from candlenut oil using KOH-activated zeolite catalyst. Increasing the methanol concentration from a ratio of 1:2 to 1:6 enhanced biodiesel yield and reduced density, indicating improved conversion of triglycerides into fatty acid methyl esters. The highest biodiesel yield (95.47%) was obtained at a methanol-to-oil ratio of 1:6. Based on collision theory, the optimum ratio of 1:6 provided the most favorable conditions for effective molecular collisions during transesterification. Further increases in methanol concentration resulted in lower biodiesel yields, likely due to

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separation limitations and excess methanol effects. Therefore, a methanol-to-oil ratio of 1:6 was identified as the optimum condition for biodiesel production from candlenut oil.

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