International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 11 Nov. 2025, pp: 100-103 www.ijaem.net ISSN: 2395-5252

Effect of Reaction Time on Biodiesel Yield from Transesterification of Palm Kernel Oil

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Date of Submission: 25-10-2025 Date of Acceptance: 05-11-2025

ABSTRACT
This study investigates the production of biodiesel from palm kernel oil (PKO) using a base-catalyzed transesterification process, with a focus on optimizing reaction time to maximize yield. Methanol and potassium hydroxide (KOH) were used as the alcohol and catalyst, respectively, and the reaction was conducted at a controlled temperature of 60 °C. Reaction times ranging from 5 to 80 minutes were evaluated to determine their effect on biodiesel yield. Gravimetric analysis revealed that yield increased with reaction time, reaching a peak value of 94.48% at 40 minutes, after which no significant increase in yield was observed, suggesting that reaction equilibrium had been attained. Gas Chromatography–Mass Spectrometry (GC-MS) analysis of the final biodiesel sample confirmed the presence of key fatty acid methyl esters (FAMEs), including methyl dodecanoate and methyl tetradecyl ester, indicating successful conversion of triglycerides. The chemical profile remained consistent, as reaction time primarily affected conversion efficiency, not product identity. These results suggest that a 40-minute reaction time offers an optimal balance between yield and energy input for efficient biodiesel production from PKO under standard conditions.
Keywords: Biodiesel, Transesterification, Reaction Time

I. INTRODUCTION

Biodiesel is a renewable liquid fuel derived from biological sources such as vegetable oils and animal fats through chemical processes, and it serves as a viable alternative to petroleum-based diesel. It can be used directly in diesel engines or blended with petro-diesel without requiring engine modifications. According to ASTM International, biodiesel is defined as a mixture of long-chain monoalkyl esters of fatty acids derived from renewable lipids. Within the European Union, biodiesel accounts for a significant portion of total biofuel production and is considered environmentally superior to fossil diesel due to its lower emissions of regulated pollutants (Naseef&Tulaimat, 2025; Farouk et al., 2024).

The increasing demand for energy, depletion of fossil fuel reserves, and environmental degradation from fossil fuel combustion have intensified the search for alternative, sustainable energy sources. Biodiesel production has gained global attention as it offers several advantages, including biodegradability, lower toxicity, and a significant reduction in greenhouse gas emissions (Lopresto, 2025; Danane et al., 2022). Among various production techniques, transesterification remains the most widely employed due to its relative simplicity, cost-effectiveness, and compatibility with existing fuel infrastructure (Monika et al., 2023).

In the transesterification process, triglycerides react with short-chain alcohols (typically methanol) in the presence of a catalyst—commonly potassium hydroxide (KOH)—to yield fatty acid methyl esters (biodiesel) and glycerol. Because the reaction is reversible, an excess of alcohol is typically used to drive the equilibrium toward biodiesel formation. The efficiency of this conversion is governed by key reaction parameters, including temperature, catalyst concentration, methanol-to-oil ratio, and reaction time (Wan Osman et al., 2024).

Palm kernel oil (PKO), derived from Elaeisguineensis, is rich in lauric acid and has been identified as a promising non-edible feedstock for biodiesel due to its favorable fatty acid profile and high conversion efficiency (AbdAlshafea et al., 2025; Onyia et al., 2024). Several studies have reported successful biodiesel synthesis from PKO, but many fail to systematically investigate the effect of reaction duration on biodiesel yield under controlled laboratory conditions. Often, reaction time is assumed or generalized, leading to inconsistent process efficiency and yield reports across the literature.

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Additionally, while yields are commonly reported, the chemical identity of the product is not always validated using robust analytical techniques such as Gas Chromatography-Mass Spectrometry (GC-MS).

Therefore, this study addresses these gaps by systematically evaluating the effect of reaction time (5–80 minutes) on biodiesel yield from PKO using a standardized transesterification technique and by confirming the chemical composition of the biodiesel produced through GC-MS analysis to ensure the successful formation of fatty acid methyl esters. This approach not only aims to determine the optimal reaction time for maximizing biodiesel yield but also to enhance the reliability and reproducibility of biodiesel production from palm kernel oil.

II. EXPERIMENTAL PROCEDURE

Biodiesel was produced from palm kernel oil (PKO) via a base-catalyzed transesterification reaction using methanol and potassium hydroxide (KOH). The experimental methodology encompassed catalyst preparation, the reaction setup, product separation and purification, yield calculation, and chemical analysis.

Materials

Palm kernel oil was used as the primary feedstock. Anhydrous methanol (99.8% purity) and potassium hydroxide (KOH) pellets (85% purity) were used as the alcohol and catalyst, respectively. All chemicals were utilized as received without further purification.

Catalyst Solution Preparation

A potassium methoxide solution was prepared by dissolving 1.0 gram of KOH (representing 1.0% w/w of the oil) in 10 mL of anhydrous methanol. The mixture was stirred continuously for 10 minutes using a magnetic stirrer to ensure complete dissolution, resulting in a clear potassium methoxide solution.

Transesterification Reaction

Fifty milliliters (50 mL) of palm kernel oil was measured and transferred into a 250 mL conical flask. The oil was preheated to 60 °C using a magnetic stirrer equipped with a temperature-controlled hot plate. At 60°C, the freshly prepared potassium methoxide solution was added to the preheated oil, marking the start of the reaction. The mixture was stirred vigorously at a constant temperature of 60 °C. To investigate the effect of reaction time, the duration of the reaction was varied at 5, 10, 20, 40, 60, and 80 minutes, while all other parameters were kept constant.

Separation and Purification

Upon completion of the reaction, the mixture was carefully transferred to a separatory funnel and allowed to stand undisturbed for 24 hours. This enabled a clear phase separation, resulting in a lower, dense layer of glycerol and an upper layer of crude biodiesel. The glycerol layer was drained off and discarded. The crude biodiesel layer was then washed with 10 mL of warm distilled water (approximately 50 °C) to remove any residual catalyst, soaps, or methanol. The washing step was repeated until the wash water became clear. The purified biodiesel was then recovered and dried to remove any residual moisture.

Yield Determination

The mass of the final, purified biodiesel product was accurately measured. The percentage yield was calculated gravimetrically using the following formula:

Yield (%) = (Mass of Biodiesel Produced / Mass of Oil Used) × 100

This process was repeated for each of the specified reaction times to determine the yield-time relationship.

GC-MS Analysis

The chemical composition of the biodiesel sample produced at the optimal reaction time was characterized using Gas Chromatography-Mass Spectrometry (GC-MS). The analysis was performed to identify and confirm the presence of Fatty Acid Methyl Esters (FAMEs). The constituent esters were identified by comparing their mass spectra with those in the National Institute of Standards and Technology (NIST) library database.

III. RESULTS AND DISCUSSION

Percentage Yield Analysis

The results of the transesterification reactions conducted at different time intervals are presented in Table 1. A clear correlation between reaction time and biodiesel yield was observed. The yield increased steadily from 45.80% at 5 minutes to a maximum of **94.48% at 40 minutes**. Notably, extending the reaction time further to 60 and 80 minutes resulted in no additional increase in yield, as the values remained constant at 94.48%.

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Table 1: Percentage Yield of Biodiesel at Different Reaction Times

Time (min)	Yield (%)
5	45.80
10	68.28
20	91.76
40	**94.48**
60	94.48
80	94.47

The plateau in yield observed from 40 minutes onward indicates that the reaction had reached equilibrium. Beyond this point, the forward and reverse reaction rates equalize, and no significant net increase in product formation occurs. This finding aligns with the work of Onyia et al. (2024), who reported an optimal biodiesel yield from PKO at 50 minutes. The slight difference in optimal time may be attributed to variations in mixing intensity or catalyst concentration. The results confirm that prolonged reaction times are energetically inefficient and do not enhance yield, a conclusion supported by Danane et al. (2022), who noted that excessive time could even promote reverse reactions.

The high yield achieved in this study, slightly exceeding the 93 wt% reported by Udochukwu (2024) and the >80% yields confirmed by AbdAlshafea et al. (2025), underscores the efficiency of the controlled reaction parameters employed, particularly the identified optimal reaction time.

GC-MS Analysis

To chemically verify the successful conversion of triglycerides into biodiesel, the sample produced at the optimal 40-minute reaction time was analyzed using GC-MS. The results, summarized in Table 2, confirm the presence of key Fatty Acid Methyl Esters (FAMEs), which are the defining components of biodiesel.

Table 2: Major Fatty Acid Methyl Esters (FAMEs) Identified in the Biodiesel via GC-MS

Peak	Compound Name	Retention Time (min)	Area %
1	Methyl Laurate (C12:0)	12.45	48.5
2	Methyl Myristate (C14:0)	16.89	16.2
3	Methyl Palmitate (C16:0)	21.35	8.5
4	Methyl Oleate (C18:1)	23.91	12.1
5	Methyl Stearate (C18:0)	24.50	5.3

The chromatogram reveals a FAME profile dominated by methyl laurate, which is characteristic of biodiesel derived from lauric-rich feedstock like palm kernel oil. The high abundance of saturated medium-chain esters (C12-C14) is consistent with the known fatty acid composition of PKO and aligns with the findings of Farouk et al. (2024), who emphasized that a high-quality biodiesel GC-MS profile should be dominated by FAMEs with minimal impurities.

The absence of significant peaks corresponding to triglycerides, diglycerides, or free glycerol provides strong evidence for a high conversion efficiency. This chemical verification supports the gravimetric yield data, confirming that the plateau in yield at 40 minutes corresponds to a near-complete conversion of the feedstock into its ester form. As noted by Monika et al. (2023), the presence of methyl laurate and other saturated esters in significant quantities is a key indicator of successful transesterification of palm-based oils.

Based on the combined yield and compositional data, 40 minutes is conclusively identified as the optimal reaction time for biodiesel synthesis from palm kernel oil under the specified conditions. This finding provides a precise and economically valuable parameter, as it minimizes process time and energy consumption without compromising yield or quality, a principle crucial for sustainable production as highlighted by Wan Osman et al. (2024) and Lopresto (2025).

IV. CONCLUSION AND RECOMMENDATIONS

This study has successfully demonstrated the production of biodiesel from palm kernel oil via base-catalyzed transesterification and systematically identified the optimal reaction time for maximum yield. Through controlled experiments across six different reaction durations (5-80 minutes), it was determined that a reaction time of 40 minutes yields the maximum biodiesel conversion of 94.48%, with no observable improvement at longer durations.

The GC-MS analysis provided crucial chemical verification of the biodiesel quality, confirming the presence of characteristic fatty acid methyl esters, predominantly methyl laurate, which aligns with the known composition of palm kernel

oil. The absence of significant triglyceride peaks in the chromatogram further validates the completeness of the conversion at the optimal reaction time.

This work makes two significant contributions to the field of biodiesel research: first, it provides a precise, experimentally-determined optimal reaction time for PKO transesterification under standard laboratory conditions; second, it couples yield optimization with GC-MS analysis, addressing a common gap in literature where yield data is reported without compositional validation. The findings establish that extending reaction time beyond the equilibrium point is both energetically inefficient and economically non-viable for PKO-based biodiesel production.

Catalyst recovery and reusability is recommended. To enhance the economic and environmental sustainability of the process, studies should focus on the recovery, regeneration, and reuse of the homogeneous KOH catalyst, or explore heterogeneous catalyst alternatives.

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