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Green Synthesis of Biodiesel from Pliek U Oil using Oyster Shell–Derived Calcium Oxide Modified with PVA: Structural Characterization and Catalytic Performance

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Abstract*:* The production of biodiesel from local resources is a strategic approach to support sustainable energy transition. This study aimed to synthesize and evaluate the performance of a heterogeneous catalyst derived from oyster shell-based calcium oxide (CaO) modified with polyvinyl alcohol (PVA) as a binder, for the transesterification of Pliek U oil into biodiesel. CaO was synthesized by calcining oyster shells at 800°C, followed by PVA modification to improve structural stability and catalytic activity. The catalyst was characterized using X-ray Diffraction (XRD) to observe crystal patterns, while the resulting biodiesel was analyzed by Gas Chromatography–Mass Spectrometry (GC-MS) and Fourier Transform Infrared Spectroscopy (FTIR) to identify methyl ester compounds. Physicochemical properties including density, viscosity, acid value, water content, and flash point were also evaluated. Transesterification was carried out at a methanol-to-oil molar ratio of 12:1, catalyst concentration of 2.29% w/w, reaction temperature of 60°C, and reaction time of 90 minutes. The results showed a biodiesel yield of 96%, with dominant components being methyl caprylate, methyl laurate, and methyl caprate. FTIR spectra confirmed the presence of characteristic functional groups of methyl esters. The biodiesel properties met the SNI 7182:2015.

Keywords: biodiesel, Pliek U oil, calcium oxide, polyvinyl alcohol, heterogeneous catalyst

Abstrak: *Produksi biodiesel berbasis sumber daya lokal merupakan pendekatan strategis untuk mendukung transisi energi berkelanjutan. Penelitian ini bertujuan mensintesis dan mengevaluasi kinerja katalis heterogen kalsium oksida (CaO) yang dikembangkan dari limbah cangkang tiram (Crassostrea sp.) dan dimodifikasi dengan polyvinyl alcohol (PVA) sebagai pengikat, dalam proses transesterifikasi minyak Pliek U menjadi biodiesel. Sintesis CaO dilakukan melalui kalsinasi cangkang tiram pada suhu 800 °C, kemudian dimodifikasi dengan PVA untuk meningkatkan stabilitas struktur dan aktivitas katalitik. Karakterisasi katalis dilakukan menggunakan X-ray Diffraction (XRD) untuk mengamati pola kristal, sedangkan analisis biodiesel hasil reaksi meliputi Gas Chromatography–Mass Spectrometry (GC-MS) dan Fourier Transform Infrared Spectroscopy (FTIR) guna mengidentifikasi senyawa metil ester. Selain itu, diuji sifat fisikokimia seperti densitas, viskositas, bilangan asam, kadar air, serta titik nyala. Reaksi transesterifikasi dilaksanakan pada rasio molar metanol:minyak 12:1, konsentrasi katalis 2,29% (b/b), suhu 60 °C, dan waktu 90 menit. Hasil penelitian menunjukkan rendemen biodiesel mencapai 96% dengan komponen dominan metil kaprilat, metil laurat, dan metil kaprat. Spektrum FTIR mengonfirmasi terbentuknya gugus fungsi khas metil ester. Sifat biodiesel yang diperoleh memenuhi standar kualitas SNI 7182:2015.*

Kata kunci: *biodiesel, minyak Pliek U, kalsium oksida, polyvinyl alcohol, katalis heterogen*

INTRODUCTION

Aceh is one of the regions in Indonesia that is rich in natural resources and local wisdom potential. This wealth directly contributes to the high generation of waste, particularly organic waste, which has not yet been optimally managed. One potential that deserves further development is Pliek U oil, a by-product of the fermentation process of mature coconuts prior to the formation of the main product, Pliek U. This oil is often discarded despite being chemically rich in Free Fatty Acids (FFA) at high concentrations, as well as medium-chain fatty acids such as capric acid, lauric acid, myristic acid, and palmitic acid, which hold great potential for conversion into biodiesel (Earlia *et al.* 2019).

Global energy demand continues to increase in line with population growth and industrial activities, with projections indicating a rise of more than 25% by 2040 (International Energy Agency 2024). Dependence on non-renewable fossil fuels and their associated environmental impacts has driven the development of sustainable alternative energy sources. The utilization of non-edible oils, such as Pliek U oil, represents a promising strategy for biodiesel production, as it optimizes the use of local waste resources, avoids competition with food supplies, and reduces production costs (Hua *et al.* 2025). Biodiesel can be produced through the transesterification reaction between vegetable oils and alcohol in the presence of a catalyst, where the efficiency of the process strongly depends on the type of catalyst employed (Anil *et al.* 2024).

The selection of catalyst type is a key factor influencing the efficiency and success of the biodiesel conversion process (Fattah *et al.* 2020). Homogeneous catalysts, such as potassium hydroxide (KOH), are commonly employed due to their high reactivity in transesterification reactions. However, the main limitations of this type of catalyst lie in the difficulty of separating it from the final product, its hygroscopic nature that reduces stability during storage, and its inability to be efficiently reused, thereby increasing operational costs and generating additional waste (Wang *et al.* 2023). As an alternative, heterogeneous catalysts have advanced significantly owing to their superior characteristics, particularly the ease of separation from the final reaction products and their reusability with only minimal loss of activity (Sarangi *et al.* 2024).

Heterogeneous catalysts are classified into two main types, namely acidic and basic (Pasae *et al.* 2020). Acidic heterogeneous catalysts, such as sulfonated carbon and zeolites, are effective for feedstocks with high FFA content because they are capable of catalyzing both esterification and transesterification reactions without generating soap. However, this type of catalyst has several drawbacks, including corrosive effects on reaction equipment and low reactivity, which consequently require longer reaction times (Hua *et al.* 2025). In contrast, basic heterogeneous catalysts such as calcium oxide (CaO) are considered more practical and economical for large-scale biodiesel production. CaO not only exhibits high catalytic activity but can also be obtained from biomineral waste, such as oyster shells (Crassostrea sp.), which are abundant in the coastal regions of Aceh (Melo *et al.* 2024). The utilization of this waste not only supports a circular economy approach but also provides a sustainable and value-added local catalyst source.

Oyster shells contain a high amount of calcium carbonate ($CaCO_3$), which can be converted into CaO through thermal treatment (Chong *et al.* 2023; Ooi *et al.* 2021). However, CaO has certain limitations, such as its tendency to absorb moisture and its low active surface area due to agglomeration, which ultimately reduces its catalytic activity (Yan *et al.* 2008). To optimize its performance, CaO can be modified with the addition of polyvinyl alcohol (PVA), which functions to enhance structural stability and suppress particle agglomeration. The presence of PVA has also been reported to improve catalyst particle dispersion, expand the active surface area, and maintain catalytic structural stability (Talha & Sulaiman 2018).

This study aims to evaluate the performance of PVA-modified CaO heterogeneous catalysts in the production of biodiesel from Pliek U oil. The main focus of the research lies in the synthesis, structural characterization using X-Ray Diffraction (XRD), evaluation of the resulting biodiesel through Gas Chromatography–Mass Spectrometry (GC–MS) and Fourier Transform Infrared (FTIR) analyses, as well as biodiesel characterization tests including density, viscosity, acid value, and water content. This approach is expected to provide an effective and environmentally friendly local catalyst alternative while supporting the development of biodiesel based on the potential of local resources.

MATERIALS AND METHOD

Materials, Chemicals, and Instruments

The chemicals used in this study were of pro-analysis (p.a.) grade and supplied by Merck KGaA, including methanol (CH_3OH, ≥99.9%), concentrated sulfuric acid (H_2SO_4, 95–97%), sodium hydroxide solution (NaOH, 0.1 N), potassium hydroxide solution (KOH, 0.1 N), phenolphthalein indicator ($C_{20}H_{14}O_4$), and distilled water. The catalyst precursor, oyster shells (Crassostrea sp.), was collected from the coastal area of Banda Aceh, then dried and calcined to obtain CaO. Polyvinyl alcohol (PVA, technical grade, Sigma-Aldrich) was employed as a binder. Pliek U oil was obtained from Pliek U factory waste in Aceh, Indonesia, and used as the feedstock for biodiesel production.

Synthesis of CaO/PVA Catalyst

The CaO/PVA catalyst was synthesized using oyster shells as the calcium source. The shells were first cleaned, dried at 110°C for 48 h, crushed, and then calcined at 800 °C for 6 h (Chong *et al.* 2023). Separately, 2 g of PVA was dissolved in 30 mL of distilled water at 60 °C under continuous stirring for 4 h. After obtaining a homogeneous solution, 4 g of CaO was added into the PVA solution, and the mixture was reheated at the same temperature until thoroughly mixed. The resulting mixture was poured into a petri dish and dried in an oven at 65 °C for 24 h (Talha & Sulaiman 2018). For comparison, pure CaO was also synthesized from oyster shells under identical calcination conditions, without PVA modification, and used as a control catalyst in transesterification reactions.

Catalyst Characterization

The catalyst was characterized using an X-ray diffractometer (Shimadzu XRD-6000) equipped with a Cu Kα radiation source to identify crystalline phases and structural changes resulting from the calcination process.

Determination of Free Fatty Acid (FFA) Content

The acid value of Pliek U oil was determined by titration with 0.1 N NaOH solution using phenolphthalein as an indicator, following the standard method (AOCS Cd 3d-63). The oil sample was dissolved in warm isopropyl alcohol and titrated until a stable pink endpoint was observed.

Biodiesel Synthesis (Esterification)

The presence of free fatty acids (FFAs) in biodiesel lowers its economic value. Based on international biodiesel standards, the acceptable acid number should be less than 0.5% (mg KOH/g). Hence, after measuring the acid value and FFA content of Pliek U oil, an acid esterification pre-treatment was performed to decrease its FFA level. The esterification was carried out using conventional heating in a two-neck round-bottom flask equipped with a reflux condenser to prevent methanol loss and a thermometer for temperature control (Khosa *et al.* 2024). A total of 300 g of Pliek U oil was introduced into the flask and heated to approximately 60°C. Methanol (10% w/w) and concentrated H_2SO_4 (0.5% w/w) were added, and the mixture was refluxed for 2 h under constant stirring at 600 rpm. After the reaction was completed, the mixture was transferred to a separating funnel and allowed to settle for 24 h. The oil phase was repeatedly washed with 50–100 mL of distilled water until clear, followed by heating to remove residual water. The resulting methyl ester layer was obtained for FFA analysis and further transesterification.

Biodiesel Synthesis (Transesterification)

For the transesterification process, 50 g of esterified oil was reacted with methanol and CaO/PVA catalyst at a concentration of 2.29 wt%, using a molar ratio of 12:1 (methanol to oil). The reaction was carried out at 60°C for 90 minutes under reflux with continuous stirring at 600 rpm (Talha & Sulaiman 2018). After completion, the mixture was centrifuged at 3000 rpm for 5 minutes to separate the phases (glycerol, catalyst, and methyl esters). The biodiesel and glycerol layers were further separated using a separating funnel, while the excess methanol was removed with a rotary evaporator (Khosa *et al.* 2024). The obtained biodiesel was washed twice with warm distilled water to neutralize the pH and remove residual impurities. The biodiesel yield was then calculated using the following equation (1).

$$\text{Yield (\%)} = \frac{\text{Weight of biodiesel obtained (g)}}{\text{Weight of initial oil(g)}} \quad ...(1)$$

Biodiesel Characterization

Biodiesel characterization was carried out using Fourier Transform Infrared Spectroscopy (FTIR, PerkinElmer UATR Spectrum Two) to identify the characteristic functional groups of esters, as well as Gas Chromatography–Mass Spectrometry (GC–MS, DB-23 column, 60 m × 0.25 mm × 0.15 µm) to determine the composition of the methyl esters formed. The physical properties of biodiesel were analyzed following standard methods, including density (ASTM D1298) measured with a pycnometer at 40 °C, kinematic viscosity (ASTM D445) using an NDJ-8 viscometer at 40 °C, acid value (ASTM D664) determined by titration with KOH, water content (ASTM D6304) using the oven drying method at 105°C, and flash point (ASTM D613) determined by the open cup method.

RESULT AND DISSCUSION

Catalyst Characterization

The X-ray diffraction (XRD) pattern of the synthesized CaO/PVA catalyst is presented in Figure 1. The diffraction pattern exhibits several high-intensity peaks, indicating the presence of dominant crystalline phases within the material structure. Sharp peaks are observed at $2\theta = 32.2°$, 37.3°, 53.9°, and 63.1°, all of which correspond to the reference data of JCPDS 37-1497 for calcium oxide (CaO). The presence of these peaks confirms that the calcination of oyster shells at elevated temperature effectively converted $CaCO_3$ into CaO. This transformation is consistent with previous studies reporting that $CaCO_3$ undergoes complete decomposition into CaO and CO_2 at temperatures above 800°C (Ooi *et al.* 2021; Yue *et al.* 2022).

The XRD analysis also revealed the presence of calcium hydroxide ($Ca(OH)_2$), as indicated by the appearance of diffraction peaks at $2\theta = 28.62°$, 34.06°, 47.16°, and 50.76°. The formation of $Ca(OH)_2$ is attributed to the exposure of the calcined CaO powder to ambient air, leading to a hydroxylation reaction between moisture and the CaO phase. Post-calcination, CaO is highly hygroscopic and readily absorbs atmospheric water vapor once removed from the furnace, which promotes the conversion of CaO to $Ca(OH)_2$ (Maisyarah *et al.* 2019).

Diffraction peaks at $2\theta = 19.12°$, 19.42°, and 19.70° indicate the presence of semi-crystalline PVA structures, consistent with previous reports that PVA exhibits characteristic peaks within the range of 19°–20° (Kumar *et al.* 2015; Ji *et al.* 2021). This confirms that PVA retains part of its crystalline nature after being incorporated with CaO, thereby functioning effectively as a binding agent. The coexistence of distinctive peaks from both CaO and PVA demonstrates the successful formation of a composite with good structural integrity, which supports stability and enhances the catalytic potential in biodiesel synthesis.

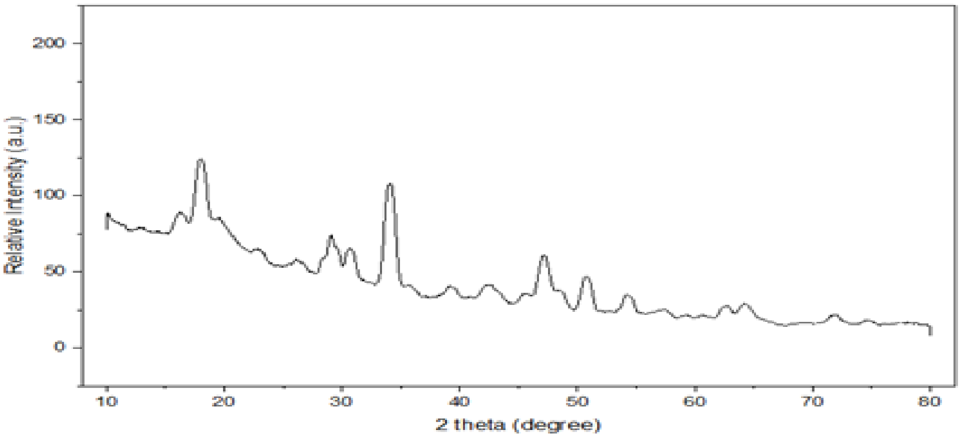

Figure 1. XRD pattern of the CaO/PVA catalyst (Hua *et al.* 2025).

Table 1. Biodiesel yield (%) from Pliek U oil using different methanol-to-oil molar ratios and catalysts

Methanol-to-oil molar ratio	**Biodiesel yield (CaO/PVA)**	**Biodiesel yield (CaO) (Kedir *et al.* 2023)**
1:12	96%	80%

The combination of characteristic CaO and PVA peaks in the XRD pattern indicates that both components were successfully integrated structurally without losing their individual crystalline characteristics. The interaction between hydroxyl (–OH) groups along the PVA polymer chains and the basic surface of the inorganic particles is known to form strong hydrogen bonds, as previously reported in PVA–AlOOH systems (Han *et al.* 2020). In such systems, hydrogen bonding plays a crucial role in enhancing the mechanical and thermal properties of the composite by establishing a stable physical network.

A similar principle applies to the PVA–CaO system, in which the –OH groups of PVA establish hydrogen bonds with the basic surface of CaO particles, thereby supporting the integration and structural stability of the composite. This interaction facilitates uniform particle dispersion within the PVA matrix and contributes to enhanced thermal stability and mechanical strength of the resulting material (Niazi *et al.* 2017). Such a stable physical structure further promotes the optimal catalytic performance of CaO in biodiesel synthesis applications.

Catalytic Activity Evaluation

The catalytic performance of CaO/PVA was evaluated to determine the efficiency of converting Pliek U oil into biodiesel under specific operating conditions. The transesterification reaction was conducted using 50 g of Pliek U oil, in which the FFA content had been reduced to 3.4%. The reaction was carried out at a methanol-to-oil molar ratio of 12:1, with 2.29 wt% catalyst loading relative to the oil weight, at 60 °C for 90 minutes.

The results demonstrated that the reaction yielded 48.2024 g of biodiesel. This high conversion efficiency highlights the effectiveness of oyster shell–derived calcium oxide modified with polyvinyl alcohol (PVA) in accelerating the transformation of fatty acids into methyl esters.

The CaO/PVA catalyst synthesized from oyster shells and modified with PVA demonstrated high efficiency in biodiesel production, achieving a yield of 96%. This represents a significant improvement in catalytic activity compared to pure CaO, which typically provides lower yields of around 80% (Kedir *et al.* 2023). The incorporation of PVA enhances structural stability and promotes better dispersion of active particles through the formation of a more uniform semi-crystalline network, thereby supporting a more efficient

Biodiesel Characterization

FTIR Analysis

The functional group analysis of biodiesel derived from the transesterification of Pliek U oil using the CaO/PVA catalyst was carried out using FTIR spectroscopy in the wavenumber range of 4000–400 cm^{-1}, as presented in Figure 2.

The FTIR spectrum presented in Figure 2 displays characteristic absorption bands indicative of methyl ester functional groups, confirming that the transesterification reaction proceeded effectively. A strong absorption band was observed at 1741.76 cm^{-1}, corresponding to the stretching vibration of the ester carbonyl group (C=O), which is a distinctive feature of methyl esters (Silva *et al.* 2012; Torres *et al.* 2020). In addition, intense bands were detected at 2923.41 cm^{-1} and 2854.02 cm^{-1}, associated with the asymmetric and symmetric stretching vibrations of –CH_2 and –CH_3 groups in the aliphatic chains of fatty acids (Bani dkk. 2022; Rosset & Perez-Lopez 2019).

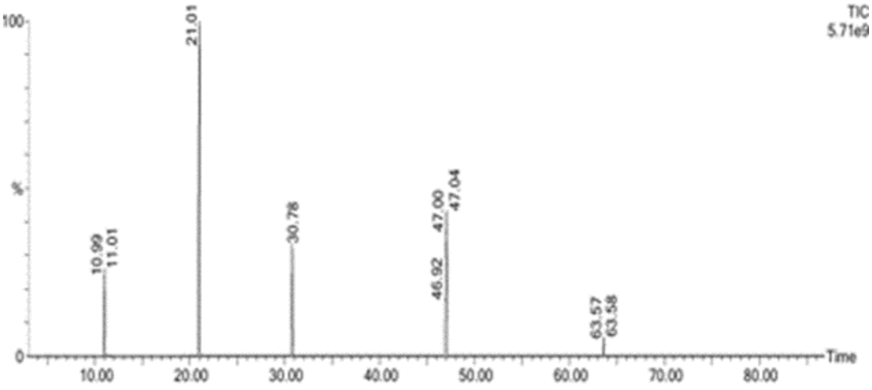

Figure 2. FTIR spectrum of biodiesel from Pliek U oil

The FTIR spectrum of the synthesized biodiesel exhibited an intense absorption band at 1435.99 cm⁻¹, attributed to the symmetric deformation vibration of the methyl group (–CH_3) within the methyl ester structure. This band is recognized as a distinctive marker of biodiesel formed through transesterification, as similarly reported for waste cooking oil-based biodiesel (Khosa *et al.* 2024). The absence of this band in the raw oil highlights that the methyl group arises from the conversion of triglycerides into methyl esters, which are chemically the primary constituents of biodiesel (Fatty Acid Methyl Esters, FAME). The presence of this band thus serves as a reliable indicator for confirming the success of the transesterification process. In the fingerprint region, absorption peaks were observed at 1168.64 cm⁻¹ and 1195.66 cm⁻¹, corresponding to C–O stretching vibrations typically found in methyl ester structures. These features have also been reported in previous FTIR studies of biodiesel as clear evidence of ester formation with a well-defined structure (Shanmugam *et al.* 2017; Suherman *et al.* 2023).

Additional absorption bands were observed at 1015.92 cm⁻¹ and 1113.95 cm⁻¹, which support the presence of C–O–C linkages within the ester structure, as well as =C–H bending vibrations in the range of 723–850 cm⁻¹ (Shanmugam *et al.* 2017; Ishaya *et al.* 2025). Furthermore, the absence of a broad band around 3300–3500 cm⁻¹ indicates that nearly all free hydroxyl groups have reacted, confirming that the transesterification process proceeded efficiently.

GC-MS Analysis

The identification of compounds in the biodiesel produced through the transesterification of Pliek U oil using the CaO/PVA catalyst was carried out by Gas Chromatography–Mass Spectrometry (GC-MS), as presented in Figure 3.

Based on the chromatogram spectrum and reference data from the NIST02 library, various fatty acid methyl esters (FAME) were detected, confirming the successful completion of the transesterification process. The dominant compound identified was methyl octanoate, with a retention time of 21.039 minutes and a peak area percentage of 49.95%. This compound represents the main biodiesel fraction derived from the reaction of caprylic acid with methanol. The high content of caprylic acid is likely influenced by the extraction and fermentation processes of Pliek U oil. In addition, methyl dodecanoate was detected at a retention time of 47.038 minutes with a contribution of 25.60%, while methyl decanoate appeared at 30.779 minutes with a peak area of 12.34%. These three compounds belong to medium-chain saturated fatty acids, which are well recognized for their high oxidative stability and efficient combustion performance (Maes *et al.* 2023; McCormick *et al.* 2024).

In general, the carbon chain length of fatty acid methyl esters (FAME) has a significant influence on the physical properties and performance of biodiesel (Refaat 2009; Hoekman *et al.* 2012).Shorter-chain FAMEs exhibit lower kinematic viscosity and density compared to their longer-chain counterparts. These characteristics are advantageous, as they reduce fuel flow resistance, facilitate injection and atomization within the combustion chamber, and minimize the risk of injector blockage at low temperatures (Gumahin *et al.* 2019).

Other FAME compounds were also detected at relatively lower proportions, including methyl nonanoate (C9:0, 0.026%), methyl tetradecanoate (C14:0, 2.15%), and methyl hexadecanoate (C16:0, 0.019%). The presence of fatty acid methyl esters ranging from short- to long-chain indicates that the produced biodiesel exhibits a complex and diverse profile, which is characteristic of biodiesel derived from waste oils with high free fatty acid (FFA) content. Notably, no polycyclic aromatic compounds or heavy contaminants were detected, suggesting a satisfactory level of purity in the biodiesel. This compositional profile demonstrates that the CaO/PVA catalyst is not only effective in promoting transesterification reactions but also exhibits selective activity toward the formation of medium-chain

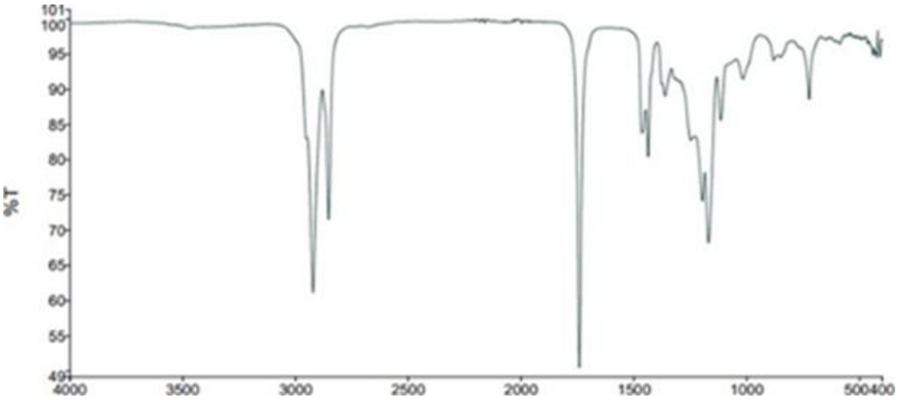

Figure 3. GC-MS chromatogram of Biodiesel

methyl esters, which are desirable for achieving optimal performance in modern biodiesel applications.

For comparison, biodiesel synthesized using pure CaO under identical reaction conditions (12:1 methanol-to-oil molar ratio, 60°C, 90 min) contained only 40% total FAMEs, as determined by GC–MS analysis. A comparison of the main FAME components between the CaO/PVA and pure CaO catalysts is summarized in Table 2.

Although both catalysts produced similar types of fatty acid methyl esters, the overall FAME composition obtained with CaO/PVA (~90%) was more than double that of pure CaO (~40%). This striking difference highlights the effectiveness of polymer modification in overcoming the intrinsic limitations of CaO catalysts. Pure CaO is known to be highly hygroscopic and prone to agglomeration, which reduces its active surface area and facilitates the formation of $Ca(OH)_2$ upon exposure to moisture, thereby lowering catalytic activity (Yan *et al*. 2008; Maisyarah *et al*. 2019). Interestingly, even though XRD analysis of the CaO/PVA catalyst also revealed the presence of $Ca(OH)_2$, the total FAME composition remained high. This suggests that PVA plays a crucial stabilizing role by dispersing CaO particles uniformly and maintaining the accessibility of basic sites through hydrogen bonding interactions, as reported for similar polymer–oxide systems (Niazi *et al*. 2017). Consequently, CaO/PVA achieved superior transesterification efficiency at a lower catalyst loading (2.29%) compared to pure CaO (3%), confirming the significance of PVA incorporation in enhancing both structural stability and catalytic performance.

Evaluation of Biodiesel Fuel Properties in Compliance with National and International Standards

The quality of biodiesel produced from the transesterification of Pliek U oil using the heterogeneous CaO/PVA catalyst was evaluated against both national and international standards, namely SNI 04-7182-2015, ASTM D6751, and EN 14214. The assessed parameters included kinematic viscosity, density, acid value, and water content, as summarized in Table 3.

The test results revealed that the produced biodiesel exhibited a kinematic viscosity of 3.95 cSt, which falls within the acceptable ranges specified by SNI (2.3–6.0 cSt), ASTM D6751 (1.9–6.0 cSt), and EN 14214 (3.5–5.0 cSt). This value indicates that the biodiesel possesses favorable flow stability within the fuel injection system and has the potential to support efficient atomization during combustion (Lin & Ma 2021) Regarding density, the measured value of 885 kg/m³ also complies with the limits set by SNI (850–890 kg/m³) and EN 14214 (860–900 kg/m³). Meeting the density standards is crucial to ensuring volumetric efficiency and optimal combustion performance in diesel engines (Gumahin *et al*. 2019).

The acid value of the biodiesel was determined to be 0.14 mg KOH/g, reflecting an exceptionally low free fatty acid (FFA) content, which is far below the maximum permissible limit of 0.5 mg KOH/g as defined by the Indonesian National Standard (SNI), EN 14214, and ASTM D6751. Such a low acid value indicates high oxidative stability, extended storage life, and reduced risks of mechanical damage and efficiency loss in engines due to corrosion and fuel degradation (Khosa *et al*. 2024). Moreover, the water content of the biodiesel was found to be as low as 0.012%, which remains well below the threshold set by SNI (<0.05%) and EN 14214 (<0.03%). Minimal water content is crucial for preventing fuel system corrosion, avoiding microemulsion formation that could impair engine performance, and reducing the risk of hydrolytic degradation that accelerates FFA formation in biodiesel (Atadashi *et al*. 2012; Yeşilyurt *et al*. 2019).

The produced biodiesel exhibited a flash point of 165°C, which substantially exceeds the minimum requirement specified by SNI (>100°C) as well as international standards. This high flash point confirms that the biodiesel is relatively safe for storage, transportation, and utilization in diesel

Table 2. Comparative FAME composition of Biodiesel using CaO/PVA and pure CaO catalysts

Compound (FAME)	RT (CaO/PVA) (min)	RT (CaO) (min)	CaO/PVA (Area %)	CaO (Area %)
Methyl octanoate	21.04	12.55	49.95	7.76
Methyl decanoate	30.78	18.09	12.34	5.58
Methyl dodecanoate	47.04	23.19	25.60	13.75
Methyl tetradecanoate	63.59	27.72	2.15	6.06
Methyl hexadecanoate	74.16	31.79	0.019	2.12
Methyl stearate	-	35.55	-	0.29
Methyl Hexanoic	-	6.824	-	1.33
Total FAME	-	-	90.059	36.89

Table 3. Comparison of fuel properties of Pliek U Biodiesel with National and International Biodiesel Standards

Parameter	Biodiesel (CaO/PVA)	SNI 04-7182-2015	ASTM D6751	EN 14214
Kinematic Viscosity (cSt)	3.95	2.3–6.0	1.9–6.0	3.5–5.0
Density (kg/m³)	885.0	850–890	860-900	860–900
Acid Value (mg KOH/g)	0.14	<0.5	<0.5	<0.5
Water Content (%)	0.012	<0.05	<0.05	<0.03
Flash Point (°C)	165	<100	<130	<101

engines, as it minimizes the risk of generating flammable vapors at ambient conditions (Fu 2019). From a chemical composition perspective, the elevated flash point obtained in this study also indicates the absence of significant residual alcohol in the biodiesel. This finding aligns with the explanation of Jafarihaghighi *et al*. (2020), who reported that free alcohol content can reduce the flash point and consequently pose safety hazards.

Accordingly, the biodiesel synthesized using the CaO/PVA catalyst not only complies with all quality requirements specified by the Indonesian National Standard (SNI) but also demonstrates internationally competitive fuel characteristics. This finding indicates that the catalyst synthesis approach based on oyster shell waste and polyvinyl alcohol (PVA) successfully produced high-quality biodiesel that is suitable for broader application as an environmentally friendly alternative fuel.

CONCLUSION

A heterogeneous CaO/PVA catalyst derived from oyster shells was successfully synthesized and applied for the transesterification of Pliek U oil, achieving a 96% biodiesel yield under optimum conditions. Structural (XRD, FTIR) and compositional (GC-MS) analyses confirmed its high catalytic activity and the dominance of medium- and long-chain FAME. The produced biodiesel fully met SNI 04-7182-2015, ASTM D6751, and EN 14214 standards. These findings highlight CaO/PVA as a sustainable catalyst route for converting low-value local waste into high-quality biodiesel suitable for broader renewable energy applications.

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