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UTILIZATION AND CHARACTERIZATION OF CaO NANOCATALYST FROM DUCK EGGSHELL IMPREGNATED WITH NaOH AND ITS APPLICATION IN BIODESEL PRODUCTION FROM COOKING OIL

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ABSTRACT

Global energy demand, including in Indonesia, remains heavily dependent on non-renewable sources (fossil fuels), whose reserves are steadily depleting. The combustion of these fuels releases various pollutants into the atmosphere, including carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NOx), which contribute to air pollution, acid rain, climate change, and adverse human health effects such as respiratory and cardiovascular diseases. This condition underscores the urgent need for the development of environmentally friendly alternative fuels such as biodiesel. This study aims to synthesize biodiesel from waste cooking oil through a transesterification reaction using a catalyst derived from duck eggshells, which was converted into a NaOH-impregnated CaO nanocatalyst. The nanocatalyst was prepared via the sol-gel method with continuous stirring for 3 hours at 4000 rpm. NaOH impregnation was applied at concentrations of 35%, 45%, and 55% of the total catalyst weight. The resulting sol-gel was separated from the residue, dried, and then calcined at 900°C for 1 hour, producing nanocatalysts designated as 35NaOH/CaO, 45NaOH/CaO, and 55NaOH/CaO. The catalysts were characterized using FTIR, XRD, and PSA. The transesterification reaction was carried out at 60°C for 2 hours, with an oil-to-methanol molar ratio of 1:9 and a catalyst loading of 3% by weight relative to the oil. The biodiesel produced was characterized using GC-MS, yielding the highest methyl ester content of 99.89% with the 55NaOH/CaO catalyst. These results indicate that the biodiesel produced had a high level of purity and complied with the EN 14103 standard.

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Introduction

Global energy demand, including in Indonesia, remains heavily reliant on non-renewable sources (fossil fuels), whose reserves are steadily depleting. This high dependency on fossil energy is concerning, as the reserves are diminishing and could be exhausted in the near future. Therefore, serious efforts are needed to increase the development of renewable energy sources, and biodiesel is one such alternative energy that can reduce CO_2 emissions by approximately 50%–78.45% (Zurqarnain et al., 2021), making it a potential substitute for fossil fuels. However, biodiesel has a major drawback—70% to 90% of its production cost depends heavily on the feedstock used, particularly due to the fluctuating price of vegetable oils. Biodiesel, as an environmentally friendly alternative fuel, is produced through the transesterification of vegetable oils or animal fats with alcohol in the presence of a base catalyst. This reaction yields biodiesel and glycerol as a by-product (Tanner et al., 2023). Homogeneous base catalysts are commonly used in biodiesel production because they are strong and highly reactive bases that rapidly break ester bonds in triglycerides, allowing the transesterification reaction to proceed efficiently. However, their main drawback is the difficulty of separation from the final product, leading to waste generation. For this reason, heterogeneous catalysts are considered a promising alternative, as they are reusable, which can reduce production costs and minimize environmental impact (Mirzan et al., 2024). In catalytic processes, deactivation of CaO catalysts can occur, so impregnation with NaOH is necessary to prevent deactivation and enhance the strong basicity of the catalyst. In this study, the catalyst was converted into a nanocatalyst to increase its surface area, thereby improving its catalytic efficiency, preventing saponification, and enhancing the transesterification process (Mosaddegh and Khani, 2014).

Research Methods

Type of Research

This study is classified as an experimental research.

Research Objectives

The research object was duck eggshell ash, which was processed into powder form ($CaCO_3$) and then calcined to convert it into CaO. The CaO was subsequently impregnated with NaOH to enhance its catalytic activity in the transesterification reaction of palm oil waste cooking oil with methanol to produce biodiesel.

Research Location and Duration

The research activities will be carried out at the Physical Chemistry Laboratory, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya, with a research duration of approximately six months.

Research Tools and Materials

The equipment to be used in this study includes glass bottles, a furnace, a 500 mL three-neck round-bottom flask, an analytical balance (Precision Balance TP-4101), porcelain crucibles, 80-mesh and 100-mesh sieves, mortar and pestle, hotplate magnetic stirrer, stopwatch, spatula, blender, desiccator, filter paper, separatory funnel, reflux apparatus, thermometer, water hoses, clamps, stands, as well as several analytical instruments: XRF (PANalytical Minipal 4), FTIR (Shimadzu IR Prestige 21), XRD (PANalytical X'Pert PRO), PSA (Malvern Nano ZS), SEM (FEI Inspect-S50), GC-MS (Shimadzu QP2010 Plus), and other common glassware used in laboratory work. The materials required for this research include eggshells obtained from street vendors in the areas of Surabaya, Sidoarjo, and Brebes; waste cooking oil collected from restaurants around Surabaya (with variations in frying frequency to increase applicability, categorized as waste cooking oil with a minimum of one frying cycle); methanol (Merck); calcium acetate hydrate 97% (LOBA Chemie); distilled water; ethanol (Merck); 0.1 N KOH or NaOH (Merck); and phenolphthalein (PP) indicator.

Result and Discussion

Results of Waste Cooking Oil (WCO) Quality

The quality analysis of WCO (Waste Cooking Oil) included testing for Free Fatty Acid (FFA) content and moisture content. The FFA content was determined using the ASTM D5555 method, while the moisture content was analyzed using the ASTM D6751 method. These two parameters are critical in evaluating the suitability of WCO as a feedstock for biodiesel production. Table 1 presents the results of the WCO quality analysis used as the raw material in this study.

Table 1. Results of Waste Cooking Oil (WCO) Quality Testing

Parameter	Test Method	Research result	Threshold Value	Reference
FFA Content(%)	**ASTM D5555**	**3,97**	**Max.2**	**(Suzihaque et al., 2022)**
Moisture Content(%)	**ASTM D6751**	**0,07**	**Max.0,5**	**(Gardy et al., 2016)**

Based on table 1, it can be observed that the FFA content in the WCO exceeds the recommended maximum standard. In this study, the FFA level in WCO was found to be 3.97%, whereas the transesterification process requires oil with an FFA content of less than 2%. A high FFA content can interfere with the transesterification reaction by triggering a saponification reaction between the catalyst and the FFA. On the other hand, the moisture content of the WCO sample was 0.07%, which is still within the acceptable limit for biodiesel feedstock (maximum 0.5%). To reduce the FFA content in the WCO to below 2%, an esterification reaction was carried out. The purpose of this reaction is to reduce the FFA content by converting free fatty acids into methyl esters. In this study, the FFA level successfully decreased from 3.97% to 0.2% after esterification. Therefore, the WCO was deemed suitable for use in the transesterification process for biodiesel production.

FTIR

FTIR characterization was carried out to identify the functional groups present in the catalyst. The analysis was performed on CTB catalyst and on $_{35}$NaOH/CaO, $_{45}$NaOH/CaO, and $_{55}$NaOH/CaO samples, within the wavenumber range of 500–4000 cm^{-1}. The resulting FTIR spectra are shown in Figure 1, and the corresponding absorption peak analysis is presented in table 2.

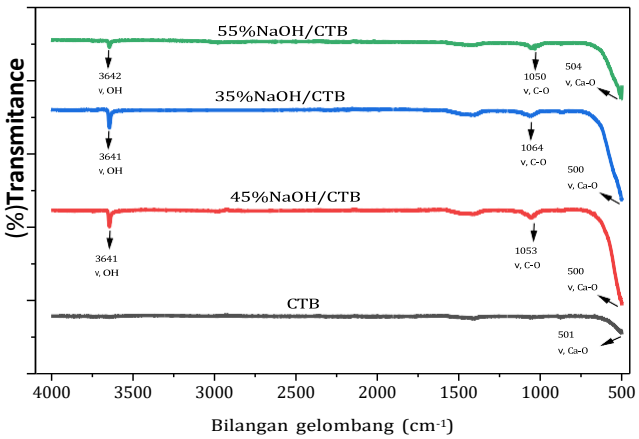


Figure 1. FTIR Spectra Results of $_{35}$NaOH/CaO, $_{45}$NaOH/CaO, and $_{55}$NaOH/CaO

Table 2 FTIR Spectral Analysis Results of the Nanocatalysts $_{55}$NaOH/CaO, $_{45}$NaOH/CaO, and $_{35}$NaOH/CaO

Functional Group Interpretation	Wavenumber (cm^{-1})				
	Reference	0NaOH/CaO	35NaOH/CaO	45NaOH/CaO	55NaOH/CaO
O–H Stretching Vibration	3500-3700*	-	3641	3641	3642
C–O Stretching Vibration	1050-1085*	-	1064	1053	1050
Ca=O Bending Vibration	500-600*	501	500	500	504

Based on Table 2, FTIR spectral results for the nanocatalysts 55NaOH/CaO, 45NaOH/CaO, and 35NaOH/CaO show absorption bands in the range of 3641–3642 cm^{-1}. These bands correspond to the presence of hydroxyl (-OH) groups, originating from water molecules. As the NaOH content increases, the intensity of the –OH peak at 3641 cm^{-1} also increases. This is due to the hygroscopic nature of CaO, which readily reacts with water vapor to form calcium hydroxide ($Ca(OH)_2$), containing O–H groups that generate O–H stretching bands in the FTIR spectrum (Widiarti et al., 2019). These hydroxyl groups appear in the samples containing a mixture of CaO and NaOH, but are absent in pure CaO. Another peak observed in the range of 1050–1064 cm^{-1} indicates C–O stretching vibrations. This peak is associated with the presence of carbonate groups (CO_3^{2-}) or interactions with carbon dioxide (CO_2) from the air, which can react with CaO to form calcium carbonate ($CaCO_3$), or with residual NaOH to form sodium carbonate (Na_2CO_3) (Suzihaque et al., 2022).

Additionally, peaks in the region of 500–504 cm^{-1} correspond to Ca=O bending vibrations, which are characteristic of Ca=O bonds in pure CaO. In the mixed spectra, the intensity of this peak tends to decrease due to the interaction between CaO and NaOH. A dominant absorption at 501 cm^{-1} (Ca=O) is still visible. The hygroscopic nature of NaOH leads to CO_2 absorption from the air, potentially forming carbonate species during the NaOH impregnation process on CaO. The FTIR spectroscopic analysis confirms the successful impregnation of NaOH into CaO, as evidenced by the characteristic absorption peaks corresponding to –OH groups. Surface modification of the catalyst due to this impregnation is further validated by the

presence of peaks corresponding to Ca=O bond vibrations. Therefore, the FTIR spectra comprehensively validate the successful incorporation of NaOH into the CaO catalyst (Suzihaque et al., 2022). A similar result was also reported in the study by Fizza Nadeem (2021), where the FTIR analysis of NaOH/CaO conducted to identify functional groups showed a sharp peak at 3640 cm^{-1}, attributed to the stretching vibration of the hydroxyl (–OH) group. A strong peak at 500 cm^{-1} indicated the presence of the Ca–O bond. Meanwhile, peaks at 1410 cm^{-1}, 1180 cm^{-1}, and 850 cm^{-1} were associated with C–O bonds, which are related to the carbonation of nano-CaO particles.

XRD

X-ray diffraction (XRD) analysis was performed to determine the phases, crystallinity, and crystal size of the catalyst. The catalysts were characterized using XRD within the 2θ range of 10–90°. The types of compounds or elements present can be identified from the peaks that appear at specific diffraction angles (2θ). The diffraction patterns of the catalysts $_{35}$NaOH/CaO, $_{45}$NaOH/CaO, and $_{55}$NaOH/CaO are shown in Figure 2

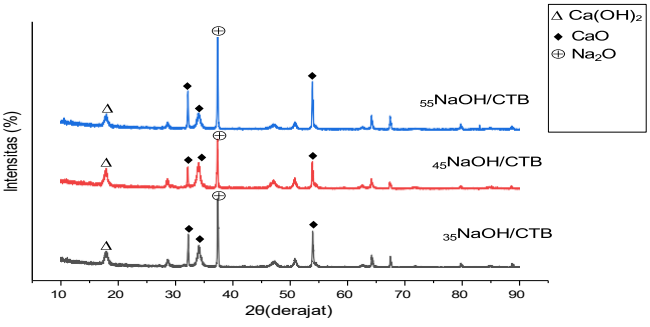


Figure 2. XRD Results of $_{35}$NaOH/CaO, $_{45}$NaOH/CaO, and $_{55}$NaOH/CaO

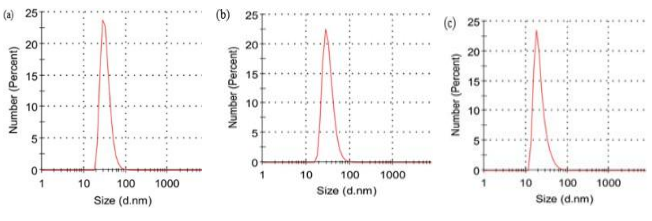
Table 3. XRD Analysis Results of $_{35}$NaOH/CaO, $_{45}$NaOH/CaO, and $_{55}$NaOH/CaO

Kode Sampel	Senyawa Teridentifikasi	2θ (derajat)	Simbol Puncak
$_{35}$NaOH/CaO	CaO, Na_2O, CaO	32.25; 37.41; 53.91	♦, ⊕, ♦
$_{45}$NaOH/CaO	CaO, Na_2O , CaO	34.15; 37.39; 53.91	♦, ⊕, ♦
$_{55}$NaOH/CaO	CaO, Na_2O , CaO	32.29; 37.43; 53.97	♦, ⊕, ♦

Based on Figure 2, the diffraction pattern of the catalyst indicates the presence of $Ca(OH)_2$ in relatively high proportions. The addition of NaOH to CaO promoted the formation of CaO, as indicated by the appearance of diffraction peaks at 2θ = 32.25°, 37.41°, and 53.91° for the 35NaOH/CaO nanocatalyst; at 2θ = 34.15°, 37.39°, and 53.91° for the 45NaOH/CaO nanocatalyst; and at 2θ = 32.29°, 37.43°, and 53.97° for the 55NaOH/CaO nanocatalyst. A characteristic peak of Na_2O was detected at 2θ = 37.0° for all nanocatalysts (35NaOH/CaO, 45NaOH/CaO, and 55NaOH/CaO), based on [JCPDS 44-1481], which corresponds to the main component of NaOH that decomposes into Na_2O. This confirms the presence of NaOH in all 35NaOH/CaO-based nanocatalysts. The formation of Na_2O is attributed to the impregnation of CaO with NaOH, aimed at increasing the number of active sites to enhance the efficiency of the transesterification process for biodiesel production (Suzihaque et al., 2022). The detection of Na_2O thus confirms the successful impregnation of NaOH into the CTB-based catalyst synthesis with the appropriate composition. Similar results were reported by Karfika Ainil Hawa et al. (2020), in which a heterogeneous NaOH/CaO/C catalyst was synthesized from eggshell waste through calcination, hydration, and dehydration processes. XRD characterization showed the strongest diffraction peak at 2θ = 37.43°, indicating the presence of Na_2O. In addition, $Ca(OH)_2$ was also detected, suggesting that not all CaO was converted during the calcination process. The presence of this compound can influence the catalytic activity in the transesterification reaction (Hawa et al., 2020).

PSA

PSA (Particle Size Analyzer) analysis was used to determine the particle size distribution and the size of particles within the sample (Nurhayati et al., 2021). Characterization was conducted on the nanocatalysts 35NaOH/CaO, 45NaOH/CaO, and 55NaOH/CaO. The results of the PSA analysis are presented in Figure 3



(a) **(b)** **(c)**

Figure 3. PSA Results of the Nanocatalysts: (a) $_{35}$NaOH/CaO; (b)$_{45}$NaOH/CaO; and (c) $_{55}$NaOH/CaO

The PSA results show a particle size distribution graph in which most particles fall within the nanoscale range (1–100 nm), with

dominant particle sizes of approximately 79.05 nm for $_{35}$NaOH/CaO, 41.24 nm for $_{45}$NaOH/CaO, and 30.7 nm for $_{55}$NaOH/CaO. The majority of the particles are classified as nanoparticles (1–100 nm), with an average particle size of 50.33 nm. This indicates that the samples exhibit relatively heterogeneous particle size distributions, yet still suggest a wide dispersion of particle sizes, which may imply overall uniformity in size.

Figure (b) shows PSA results with a narrower and more symmetrical distribution compared to Figures (a) and (c), indicating that the particles have more homogeneous sizes. This suggests that a greater number of particles are concentrated within a smaller size range (30–50 nm), reflecting a more uniform size distribution. Materials converted into nanoparticles exhibit unique properties such as high reactivity and large surface area, which can enhance the efficiency and success of the transesterification process (Mahmood et al., 2024). A similar study was conducted by Mahmood in 2024, entitled "Biodiesel Production Using CaO Nanocatalyst Extracted from Mango Leaves", which reported that the CaO nanocatalyst achieved an average particle size distribution of 24.65 nm.

Biodiesel Quality Test Results

The biodiesel produced must meet international quality standards as determined by ASTM International (American Society for Testing and Materials). Standardized biodiesel aims to provide fuel with high quality and more complete combustion. The quality parameters tested in this study included acid value, moisture content, density, and viscosity. The results of the biodiesel quality analysis are presented in Table 4.

Table 4. Biodiesel Quality Test Results

Parameter	Sampel				ASTM Standard
	0NaOH/CaO	**$_{35}$NaOH/CaO)**	**$_{45}$NaOH/CaO**	**$_{55}$NaOH/CaO**	
Acid value (mg KOH/g)	0,35	0,35	0,47	0,32	Max. 0,5 (ASTM D6751)
Moisture content (%)	0,67	0,35	0,23	0,51	Max. 0,05 (ASTM D6751)
Density (g/ml)	0,535	0,537	0,530	0,534	0,82-0,90 (ASTM D4052)
Viskosity (mm2/s)	3,52	2,86	2,97	3,29	1,9-6,0(ASTM D445)

Based on Table 4, the results of the biodiesel analysis indicate that the acid value and viscosity meet the required standards; however, the density is too low and the moisture content is too high. This condition is attributed to the high water content remaining in the transesterification product, which ideally should be further dried in an oven to reduce its moisture content. The low density may also be caused by suboptimal methyl ester content, the presence of other compounds, or residual water and impurities (such as glycerol that was not completely separated during the purification process), all of which can contribute to reduced density. Low density in biodiesel can affect its compliance with standard physical properties, potentially decreasing combustion efficiency and engine performance.

Fatty Acid Methyl Ester

(a)

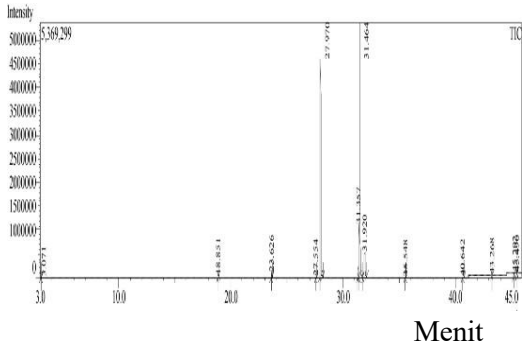


Figure 4. GC-MS Spectral Analysis of the $_{0}$NaOH/CaO Sample

(b)

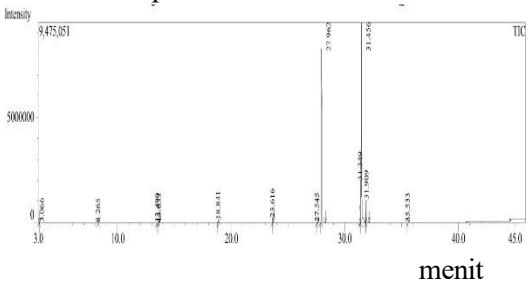


Figure 5. GC-MS Spectral Analysis of the $_{55}$NaOH/CaO Sample

In Figures 4 and 5, the GC-MS (Gas

Chromatography–Mass Spectrometry) results of biodiesel are presented, showing the ester compound peaks contained in biodiesel samples synthesized using $_0$NaOH/CaO and $_{55}$NaOH/CaO catalysts. Figure 4 shows the GC-MS results of biodiesel produced with the 0NaOH/CaO catalyst, where two dominant peaks with high intensity were observed at retention times of 31.467 minutes and 27.967 minutes. These peaks indicate the presence of methyl esters, specifically methyl oleate ($C_{19}H_{36}O_2$) and methyl palmitate ($C_{17}H_{34}O_2$). Figure 5 presents the GC-MS results of biodiesel produced with the 55NaOH/CaO catalyst. The chromatogram displays two major peaks corresponding to methyl esters, with the highest component identified as methyl oleate ($C_{19}H_{36}O_2$), accounting for 48.70% of the total peak area, followed by methyl palmitate ($C_{17}H_{34}O_2$), which contributed 36.44% of the total peak area. Several additional peaks were also detected within the retention area percentage range of 35–48%. The GC-MS results, expressed as the percentage composition of biodiesel synthesized using $_0$NaOH/CaO and $_{55}$NaOH/CaO catalysts, are summarized in Tables 5 and 6.

Table 5. GC-MS Results of Biodiesel with $_0$NaOH/CaO Catalyst

Compound Name	Molecular Formula	Retention Time (min)	% Area
9-Octadecenoic acid, methyl ester (Metil oleat)	$C_{19}H_{36}O_2$	31.467	48.61
Hexadecanoic acid, methyl ester (Metil palmitat)	$C_{17}H_{34}O_2$	27.967	37.20
9,12-Octadecadienoic acid (Z,Z)-, methyl ester (Metil linoleate)	$C_{19}H_{36}O_2$	31.920	8.45
Octadecanoic acid, methyl ester (Metil stearat)	$C_{19}H_{38}O_2$	31.920	4.46
Tetradecanoic acid, methyl ester (Metil tetradekanoat)	$C_{15}H_{30}O_2$	23.626	0.68
Undecanoic acid, methyl ester (Metil Undecanoate)	$C_{12}H_{24}O_2$	18.851	0.25
Total FAME (%):			98.61
Pentasiloxane, 1,1,3,3,5,5,7,7,9,9-decamethyl	$C_{10}H_{32}O_4Si_5$	45.292	0.10
Hexanoic acid, 2-methyl-	$C_7H_{14}O_2$	35.550	0.05
Acetic acid, 1,1-dimethylethyl ester	$C_{16}H_{32}O_2$	3.071	0.04
3-(p-Methoxybenzoyl)-propionic acid	$C_{11}H_{12}O_4$	40.642	0.03
2-(4-Benzyl-5-mercapto-4H-[1,2,4]triazol-3-yl)-phenol	$C_{15}H_{13}N_3OS$	43.268	0.01
Total Identified Compounds:			100

Table 6. GC-MS Results of Biodiesel with $_{55}$NaOH/CaO Catalyst

Compound Name	Molecular Formula	Retention Time (min)	% Area
9-Octadecenoic acid, methyl ester (Metil oleate)	$C_{19}H_{36}O_2$	31.456	48,70
Hexadecanoic acid, methyl ester (Metil palmitate)	$C_{17}H_{34}O_2$	31,438	36,44
9,12-Octadecadienoic acid, methyl ester (Metil linoleate)	C19H36O2	31.349	8,20
Dodecanoic acid, methyl ester (Metil laurat)	$C_{13}H_{26}O_2$	18.841	0,40
9-Octadecenoic acid (Z)-, methyl ester (Metil oleate)	$C_{19}H_{36}O_2$	23.616	0,11
Tetradecanoic acid, methyl ester (Metil miristat)	$C_{16}H_{32}O_2$	35.533	0,05
Octadecanoic acid, methyl ester (Metil stearat)	$C_{19}H_{38}O_2$	31,909	5,17
Tetradecanoic acid, methyl ester (Metil tetradekanoat)	$C_{15}H_{30}O_6Si_4$	23.616	0,82
Total FAME (%):			99.89
2-Pentanone, 4-hydroxy-4-methyl-	$C_6H_{12}O_2$	3,066	0,03
Hexanoic acid, 2-methyl-	$C_7H_{14}O_2$	8.265	0.03
Cyclopropanecarboxaldehyde, methylene-	C_2H_6O	13.490	0.04
Hexanoic acid, 2-methyl-	$C_7H_{14}O_2$	13.633	0.67
Total Identified Compounds:			100

Based on the results presented in Tables 5 and 6, the total methyl ester content in biodiesel produced from the transesterification reaction using the 0NaOH/CaO nanocatalyst was 98.61%, while that using the 55NaOH/CaO nanocatalyst reached 99.89%. The biodiesel obtained with the 55NaOH/CaO nanocatalyst met the EN14103 standard, which requires a minimum methyl ester content of 96.50%. These data indicate that the

methyl ester content in biodiesel produced with the 55NaOH/CaO nanocatalyst was higher than that with $_{0}$NaOH/CaO, confirming that the transesterification process proceeded effectively, yielding a methyl ester content of 99.89%.

This increase can be attributed to the strong basic properties of NaOH. When impregnated into CaO, which functions as a heterogeneous catalyst in the transesterification process, the NaOH enhances the number of basic sites on the catalyst surface. The increase in basic sites facilitates greater conversion of triglycerides into methyl esters, resulting in higher-purity biodiesel (Suzihaque et al., 2022).

Conclusion

Based on this study, it can be concluded that the physicochemical characteristics of the NaOH/CaO nanocatalyst were obtained through FTIR, XRD, and PSA analyses. The XRD characterization revealed a diffraction peak at 2θ = 37°, which is a characteristic peak of Na_2O, indicating the successful impregnation of CaO with NaOH. FTIR analysis also confirmed the presence of OH groups resulting from NaOH impregnation. Furthermore, PSA results showed that most particles were within the nanoscale range (1–100 nm), with dominant particle sizes of approximately 79.05 nm for $_{35}$NaOH/CaO, 41.24 nm for $_{45}$NaOH/CaO, and 30.7 nm for $_{55}$NaOH/CaO. The majority of the particles fell into the nanoparticle category, indicating that PSA characterization produced favorable results, which suggest high reactivity and a large surface area—factors that can enhance the transesterification process.

Catalytic activity was determined based on the methyl ester content in biodiesel as measured by GC-MS analysis. Biodiesel synthesized using the 0NaOH/CaO nanocatalyst showed a methyl ester content of 98.61%, which meets the EN 14103 standard of 96.50%. Biodiesel with the 55NaOH/CaO nanocatalyst exhibited an even higher methyl ester content of 99.89%, also meeting the EN 14103 standard. These results suggest that the study was successful in producing biodiesel that meets international standards for methyl ester purity. However, the relatively high water content and low density of the biodiesel may indicate that the production process is not yet fully optimized. These factors could negatively affect engine performance and combustion due to the presence of excess water and suboptimal fuel density.

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References

Agusliana, S., Kalla, R., & Suryanto, A. (2021). Pembuatan Biodisel Dengan Penambahan Katalis CaO dari Cangkang Telur.

Ashok, C., Kiran Kumar, M., Chakra, C. S., Rao, K. V., & Dayakar, T. (2021). Calcium Oxide Nano Particles Synthesized from Chicken Egg Shells by Physical Method.

Awogbemi, O., Ojo, A. A., & Adeleye, S. A. (2024). Advancements in the application of metal oxide nanocatalysts for sustainable biodiesel production. In Discover Applied Sciences (Vol. 6, Issue 5). Springer International Publishing. https://doi.org/10.1007/s42452-024-05920-3

Bakti manggara, A., Papilaka, T., & Rachmat Triandi, dan T. (n.d.). Penentuan ukuran Kristal (crystallite size) lapisan tipis PZT dengan metode XRD melalui pendekatan persamaan Debye Scherrer.

Bethan, M. S., & Supriyo, E. (2021). Transesterifikasi minyak kelapa menjadi biodiesel dengan katalis cao dan penerapan biodiesel (b40) pada alat fogging. Gema Teknologi, 21(2), 81–85.

Biodiesel Yang Dibuat Dari Minyak Jelantah Menggunakan Katalis Abu Sabut Kelapa, K., & Eka Pratiwi, D. (2024). Biodiesel characterization made of recycled frying oil with coconut fiber (C. nucifera L.) catalyst (Vol. 25).

Burks, T., Uheida, A., Saleemi, M., Eita, M., Toprak, M. S., & Muhammed, M. (2013).

Removal of Chromium(VI) Using Surface Modified.

Nurhasyiri, A. I., Zamhari, M., & Mediniariasty, D. A. (2022). Sintesis Katalis Abu Sekam Padi Terimpregnasi dengan CaO dari Cangkang Telur dan KOH untuk Pembuatan Biodisel dariminyakJelantah.JurnalKinetika,13(03),56-61. https://jurnal.polsri.ac.id/index.php/kimia/index.

Oko, Syarifuddin, Andri Kurniawan, Karina Nur, Eka Putri, and Jurusan Teknik Kimia. 2021. "Sintesis biodiesel dari minyak jelantah menggunakan katalis NaOH/CaO/C dari cangkang telur."

Oko, S., & Feri, M. (2019). Pengembangan katalis cao dari cangkang telur ayam dengan impregnasi koh dan aplikasinya terhadap pembuatan biodiesel dari minyak jarak. 11(2). https://doi.org/10.24853/jurtek.11.2.103-110.

Oko, S., Kurniawan, A., Willain, D., & Studi Teknik Kimia Politenik Negeri Samarinda Jalan Ciptomangunkusumo Kampus Gunung Lipan PoBox, P. (2021). Sintesis biodiesel dari minyak kedelai melalui reaksi transesterifikasi dengan katalis CaO/NaOH.

P., Ling, Jt., Djamin, M., Soni .S. Wirawan, dan, di Pusat Pengkajian dan Penerpan Teknologi Konversi dan Konservasi Energi, P., di Balai Rekayasa Desain dan Sistem Teknologi, P., & Pengkajian dan Penerapan Teknologi, B. (2021). Pengaruh komposisi biodiesel terhadap kinerja mesin dan emisi gas buang.

Pamungkas, A., Amri, K., Pratiwi, F. T., Arisant, A. G., Solikhah, M. D., Teknologi Bahan Bakar dan Rekayasa Disain, B., & Riset dan Inovasi Nasional, B. (2021). Pengaruh Waktu Penyimpanan Terhadap Kadar Air dan Angka Asam pada Sampel Biodiesel dan Campuran Biodiesel (BXX).

Permata Lestari, L., & Sylvia, N. (2021). Pengaruh suhu dan waktu reaksi transesterifikasi minyak jarak kepyar (castor oil) terhadap metil ester dengan menggunakan katalis abu.

Prastyo, E., Farkhatus, D. S., & Astuti Ibrahim, P. (2021). Pengaruh Waktu Reaksi Terhadap Yield dan Kandungan Metil Ester Sintesis Biodiesel Ampas Tahu Metode Elektrokatalitik. In Jurnal Tekno Insentif | (Vol. 15, Issue 1).

Shahzad, M. F., Xu, S., Lim, W. M., Yang, X., & Khan, Q. R. (2024). Artificial intelligence and social media on academic performance

Suzihaque, M. U. H., Syazwina, N., Alwi, H., Ibrahim, U. K., Abdullah, S., & Haron, N. (2022). A sustainability study of the processing of kitchen waste as a potential source of biofuel: Biodiesel production from waste cooking oil (WCO). Materials Today: Proceedings, 63, S484–S489.

Syarifudin, S., Cahyo, H. N., & Suprihadi, A. (2020). Korelasi Propertis Biodiesel Terhadap Emisi Gas Buang dan Performa Mesin Diesel. Infotekmesin, 11(1), 9–13.

Symoniuk, E., Wroniak, M., Napiórkowska, K., Brzezińska, R., & Ratusz, K. (2022). Oxidative Stability and Antioxidant Activity of Selected Cold-Pressed Oils and Oils Mixtures. Foods, 11(11).

Taufik, M., & Atma, Y. (2021). Perubahan karakteristik fisikokimia minyak selama penggorengan dengan metode deep fat frying: kajian literatur. Agrointek : Jurnal Teknologi Industri Pertanian, 15(3), 964–975.

Tahvildari, K., Anaraki, Y. N., Fazaeli, R., Mirpanji, S., & Delrish, E. (2015). The study of CaO and MgO heterogenic nano-catalyst coupling on transesterification reaction efficacy in the production of biodiesel from recycled cooking oil. Journal of Environmental Health Science and Engineering, 13(1).