2026 Jurnal Kejuruteraan, Teknologi dan Sains Sosial
Journal of Engineering, Technology and Social Science
Volume 12 Issue 2, e-ISSN: 27166848

SYNTHESIS OF BIODIESEL FROM WASTE COOKING OIL BY USING EGGSHELL AS CATALYST

Ts. Rusyidah binti Mat Zin Boestami[1*] and Ts. Farah Waheda binti Othman[2]

[1] *Jabatan Matematik, Sains dan Komputer, Politeknik Sultan Idris Shah, Sabak Bernam, Selangor*
[2] *Teknologi Maklumat dan Komunikasi, Politeknik Sultan Idris Shah, Sabak Bernam, Selangor*
[1] *rusyidahmatzin@gmail.com*

ARTICLE INFO

Article history:
Received
31 July 2025
Received in revised form
22 October 2025
Accepted
04 April 2026
Published online
30 June 2026

Keywords*:*
Biodiesel; Waste Cooking Oil; Eggshell Catalyst; Green Synthesis

ABSTRACT

In the quest for sustainable alternatives to fossil fuels, biodiesel has emerged as a promising solution. This research explores a green synthesis route for biodiesel production using waste cooking oil (WCO) and a novel heterogeneous catalyst derived from calcined chicken eggshells. This study also highlights a sustainable waste-to-energy pathway aligned with the UN Sustainable Development Goals (SDGs), particularly SDGs 7, 12, and 13. The primary objective is to investigate the efficacy of calcium oxide (CaO) obtained from eggshells as a low-cost, eco-friendly catalyst in the transesterification process. Eggshells were calcined at high temperatures to yield CaO, which was then utilized in the transesterification of WCO with methanol. The catalyst was characterized using Fourier-transform infrared spectroscopy (FTIR), while Gas Chromatography-Flame Ionization Detection (GC-FID) was used to analyze the fatty acid methyl esters (FAMEs) produced. Results indicate that use of catalyst and methanol to oil molar ratios significantly influence biodiesel yield, with an optimal yield achieved at a 12:1 methanol to oil ratio and 5g of catalyst. FTIR confirmed the successful conversion of calcium carbonate to calcium oxide and GC-FID data validated biodiesel production. The research highlights the potential of converting kitchen waste into valuable energy, aligning with circular economy principles and environmental conservation. This work provides a scalable and sustainable methodology that contributes to the reduction of both waste and reliance on petroleum-based fuels.

2026 Jurnal Kejuruteraan, Teknologi dan Sains Sosial
Journal of Engineering, Technology and Social Science
Volume 12 Issue 2, e-ISSN: 27166848

1. Introduction

Global reliance on fossil fuels has contributed significantly to climate change, environmental degradation and health related problems due to greenhouse gas emissions and air pollution (Wolf et al., 2025). In response, sustainable energy sources have gained increasing attention. Biodiesel is one such promising renewable energy alternative. It is biodegradable, non-toxic and can reduce emissions of carbon monoxide and particulate matter when compared to traditional petroleum diesel (Idris et al., 2024). Biodiesel, a renewable, biodegradable fuel, offers a cleaner alternative to conventional diesel. Traditional biodiesel production relies on chemical catalysts like sodium hydroxide or potassium hydroxide, which pose operational and environmental challenges such as soap formation and wastewater generation. Heterogeneous catalysts, such as calcium oxide (CaO), provide advantages like reusability, ease of separation, and reduced environmental impact (Singh et al., 2021 and Sharifi et al., 2025).
Chicken eggshells, an abundant biowaste, primarily comprise calcium carbonate ($CaCO_3$), which can be thermally converted into calcium oxide (CaO) a highly active catalyst for transesterification. Eggshells, typically discarded as kitchen waste, are rich in calcium carbonate and can be transformed into CaO through calcination. Using waste cooking oil (WCO) and eggshells not only provides a dual waste utilization strategy but also aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) by promoting clean biofuel production, minimizing waste, and reducing greenhouse gas emissions. This approach supports circular economy principles and sustainable resource management, contributing to environmental protection and energy security (Yaashikaa et al., 2022; Chung et al., 2019).
This study investigates the application of eggshell derived CaO as a green, low cost catalyst in the transesterification of WCO for biodiesel production. The findings contribute to sustainable energy solutions through waste valorization. The objective is to optimize the transesterification process by varying methanol to oil ratios and catalyst loading, with thorough analysis using FTIR and GC-FID techniques.

2. Previous Studies

Recent advances in biodiesel synthesis have increasingly focused on the use of biowaste-derived catalysts due to their cost-effectiveness, sustainability, and catalytic efficiency. Several studies have demonstrated the successful application of such catalysts in transesterification reactions.

Alsaiari et al. (2023) reported that eggshell-derived calcium oxide (CaO) catalysts calcined at 950 °C exhibit excellent catalytic activity and can be reused over multiple cycles with minimal loss in biodiesel yield, achieving approximately 88% fatty acid ethyl esters. The catalyst was thoroughly characterized, and FAME formation was confirmed by GC-MS analysis, highlighting the potential of eggshell waste valorization for green catalysis (Alsaiari et al., 2023). Similarly, a recent study demonstrated that CaO derived from calcined snail shells can achieve biodiesel yields up to 96.1%, maintaining high stability over six reuse cycles, underscoring mollusk shell waste as a sustainable and efficient catalyst source (Das et al., 2024).

Optimization of reaction parameters remains crucial for maximizing biodiesel production efficiency. Erchamo et al. (2021) emphasized that increasing the methanol to oil molar ratio and catalyst loading enhances transesterification conversion; however, exceeding optimal values leads to soap formation, which adversely affects biodiesel yield and purification. They identified an optimal temperature around 60 °C for base-catalyzed biodiesel synthesis, aligning with previous findings (Erchamo et al., 2021). Abu Bakar et al. (2024) further demonstrated that reaction time and temperature significantly influence biodiesel yield, with optimal results obtained at 50 °C and 2 hours reaction time, beyond which yields decline due to side reactions (Abu Bakar et al., 2024).

In addition to performance metrics, the environmental impact and sustainability of catalysts are gaining attention. Yaashikaa et al. (2022) underscored that biowaste-derived catalysts align well with green chemistry principles by reducing environmental toxicity, promoting catalyst reusability, and valorizing waste streams, thereby contributing to circular economy goals (Yaashikaa et al., 2022). Analytical techniques such as GC-MS and FTIR have been validated as reliable methods for monitoring catalyst quality and confirming fatty acid methyl ester (FAME) formation during biodiesel synthesis (Alsaiare, 2023).
Overall, these studies collectively highlight the promising role of biowaste-derived CaO catalysts in sustainable biodiesel production, emphasizing the importance of optimizing reaction conditions and employing robust analytical tools for process monitoring.

3. Materials and Methods

The experimental procedures and analytical techniques employed in the production and characterization of biodiesel from waste cooking oil (WCO) using eggshell-derived calcium oxide (CaO) as a heterogeneous catalyst. The methodology is divided into two main components: the experimental procedures involved in biodiesel synthesis and the data collection and analysis methods used to evaluate the efficiency and quality of the produced biodiesel. An overview of the experimental workflow is illustrated in Figure 1, which presents a simplified flowchart of the entire process, from material preparation to biodiesel analysis.

3.1 Experimental Procedures

Waste cooking oil (WCO) was collected from the cafeteria of a restaurant and food stalls, while chicken eggshells were sourced as the raw material for the catalyst. The eggshells were thoroughly washed, dried, and crushed. All reagents, including methanol, were of analytical grade.
To prepare the catalyst, the eggshells were calcined in a muffle furnace at 900 °C for 4 hours. The calcined white powder, predominantly calcium oxide (CaO), was then stored in a desiccator. The successful conversion of calcium carbonate ($CaCO_3$) to calcium oxide (CaO) was confirmed using Fourier-transform infrared (FTIR) spectroscopy, as shown in Figure 2.

Figure 1: Biodiesel and Catalyst production process

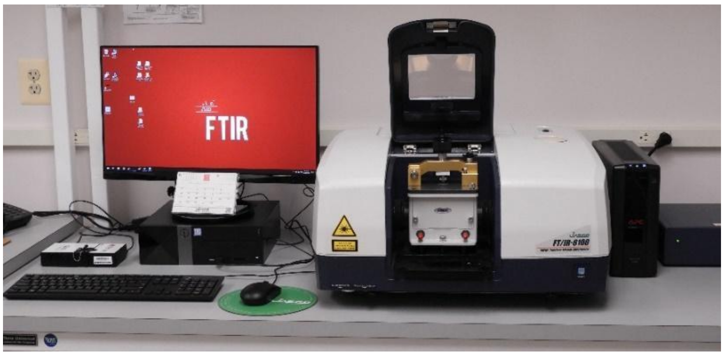

Figure 2: Fourier-transform infrared spectroscopy (FTIR)

Prior to transesterification, WCO was filtered and pre-heated to remove impurities. The reaction was conducted by mixing WCO with methanol in a 12:1 molar ratio, using 5 g of the prepared CaO catalyst. The mixture was stirred continuously at 60 °C for 2 hours to ensure efficient conversion into biodiesel.

3.2 Data Collection and Analysis

Data were collected through direct observation and organized into tables to compare the differences in biodiesel yield based on varying methanol-to-oil ratios and catalyst amounts. The experimental results were evaluated to determine the optimal reaction conditions for biodiesel production.

Additionally, gas chromatography equipped with a flame ionization detector (GC–FID), illustrated in Figure 3, was used to identify and quantify the components present in the biodiesel samples. The detector operates by ionizing organic compounds as they exit the chromatographic column, generating a measurable signal proportional to the amount of carbon in the sample.

Figure 3: Gas Chromatography - Flame Ionization Detection (GC- FID)

A systematic sampling method was employed to gather supporting data from a selected group of Polytechnic students and staff. This approach reduces sampling bias while maintaining representative coverage of the target population.
For data interpretation, quantitative data analysis was applied. Statistical methods were used to convert raw observational data into numerical values, enabling the generalization of results and validation of the effectiveness of the catalyst and reaction conditions.

4. Results

Biodiesel is an earth-friendly fuel and a decent replacement for non-renewable energy sources. Notwithstanding, the immaculateness of this fuel is a significant worry that challenges scientists. In this examination, a calcium oxide-based catalyst has been set up from nearby waste eggshells by the calcination process and tested for in situ biodiesel. The ideal catalyst was obtained from eggshells were powdered and calcined at temperatures of 900°C for 3 hours. The catalyst was inspected by Fourier change infrared spectroscopy (FTIR). Transesterification of WCO and methanol by utilizing calcined chicken eggshells (CES) as a catalyst was done in a shut production for biodiesel fuel (BDF) creation. The boundaries that engaged with this examination are a methanol to oil molar ratio of 12:1 and a catalyst of 5 grams. This result may be divided by subheadings.

4.1 Catalyst Characterization

FTIR spectra confirmed the presence of CaO in calcined eggshells with absorption peaks around 3638 cm^{-1} correspond to Ca-O bond. Peaks at 1415cm^{-1} and 873 cm^{-1} due to stretching vibration of Ca-O bond indicate the presence of CaO in the prepared catalyst as shown in figure 4 below indicating the successful removal of CO_2 from $CaCO_3$ (Usman et al, 2021).

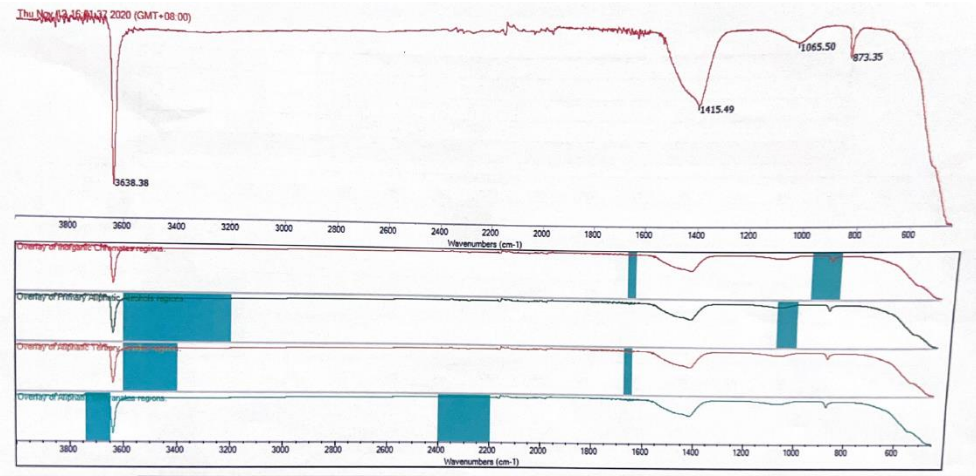

Figure 4: FTIR spectra of calcinated eggshell

Table 1: Functional group in the calcinated eggshells

Wavelengh (cm^{-1})	Functional Group of Eggshell Calcination
3638	C-O bond
1415	Ca-O stretching
873	Ca-O stretching

4.2 Transesterification Yield

To examine the impact of amount of catalyst on ester yield, the examination was done in shifting amount of catalyst 5g. Catalyst is commonly accepted to accelerate the response cycle by bringing down the actuation energy. Change of fatty acids or lipids to biodiesel includes the utilization of catalyst which velocities up the response cycle by bringing down the required initiation energy. Lower catalyst stacking is normally applied in the underlying phase of the response and the change yield is estimated (Masango et al., 2024; Naagar et al., 2021; Sajjad et al., 2022). The yield of FAME (~95%) was achieved with a 12:1 methanol to oil ratio and 5g of catalyst.

4.3 GC-FID Analysis of WCO Biodiesel

Gas chromatography and flame ionization detector (GC-FID) is the combined equipment used for the determination of the composition of FAME from biodiesel, which follows the EN 14103 procedure. The GC setup is made up of an HP-INNOWax polar capillary column with a length of 30 m and a thickness of 5 µm with the internal diameter of 0.33 mm; the carrier gas and the internal standard of FID are Helium gas. During the GC-FID analysis 1 µL of each sample is

2026 Jurnal Kejuruteraan, Teknologi dan Sains Sosial
Journal of Engineering, Technology and Social Science
Volume 12 Issue 2, e-ISSN: 27166848

usually mixed with hexane as internal standard and injected manually (AOAC Official Method of Analysis , 2000) The starting temperature is 50 °C, the initial rate is 15 °C/min up to 180 °C followed by second rate at 17 °C/min up to 230 °C and finally from the rate of 30 °C up to 380 °C with a holding time of 10 min. Table 2 and 3 show the result of GC-FID for WCO samples of FAME with different methanol to oil proportions and a constant amount of catalyst.

Table 2 WCO sample with 5g of catalyst and constant methanol in oil molar ratio (12:1)

WCO sample	Component	Result (mg/L)
Oil:Methanol:Catalyst (100:55:5) g	C16:0	217.5
	C18:0	97.47
	C18:1 Cis	42.87
	C18:2 Cis	17.95

Table 3 WCO sample with different methanol to oil molar ratio (12:1) and constant amount of catalyst

WCO sample	**Component**	**Result (mg/L)**
Oil:Methanol:Catalyst (100:55:5) g	C16:0	92.28
	C18:0	46.28
	C18:1 Cis	31.78
	C18:2 Cis	12.7

5. Discussion

The optimized reaction conditions 900°C calcination, 5g catalyst, and 12:1 methanol to- oil molar ratio produced biodiesel yields 97.46%. The empirical value of yield obtained from RSM (97.8026%) was comparable to that obtained experimentally (97.46%). The relationship between the predicted and experimental yield indicated that the values were in reasonable agreement and the data fit well with the model by giving a good estimate of response for the system in the range studied. The catalyst retained substantial activity after three cycles with minimal loss in yield, demonstrating good reusability. Furthermore, the FTIR findings confirmed complete $CaCO_3$ conversion to CaO, while GC-FID verified fuel compliance with ASTM D6751 and EN 14214 standards.

The highest biodiesel yield (>95%) was obtained with a 12:1 methanol to oil ratio and 5g of catalyst. This result is consistent with Erchamo et al. (2021), who reported optimal conversion at similar ratios. FTIR confirmed CaO formation, matching Alsaiari et al. (2023) findings.
The GC-FID chromatogram confirmed the presence of key FAME compounds, validating fuel quality. Overall, the findings support that eggshell-derived CaO is effective and aligns with zero-waste objectives (Anil et al., 2022).

These findings collectively confirm that calcined eggshell-derived CaO is a highly functional, reusable, and low-cost catalyst. The use of biowaste not only reduces environmental problem but also aligns with green chemistry principles and circular economy goals.

6. Conclusion

This study presents a cost-effective and sustainable method for biodiesel production by repurposing eggshell waste as a CaO catalyst. The optimal yield (>95%) was achieved using a 12:1 methanol-to-oil molar ratio with 5g of catalyst. This result shows a sustainable approach to biodiesel production by utilizing waste cooking oil and eggshell-derived CaO as a catalyst. Optimal conditions achieved high biodiesel yields, and analytical methods confirmed the efficiency of the process. The findings promote circular economy practices and suggest a scalable, eco-friendly alternative to traditional biodiesel production methods. The process supports SDGs 7, 12, and 13 by reducing waste, minimizing environmental pollution, and promoting clean energy. Using eggshells and WCO tackles food and chemical waste simultaneously. The method is cost-effective and minimizes environmental impact, aligning with green chemistry principles.

Acknowledgements

The authors wish to thank the Department of Science and Mathematics (JMSK), Politeknik Sultan Idris Shah for providing facilities and support. Authors also want to thank MYIPO for copyright products in notification number CRLY2025W03834.

Declaration of generative AI and AI-assisted technologies in the writing process

(Authors must disclose any use of generative AI or AI-assisted technologies in the preparation of their manuscript. This includes assistance with language refinement, content generation, or any other part of the writing process)

During the preparation of this manuscript, the author(s) used OpenAI's ChatGPT to assist in improving the readability and language of the text. All content generated by ChatGPT was subject to thorough review, editing, and revision by the author(s) to ensure its accuracy, completeness, and alignment with the research objectives. The author(s) take full responsibility for the integrity and content of the published work. This declaration complies with ICGESD 2025 guidelines on the use of generative AI in scientific writing.

References

Abu Bakar, A., Main, N. M., & Nasir, N. F. (2024). Effect of Reaction Time and Temperature on Biodiesel Production from Vegetable Oil. *Research Progress in Mechanical and Manufacturing Engineering*, *5*(1), 419-427. https://publisher.uthm.edu.my/periodicals/index.php/rpmme/article/view/15790

Alsaiari, R. A., Musa, E. M., & Rizk, M. A. (2023). Effects of calcination temperature of eggshell-derived cao as a catalyst for biodiesel production from waste cooking oil. *South African Journal of Chemistry*, *77*(1), 30-35.

Anil, N., Rao, P. K., Sarkar, A., Kubavat, J., Vadivel, S., Manwar, N. R., & Paul, B. (2024). Advancements in sustainable biodiesel production: A comprehensive review of bio-waste derived catalysts. *Energy Conversion and Management*, *318*, 118884. https://doi.org/10.1016/j.enconman.2024.118884

Chung, Z. L., Tan, Y. H., San Chan, Y., Kansedo, J., Mubarak, N. M., Ghasemi, M., & Abdullah, M. O. (2019). Life cycle assessment of waste cooking oil for biodiesel production using waste chicken eggshell derived CaO as catalyst via transesterification. *Biocatalysis and Agricultural Biotechnology*, *21*, 101317. https://doi.org/10.1016/j.bcab.2019.101317

Das, S., Anal, J. M. H., Kalita, P., Saikia, L., & Rokhum, S. L. (2024). Upcycling waste snail shells into high-performance nanocatalyst for optimized biodiesel production: A sustainable approach. *Invention Disclosure*, *4*, 100024. https://doi.org/10.1016/j.inv.2024.100024

Erchamo, Y. S., Mamo, T. T., Workneh, G. A., & Mekonnen, Y. S. (2021). Improved biodiesel production from waste cooking oil with mixed methanol–ethanol using enhanced eggshell-derived CaO nano-catalyst. *Scientific Reports*, *11*(1), 6708. https://doi.org/10.1038/s41598-021-86062-z

Idris, M. ., Abdul Rasid, A. F. ., Mohd Zamberi, M. ., & Zhang, Y. . (2024). Biodiesel Production from Waste Cooking Oil: A Review of Prospects and Challenges. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *124*(1), 28–52. https://doi.org/10.37934/arfmts.124.1.2852

Masango, S. B., Ngema, P. T., Olagunju, O. A., & Ramsuroop, S. (2024). The effect of reaction temperature, catalyst concentration and alcohol ratio in the production of biodiesel from raw and purified castor oil. *Advances in Chemical Engineering and Science*, *14*(3), 137-154. https://doi.org/10.4236/aces.2024.143009

Naagar, M., Chalia, S., Thakur, P., Sridhara, S. N., Thakur, A., & Sharma, P. B. (2021). Nanoferrites heterogeneous catalysts for biodiesel production from soybean and canola oil: a review. *Environmental Chemistry Letters*, *19*(5), 3727-3746. https://doi.org/10.1007/s10311-021-01247-2

Sajjad, N., Orfali, R., Perveen, S., Rehman, S., Sultan, A., Akhtar, T., Nazir, A., Muhammad, G., Mehmood, T., Ghaffar, S., Al-Taweel, A., Jilani, M. I., & Iqbal, M. (2022). Biodiesel Production from Alkali-Catalyzed Transesterification of *Tamarindus indica* Seed Oil and Optimization of Process Conditions. *Molecules (Basel, Switzerland)*, *27*(10), 3230. https://doi.org/10.3390/molecules27103230

Sharifi, M., Tangestaninejad, S., Moghadam, M., Marandi, A., Mirkhani, V., Mohammadpoor-Baltork, I., & Aghayani, S. (2025). Metal-organic frameworks-derived CaO/ZnO composites as stable catalysts for biodiesel production from soybean oil at room temperature. *Scientific reports*, *15*(1), 3610. https://doi.org/10.1038/s41598-025-87393-x

Singh, B., Thakur, D., & Kaur, G. (2021). Optimization of biodiesel production using waste eggshell catalyst. *Environmental Technology & Innovation*, 22, 101543. https://doi.org/10.1016/j.eti.2021.101543

Usman, A. A. G. B. (2021). *Optimization and evaluation of biodiesel quality produced from cattle fat using CAO/Al2O3 as Catalyst*. Moroccan Journal of Chemistry. https://revues.imist.ma/index.php/morjchem/article/view/17260

Wolf, S., Bullard, R., Buonocore, J. J., Donley, N., Farrelly, T., Fleming, J., ... & Willis, M. D. (2025). Scientists' warning on fossil fuels. *Oxford Open Climate Change*, *5*(1), kgaf011. https://doi.org/10.1093/oxfclm/kgaf011

Yaashikaa, P. R., Kumar, P. S., & Karishma, S. (2022). Bio-derived catalysts for production of biodiesel: A review on feedstock, oil extraction methodologies, reactors and lifecycle assessment of biodiesel. *Fuel*, *316*, 123379. https://doi.org/10.1016/j.fuel.2022.123379