

Application of the Semi-Batch Method in Biodiesel Processing Using Refined Bleached Deodorized Palm Oil (RBDPO) with Variations in Feed Addition and Temperature

**Indra Muhammad
Faizin**

Institut Pertanian Stiper,
INDONESIA

**Mohammad Prasanto
Bimantio***

Institut Pertanian Stiper,
INDONESIA

**Reni Astuti
Widyowanti**

Institut Pertanian Stiper,
INDONESIA

*** Corresponding author:**

Mohammad Prasanto Bimantio, Institut Pertanian Stiper, INDONESIA. ✉ bimantiomp@instiperjogja.ac.id

Article Info

Article history:

Received: January 06, 2026

Revised: February 09, 2026

Accepted: February 27, 2026

Keywords:

Biodiesel
Feed variation
RBDPO
Semi-batch process
Temperature

Abstract

Background: Biodiesel production efficiency is strongly influenced by reaction method, temperature, and reactant feeding strategy. Semi-batch transesterification offers better molar ratio control and reduced methanol waste compared to conventional batch systems.

Aims: This study analyzes the effect of feed addition frequency and reaction temperature on biodiesel efficiency and characteristics using Refined Bleached Deodorized Palm Oil (RBDPO) as raw material.

Methods: A Complete Block Design with two factors was applied: feed addition frequency (4×, 5×, 6× per period) and reaction temperature (40°C, 50°C, 60°C) with two replications. Biodiesel was produced using semi-batch transesterification with sodium methylate catalyst. Parameters measured included yield, density, pH, water content, glyceride profile, and methyl ester content. Data were analyzed using Duncan's Multiple Range Test (5%).

Result: The best treatment was 5× feed addition, 50°C, producing the highest methyl ester content (67.18%), yield (92.98%), density (877 kg/m³), pH 6.78, and low water content (1,401 ppm). Most quality parameters approached SNI 7182:2015 biodiesel standards.

Conclusion: Semi-batch operation improves conversion control but is not yet fully optimal due to reverse reactions. Further optimization of methanol ratio and reaction time is required to suppress monoglyceride and diglyceride reformation.

To cite this article: Faizin, I. M., Bimantio, M.P., & Widyowanti, R.A. (2026). Application of the Semi-Batch Method in Biodiesel Processing Using Refined Bleached Deodorized Palm Oil (RBDPO) with Variations in Feed Addition and Temperature. *Journal of Innovation in Applied Natural Science*, 2(1), 11-19.

This article is licensed under a [Creative Commons Attribution-ShareAlike 4.0 International License](https://creativecommons.org/licenses/by-sa/4.0/) ©2026 by author/s

INTRODUCTION

Biodiesel is a renewable fuel derived from vegetable oils such as Refined Bleached Deodorized Palm Oil (RBDPO), which has low free fatty acid and moisture content, making it suitable for efficient transesterification. Biodiesel is produced mainly through esterification and transesterification reactions using alcohol and catalysts. Esterification converts free fatty acids into methyl esters and water, whereas transesterification converts triglycerides into methyl esters and glycerol with the aid of a base catalyst and an alcohol such as methanol (Farouk et al., 2024).

In biodiesel production processes, the efficiency of oil-to-biodiesel conversion is strongly influenced by several operational parameters, including reaction temperature, catalyst type, molar ratio, and mixing conditions (Bimantio et al., 2020; Suleman et al., 2019). The most used production method is the batch reaction system; however, this method has several limitations, such as suboptimal conversion efficiency and excessive methanol consumption due to overuse (Novita et al., 2024). These limitations have encouraged the development of alternative reaction methods that can improve conversion efficiency while reducing excess alcohol usage.

Application of the Semi-Batch Method in Biodiesel Processing...

Variables such as temperature, agitation speed, catalyst concentration, and reaction time play critical roles in the transesterification process. The ideal molar ratio of reactants can produce optimal conversion, with the stoichiometric molar ratio of oil to methanol in transesterification being 1:3. In practical applications, the oil-to-methanol molar ratio typically ranges from 1:4.5 to 1:12. Ratios higher than the stoichiometric value provide excess methanol, which can increase reaction rates and shift the equilibrium toward methyl ester formation. However, excessive methanol also increases process costs and downstream purification requirements.

Transesterification efficiency depends on temperature, catalyst type, molar ratio, and mixing conditions. Conventional batch systems often require excess methanol and may produce incomplete conversion. Semi-batch systems allow staged oil addition, improving molar control and reaction stability ([Al-Saadi et al., 2020](#)). The frequency of oil addition during the reaction also plays an important role in mixing efficiency and reaction direction in transesterification systems. The semi-batch transesterification method has been developed to improve biodiesel conversion closer to the stoichiometric ratio, reduce methanol waste, and enhance production efficiency ([Anil et al., 2024](#); [Wulandari et al., 2024](#)). By adding oil gradually, the molar ratio and reaction conditions can be more precisely controlled compared to fully batch systems. The development of simpler and more controllable methods is expected to reduce biodiesel production costs, improve economic competitiveness, and support the use of biodiesel as a more environmentally friendly alternative fuel ([Szkudlarek et al., 2024](#)).

Previous biodiesel studies mainly emphasize catalyst and molar ratio optimization, while limited research evaluates staged feed addition combined with temperature variation under semi-batch operation. The relationship between staged feeding strategies and the resulting biodiesel characteristics has not yet been comprehensively evaluated ([Ceran et al., 2025](#)). Controlled feed addition may improve reaction homogeneity and reduce side reactions, thereby improving biodiesel quality and conversion efficiency. To optimize biodiesel conversion and minimize methanol waste, the semi-batch transesterification method has been introduced by combining characteristics of batch and continuous systems ([Biji et al., 2025](#)). In this method, oil is added gradually into the catalyst-methanol mixture, allowing better control of the molar ratio and reaction conditions. Through this approach, biodiesel conversion efficiency can be improved, and methanol losses can be minimized, making the semi-batch method a promising strategy for enhancing both process efficiency and product quality. Therefore, an experimental evaluation is required to determine the most efficient operating conditions.

This study aims to analyze the effects of feed addition frequency and reaction temperature variation on conversion efficiency and the physicochemical characteristics of biodiesel produced from RBDPO using the semi-batch transesterification method.

METHOD

Research Design

This study employed a Complete Block Design with two treatment factors and two replications. The first factor was the frequency of RBDPO feed addition consisting of three levels: X1=4-stage addition, X2=5-stage addition, and X3 = 6-stage addition. The second factor was transesterification reaction temperature consisting of three levels: Y1 = 40°C, Y2 = 50°C, and Y3 = 60°C. The factorial combination (3 × 3) with two replications resulted in 18 experimental units.

Participant / Material

The equipment used for biodiesel production included a 1000 mL Erlenmeyer flask, 100 mL graduated cylinder, 500 mL beaker glass, thermometer, magnetic stirrer, spatula, hotplate, and analytical balance. The materials used were Refined Bleached Deodorized Palm Oil (RBDPO), methanol, citric acid, sodium methyllate (CH₃ONa) as catalyst, and distilled water.

Instrument

Density was measured using a DA-645 density meter. The instrument was cleaned and prepared prior to measurement. Biodiesel samples were introduced using a syringe or pipette while ensuring no air bubbles were present. The measurement was run automatically, and the displayed

value was recorded. After each measurement, the instrument was rinsed several times with methanol and dried before subsequent use.

Water content was determined using volumetric Karl Fischer titration according to SNI 01-2901-2006. Karl Fischer reagent containing iodine was added to the sample until the first excess iodine endpoint was detected. The volume of reagent consumed was recorded and used to calculate water content.

Biodiesel yield was calculated by comparing the mass of purified methyl ester obtained to the mass of RBDPO feedstock used ([Mukminin et al., 2022](#)). pH was measured using a calibrated pH meter. The sample was diluted with 10–20 mL distilled water in a beaker, and the electrode was immersed in the diluted sample. The pH value displayed on the instrument was recorded.

Glyceride composition and ester content were analyzed using an Agilent 7890B Gas Chromatograph. Approximately 0.1 g of sample was weighed, followed by the addition of 80 μ L butanetriol, 100 μ L tricaprln, and 100 μ L MSTFA. The mixture was vortexed for 5–10 minutes, then 8 mL n-hexane was added and vortexed again. The prepared sample was injected into the GC system and chromatographic data were recorded .

Procedures

Biodiesel was produced using a semi-batch transesterification method in which RBDPO was added gradually during the reaction. The process began with the preparation of a methoxide solution consisting of methanol (22.56 g) and sodium methylate catalyst at 1% (w/w) of total oil mass. The methoxide solution was introduced into a three-neck flask reactor.

RBDPO with a total mass of 200 g was added periodically according to the treatment levels (4, 5, or 6 stages of addition) with adjusted time intervals. The reaction was conducted at controlled temperatures of 40°C, 50°C, or 60°C with a stirring speed of 500 rpm.

After completion of the reaction, the mixture containing biodiesel, excess alcohol, catalyst, soap, and glycerol was separated using centrifugation for 10 minutes. The purification step was performed through washing using warm distilled water (50–60°C) containing citric acid to adjust the pH to 5.8–7.0 and prevent soap formation. The washed product was centrifuged again for 10 minutes and subsequently dried using vacuum distillation at 100°C for 30 minutes. The final biodiesel product was then subjected to physicochemical analysis.

Analysis plan

Experimental data were analyzed using Duncan's Multiple Range Test at a 5% significance level to determine significant differences among treatment means. Standard statistical procedures were applied for factorial experimental design.

Scope and/or limitations of the methodology you used

This study focused on feed addition frequency and temperature variation in semi-batch transesterification. Methanol ratio, catalyst concentration, and reaction duration were held constant; therefore, further optimization of these parameters was beyond the scope of this work.

RESULTS AND DISCUSSION

Results:

Yield

Yield represents the conversion efficiency, expressed as the ratio between the mass of biodiesel produced and the mass of raw material used. Duncan's Multiple Range Test was applied to determine significant differences among treatments. The yield analysis results are presented in Table 1.

Table 1. Yield analysis under different feed addition frequencies and reaction temperatures.

Treatment	Yield (%)			Mean
	40°C	50°C	60°C	
4x addition	91.33	92.42	92.15	91.96 ^b
5x addition	92.66	92.98	91.29	92.31 ^c
6x addition	91.27	91.69	92.20	91.72 ^a

Application of the Semi-Batch Method in Biodiesel Processing...

Mean	91.75 ^x	92.36 ^y	91.88 ^x	
------	--------------------	--------------------	--------------------	--

Duncan's test results indicate that the frequency of RBDPO feed addition (4, 5, and 6 staged additions within 60 minutes) had a significant effect on biodiesel yield. The findings show that increasing feed addition frequency does not always increase yield; instead, an optimum point was observed at five-stage addition, which produced the highest average yield. Properly staged reactant addition can improve biodiesel yield, whereas excessive staging may disturb reaction equilibrium.

This result differs from [Sidabutar et al., \(2025\)](#), who reported that more frequent feed addition had little effect on yield because the transesterification reaction had already reached equilibrium. Such differences are likely caused by variations in operating conditions, particularly reaction temperature and catalyst concentration.

Reaction temperature variation (40°C, 50°C, and 60°C) also significantly affected biodiesel yield. Increasing temperature from 40°C to 60°C increased reaction rate and triglyceride conversion as shown in table 1. However, the optimum condition was observed at 50°C combined with five-stage feed addition, which provided better reactant distribution and maximum conversion. Excessive temperature may promote methanol evaporation and catalyst degradation, leading to yield reduction ([Putri et al., 2024](#)).

Density

Density is defined as mass per unit volume and reflects biodiesel purity and conversion completeness. Duncan's test results for density are shown in Table 2.

Table 2. Density analysis under different treatments.

Treatment	Density (g/cm ³)			Mean
	40°C	50°C	60°C	
4x addition	0.88	0.87	0.88	0.88
5x addition	0.88	0.88	0.88	0.88
6x addition	0.88	0.88	0.87	0.88
Mean	0.88	0.88	0.88	

Feed addition frequency significantly influenced biodiesel density. In the semi-batch system, staged oil addition helps control reaction rate and reduce undesirable side products. Feed distribution affects reaction homogeneity and therefore transesterification efficiency. Higher density values are associated with incomplete conversion and residual glycerol content. This finding contrasts with [Sidabutar et al., \(2025\)](#), who reported no significant density effect from feed frequency due to constant methanol ratio. Differences likely arise from reaction condition variations.

Temperature also affected density. Higher temperatures improved conversion and reduced residual glycerol, generally lowering density values. However, excessive temperature may introduce negative effects. Lower temperatures tend to produce higher density biodiesel due to incomplete conversion.

pH

Duncan's test results for pH are presented in Table 3.

Table 3. pH analysis under different treatments.

Treatment	pH			Mean
	40°C	50°C	60°C	
4x addition	6.58	6.63	6.53	6.58 ^b
5x addition	6.73	6.78	6.68	6.73 ^b
6x addition	6.63	6.61	6.48	6.57 ^a
Mean	6.64 ^x	6.67 ^y	6.56 ^x	

Feed addition frequency significantly influenced biodiesel pH. More frequent staged addition improved reactant and catalyst distribution, affecting reaction equilibrium and by-product formation. Biodiesel with pH closer to neutral (6–7) indicates lower acid number and higher methyl ester formation ([Bethan & Supriyo, 2021](#)). These results are consistent with [Sidabutar et al., \(2025\)](#), who observed improved mixing and catalyst dispersion with more frequent feed addition.

Reaction temperature significantly affected pH. Higher temperature accelerates transesterification but may also increase side reactions such as saponification, influencing final pH. Incomplete reactions may leave catalyst residues or free fatty acids, altering acidity. Water formation from side reactions also contributes to increased H⁺ concentration.

Water Content

Water content results are summarized in Table 4.

Table 4. Water content analysis.

Treatment	Water Content (ppm)			Mean
	40°C	50°C	60°C	
4x addition	2612.48	1482.86	2676.00	2257.11 ^c
5x addition	1758.50	2376.36	1547.22	1894.02 ^b
6x addition	2029.79	1987.32	1401.53	1806.21 ^a
Mean	2133.59 ^z	1948.85 ^y	1874.92 ^x	

Feed addition frequency significantly affected biodiesel water content. More frequent staged feeding improves reactant contact and reduces soap formation that can retain water. High water content promotes hydrolysis of triglycerides and increases free fatty acids, reducing biodiesel quality ([Habib & Suhendri, 2024](#)).

Reaction temperature showed a significant effect on water content. Higher temperatures accelerated reaction kinetics and phase separation, thereby reducing water content. However, excessively high temperature may cause methanol loss and product degradation ([Ramadani et al., 2023](#)).

Free Glycerol

Free glycerol results are shown in Table 5.

Table 5. Free glycerol analysis.

Treatment	Free glycerol (%)			Mean
	40°C	50°C	60°C	
4x addition	0.02	0.02	0.02	0.02
5x addition	0.02	0.01	0.02	0.02
6x addition	0.02	0.02	0.03	0.02
Mean	0.02	0.02	0.02	

Feed addition frequency significantly affected free glycerol levels. More frequent feeding increased reactant interaction but may also create imbalance that inhibits complete conversion. Improper staged addition can increase intermediate glyceride accumulation ([Kurniasih et al., 2024](#)). Moderate staged addition improved homogeneity and reduced free glycerol, consistent with [Sidabutar et al., \(2025\)](#).

Temperature also significantly influenced free glycerol. The lowest values were observed at 50°C, indicating an optimal reaction window. Higher temperatures promoted side reactions and alcohol evaporation, increasing residual glycerol ([Melani et al., 2024](#)).

Monoglycerides

Monoglyceride results are presented in Table 6.

Table 6. Monoglyceride analysis.

Treatment	Monoglyceride (%)			Mean
	40°C	50°C	60°C	
4x addition	3.17	2.95	2.83	2.98 ^b
5x addition	2.62	2.30	2.41	2.44 ^a
6x addition	2.71	2.55	2.59	2.62 ^a
Mean	2.83 ^y	2.60 ^x	2.61 ^x	

Feed addition frequency significantly influenced monoglyceride levels. More uniform reactant distribution improved conversion and reduced intermediate accumulation. Effective mixing is essential to prevent monoglyceride and diglyceride buildup.

Temperature significantly affected monoglycerides. Higher temperatures increased reaction rate and conversion of monoglycerides to diglycerides and esters. Lower temperatures slowed kinetics and increased accumulation ([Lestari et al., 2021](#)).

Diglycerides

Diglyceride results are shown in Table 7.

Table 7. Diglyceride analysis.

Treatment	Diglyceride (%)			Mean
	40°C	50°C	60°C	
4x addition	14.26	13.21	12.51	13.33 ^a
5x addition	10.81	9.85	10.36	10.34 ^a
6x addition	11.41	11.12	11.88	11.47 ^a
Mean	12.16 ^y	11.40 ^x	11.58 ^x	

Feed addition frequency did not significantly affect diglyceride levels. Diglyceride formation is more strongly influenced by temperature, molar ratio, and catalyst concentration than feeding frequency. Transesterification equilibrium behavior explains this observation.

Temperature significantly affected diglyceride content. Higher temperature increased kinetic energy and ester formation, reducing diglyceride accumulation ([Sinaga et al., 2023](#)).

Triglycerides

Triglyceride results are shown in Table 8.

Table 8. Triglyceride analysis.

Treatment	Triglyceride (%)			Mean
	40°C	50°C	60°C	
4x addition	23.52	21.95	20.87	22.11 ^a
5x addition	18.13	16.60	17.31	17.35 ^a
6x addition	19,38	18.27	23.67	20.44 ^a
Mean	20.34 ^y	18.94 ^x	20.62 ^y	

Feed addition frequency showed no significant effect on triglyceride levels because total reactant volume and other conditions remained constant. Temperature had a significant effect. The lowest triglyceride levels were observed at 50°C. Lower temperatures increased viscosity and limited mixing, while excessive temperatures caused methanol evaporation and incomplete reaction.

Ester Content

Ester content results are shown in Table 9.

Table 9. Methyl ester content analysis

Treatment	Methyl Ester (%)			Mean
	40°C	50°C	60°C	
4x addition	53.35	56.68	58.71	56.25 ^a
5x addition	64.05	67.18	65.76	65.67 ^a
6x addition	61.83	63.49	56.74	60.69 ^a
Mean	59.75 ^x	62.45 ^x	60.41 ^y	

Feed addition frequency did not significantly affect ester content overall, indicating that molar ratio remains the dominant factor (Zalfiatri et al., 2019). Extremely frequent feeding may dilute the reaction phase and reduce efficiency, while moderate staging improves mixing.

Temperature significantly affected ester content. The highest ester level was obtained at 50°C. This temperature range provided optimal kinetics without promoting decomposition or excessive methanol evaporation. Excessive temperature shifts equilibrium backward and increases reverse reactions forming mono- and diglycerides.

Discussion:

Implications:

Based on overall biodiesel characterization and comparison with SNI 7182:2015 standards, treatment X2Y2 (five-stage feed addition at 50°C) was identified as the best treatment. It produced yield of 92.98%, free glycerol 0.014%, monoglycerides 2.302%, diglycerides 9.855%, triglycerides 16.60%, density 0.877 g/cm³ (within the 850–890 kg/m³ standard range), water content 2.376 ppm, and pH 6.78. Most quality parameters satisfied or closely approached the required standard values.

Research contribution:

This study provides experimental evidence on the combined effects of staged feed addition frequency and reaction temperature in semi-batch transesterification of RBDPO for biodiesel production. The results demonstrate that reaction performance is not only governed by molar ratio and catalyst concentration, but also by feeding strategy and thermal conditions. The identification of an optimal condition (five-stage feed addition at 50°C) contributes a practical operational window for improving yield, ester content, and impurity control in semi-batch biodiesel processing. These findings support the development of more efficient semi-batch reactor strategies for palm-based biodiesel production and offer a reference framework for process optimization studies.

Limitations:

This study has several limitations. The methanol-to-oil molar ratio, catalyst concentration, and total reaction time were kept constant and were not further optimized, which may limit the maximum achievable ester conversion. Reverse reactions and intermediate glyceride accumulation were still observed, indicating that equilibrium control was not yet fully achieved. In addition, the study was conducted at laboratory scale, so hydrodynamic behavior, heat transfer, and mixing performance may differ under pilot or industrial-scale conditions. Some quality parameters approached but did not fully satisfy biodiesel standard limits, indicating that further process refinement is required.

Suggestions:

Future studies should focus on optimizing methanol ratio, staged reaction time, and catalyst loading in combination with feed addition frequency to suppress reverse reactions and improve ester conversion. Kinetic modeling and time-resolved sampling are recommended to determine the optimal stopping point before equilibrium reversal occurs. The use of heterogeneous or more temperature-stable catalysts should also be evaluated to reduce side reactions and simplify separation. Further work at pilot scale is suggested to validate semi-batch feeding strategies under more realistic process conditions and to improve compliance with biodiesel quality standards.

CONCLUSION

Application of the Semi-Batch Method in Biodiesel Processing...

This study set out to evaluate whether staged feed addition and reaction temperature control in a semi-batch transesterification system could improve biodiesel conversion efficiency and product quality when using RBDPO as feedstock. The results and discussion confirm that these operational variables significantly influence yield, ester content, glyceride composition, density, pH, and water content, thereby demonstrating consistency between the research objectives stated in the Introduction and the experimental findings obtained.

The optimal condition was achieved at five-stage feed addition and a reaction temperature of 50°C, which produced the best overall biodiesel characteristics, including the highest yield and methyl ester content, low impurity levels, and physicochemical properties close to the required quality standards. These findings indicate that semi-batch operation with controlled staged feeding can enhance reaction homogeneity and conversion performance, although reverse reactions and intermediate glyceride formation still limit full optimization.

The research outcomes provide a practical basis for further development of semi-batch biodiesel processing, particularly through optimization of methanol ratio, catalyst stability, and reaction time control to suppress backward reactions. Future studies should extend this work toward kinetic modeling, advanced catalyst systems, and pilot-scale validation to strengthen process reliability and industrial applicability. With further refinement, the semi-batch approach has strong prospects for scalable, cost-efficient, and higher-quality biodiesel production in subsequent applications and research.

AUTHOR CONTRIBUTION STATEMENT

IF conducted the experiments, collected the data, and prepared the initial manuscript draft. MB designed the research methodology, supervised the experimental process, and performed critical revision of the manuscript. RW contributed to analytical validation, data interpretation, and final manuscript review. All authors approved the final version of the manuscript.

REFERENCES

- Al-Saadi, A., Mathan, B., & He, Y. (2020). Biodiesel production via simultaneous transesterification and esterification reactions over SrO–ZnO/Al₂O₃ as a bifunctional catalyst using high acidic waste cooking oil. *Chemical Engineering Research and Design*, 162, 238–248. <https://doi.org/10.1016/j.cherd.2020.08.018>
- 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(15), 118884. <https://doi.org/10.1016/j.enconman.2024.118884>
- 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. <https://doi.org/10.14710/gt.v21i2.37297>
- Biji, D., Kepyar, J., & Communis, R. (2025). Penentuan Waktu Transesterifikasi Optimum Biodiesel. *JURNAL KIMIA (JOURNAL OF CHEMISTRY)*, 19(2), 233–240. <https://doi.org/10.24843/JCHEM.2025.v19.i02.p13>
- Bimantio, M. P., Oktavianty, H., & Widyasaputra, R. (2020). Perancangan Desain Portable Fixed-Bed Composite Adsorber Column Sebagai Media Pemurnian Biodiesel Dengan Sistem Packing Bed. *TEKNIK*, 41(3), 253–260. <https://doi.org/10.14710/teknik.v41i3.32661>
- Ceran, Z. D., Demir, V., & Akgün, M. (2025). Optimization and kinetic study of biodiesel production from *Jatropha curcas* oil in supercritical methanol environment using ZnO/γ-Al₂O₃ catalyst. *Biomass Conversion and Biorefinery*, 15(3), 3903–3914. <https://doi.org/10.1007/s13399-024-05307-9>
- Farouk, S. M., Tayeb, A. M., Abdel-Hamid, S. M. S., & Osman, R. M. (2024). Recent advances in transesterification for sustainable biodiesel production, challenges, and prospects: a comprehensive review. *Environmental Science and Pollution Research*, 31(9), 12722–12747. <https://doi.org/10.1007/s11356-024-32027-4>
- Habib, A. A. Y., & Suhendri, S. (2024). Pengaruh Waktu Reaksi Transesterifikasi Biodiesel Dari Minyak Lemak Ayam Dengan Menggunakan Katalis MgO. *Journal Of Bioprocess, Chemical And Environmental Engineering Science*, 5(2), 69–76. <https://doi.org/10.31258/jbchees.5.2.69-76>

- Kurniasih, E., Rahmi, R., Supardan, M. D., & Darusman, D. (2024). Pemurnian Gliserol Dari Limbah Produksi Biodiesel Dan Pemanfaatannya Sebagai Substrat Pada Sintesis Mono-Digliserida. *Prosiding SENASTITAN: Seminar Nasional Teknologi Industri Berkelanjutan*.
- Lestari, L. P., Meriatna, M., Suryati, S., & Jalaluddin, J. (2021). Pengaruh Suhu Dan Waktu Reaksi Transesterifikasi Minyak Jarak Keyar (Castor Oil) Terhadap Metil Ester Dengan Menggunakan Katalis Abu Tandan Kosong Kelapa Sawit. *Chemical Engineering Journal Storage (CEJS)*, 1(2), 64–80. <https://doi.org/10.29103/cejs.v1i2.5478>
- Melani, H., Agustine, D., & Maftukhah, S. (2024). Pengaruh Suhu Dalam Katalis Reaksi Transesterifikasi Biodiesel Dari Minyak Jelantah Menggunakan Katalis CaO Cangkang Keong Mas (*Pomacea canaliculata* Lamarck). *UNISTEK*, 11(1), 40–46. <https://doi.org/10.33592/unistek.v11i1.3764>
- Mukminin, A., Megawati, E., Warsa, I. K., Yuniarti, Y., Umoro, W. A., & Islamiati, D. (2022). Analisis Kandungan Biodiesel Hasil Reaksi Transesterifikasi Minyak Jelantah Berdasarkan Perbedaan Konsentrasi Katalis NaOH Menggunakan GC-MS. *Sang Pencerah: Jurnal Ilmiah Universitas Muhammadiyah Buton*, 8(1), 146–158. <https://doi.org/10.35326/pencerah.v8i1.1897>
- Novita, L., Safni, Emriadi, De Freitas, F. A., Fauzia, S., & Zein, R. (2024). Enhanced Conversion Of Used Palm Cooking Oil To Biodiesel By A Green And Recyclable Palm Kernel Shell Ash-Derived Catalyst: Process Optimization By Response Surface Methodology. *Case Studies In Chemical And Environmental Engineering*, 9, 100678. <https://doi.org/10.1016/j.cscee.2024.100678>
- Putri, S. D. E., Cahyo, A. N., Dian, S. E., Rukmana, M. D., & Asni, N. (2024). Optimasi Temperatur Pengadukan Terhadap Yield Biodiesel Dari Minyak Jelantah. *Journal Of Polymer Chemical Engineering And Technology*, 2(1), 29–36. <https://jurnal.stmi.ac.id/index.php/jpcet/article/view/315>
- Ramadani, R., Azhari, A., Mulyawan, R., Za, N., & Hakim, L. (2023). Pembuatan Biodiesel Dari Minyak Biji Kepayang (*Pangium edule* Reinw) Menggunakan Katalis Basa Heterogen Dari Limbah Cangkang Kerang Darah. *Journal Of Biodiesel Research And Innovation (Journal Of BRAIN)*, 1(1), 9–16. <https://doi.org/10.29103/jbrain.v1i1.13378>
- Sidabutar, E. D. C., Sujana, I. M. I. W. C., Oktavia, F. D., Putri, N. A., & Sari, M. P. (2025). Pengaruh Parameter Operasi Pada Proses (Effect Of Operating Parameters On The Transesterification Process Of Waste Cooking Oil Using Bovine Bone Catalyst On Biodiesel Yield And Density). *Indonesian Journal of Pure and Applied Chemistry*, 8(2), 101–108. <https://doi.org/10.26418/indonesian.v8i2.96860>
- Sinaga, H., Silalahi, M. V., & Situmorang, M. V. (2023). Pengembangan Media Pembelajaran E-Booklet pada Materi Keanekaragaman Hayati terhadap Hasil Belajar Siswa Kelas X SMA Negeri 4 Pematang Siantar. *INNOVATIVE: Journal Of Social Science Research*, 3(5), 7116–7130.
- Suleman, N., Abas, & Papatungan, M. (2019). Esterifikasi Dan Transesterifikasi Stearin Sawit Untuk Pembuatan Biodiesel. *Jurnal Teknik*, 17(1), 66–77. <https://doi.org/10.37031/jt.v17i1.54>
- Szkudlarek, Ł., Spiewak, K. C., Maniukiewicz, W., & Nowosielska, M. (2024). Biodiesel Production by Methanolysis of Rapeseed Oil — Influence of SiO₂ / Al₂O₃ Ratio in BEA Zeolite Structure on Physicochemical and Catalytic Properties of Zeolite Systems with Alkaline Earth Oxides (MgO , CaO , SrO). *International Journal of Molecular Sciences*, 25(3570), 1–24. <https://doi.org/10.3390/ijms25073570>
- Wulandari, Y., Irawan, M. H., Muttaqii, M. Al, Ma'sum, Z., Asri, N. P., Jia-Ming, & Chern, L. M. (2024). Performance of In-Situ Stirring Batch Reactor Transesterification of Nannochloropsis sp Microalgae into Biodiesel. *International Journal of Technology*, 15(4), 291–319. <https://doi.org/10.14716/ijtech.v15i4.6678>
- Zalfiatri, Y., Restuhadi, F., & Zulhardi, R. (2019). Karakteristik Biodiesel Dari Minyak Jelantah Menggunakan Katalis Abu Gosok Dengan Variasi Penambahan Metanol. *Chempublish Journal*, 4(1), 1–8. <https://doi.org/10.22437/chp.v3i1.5774>