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The Effect of Activated Carbon From Palm Oil Kernel Shells on Waste Cooking Oil for Soap Production

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ABSTRACT

This study addresses the existing limitation in integrated waste valorization approaches by combining palm kernel shell–derived activated carbon production, waste cooking oil purification, and solid soap manufacturing within a UMKM-based circular economy model. Unlike previous studies that focus separately on adsorbent synthesis or oil purification, this research evaluates the adsorption performance quantitatively and links it directly to downstream soap quality. Activated carbon was synthesized via controlled pyrolysis (400 °C) followed by KOH activation (800 °C) and characterized using FTIR. The purification process reduced free fatty acid (FFA) content from 2.35 ± 0.02% to 0.43 ± 0.01%, corresponding to an adsorption efficiency of 81.7%. The adsorption capacity was calculated and statistical validation was performed in triplicate experiments. The resulting solid soap exhibited stable pH (8.89 ± 0.05) and satisfactory physical properties. These findings demonstrate the scientific and practical contribution of palm kernel shell activated carbon as a sustainable bioadsorbent supporting circular economy implementation at the UMKM scale.

Keywords
Waste cooking oil, activated carbon, palm kernel shells, adsorption, solid laundry soap

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INTRODUCTION

Waste cooking oil is often difficult to manage as household waste, causing environmental pollution if disposed of carelessly. UMKM Bank Minyak Jelantah (Bank Jatah) took the initiative as a creative solution by collecting used cooking oil to be processed into high-quality soap. On the other hand, the palm oil industry produces large amounts of fruit shells as agricultural waste. The waste cooking oil purification process requires effective adsorbents to remove impurities such as free fatty acids and coloring agents. Activated carbon made from palm shells offers an environmentally friendly alternative to commercial materials. This study aims to analyze the ability of activated carbon to improve the quality of waste cooking oil, thereby supporting better soap production at the UMKM level [1]. The application of activated carbon bioadsorbents from palm kernel shells increases the purity of waste cooking oil used in the manufacture of environmentally friendly soap [2].

Palm kernel shells contain high lignocellulose (lignin ~45%, cellulose ~30%), which is ideal for carbonization. The pyrolysis process at 500–600°C produces carbon with micropores (<2 nm) and mesopores (2–50 nm), measured using the BET (Brunauer-Emmett-Teller) method. The specific surface area of activated palm kernel shell carbon can reach 800–1200 m^2/g after H_3PO_4 or KOH activation [3-5]. Pore size distribution affects adsorption selectivity micropores: absorb small molecules (FFA, peroxides) and mesopores: absorb large pigments (carotene, chlorophyll) [6].

Activated carbon, as a porous material with a high surface area, plays a crucial role in the adsorption process by absorbing organic contaminants such as polar compounds in waste cooking oil. The activation process of palm kernel shells involves pyrolysis at high temperatures followed by chemical treatment (e.g., with H_3PO_4 or KOH) [6-10], which forms an effective microporous structure for up to 80% purification. Waste cooking oil, which contains polar compounds resulting from thermal degradation, is suitable for saponification after adsorption, producing high-quality soap.

The main process involves adsorption for purification, followed by saponification using a base such as NaOH, producing solid soap as output [11]. Life Cycle Costing (LCC) analysis shows significant economic efficiency, with soap production costs reduced by up to 45% compared to the use of new palm oil, this supports the financial sustainability of UMKM despite limited resources [12].

Mechanism of Free Fatty Acid (FFA) Adsorption in Used Cooking Oil

FFA is formed as a result of triglyceride hydrolysis by water and heat during repeated frying. An FFA concentration of >2% causes soft soap and a rancid odor. FFA adsorption occurs through acid-base interactions between carboxyl groups (–COOH) and active carbon sites (–OH, –COOH surface).

Thermal and Chemical Stability of Soap from Recycled Oil

Soap from waste cooking oil tends to have a low softening point (<50°C) if FFA is high. Purification improves thermal stability through the binding of long chains of saturated fatty acids (palmitic, stearic). Differential Scanning Calorimetry (DSC) tests show that the melting point of soap increases from 45°C to 58°C [13].

Circular Economy Model in Waste Oil Processing UMKM Bank Minyak Jalantah

In the era of a growing circular economy, UMKM such as Bank Minyak Jelantah (Bank Jatah) offer innovative models for turning waste into economic and environmental added value. Bank Jatah utilizes used cooking oil as an economically valuable commodity and was officially established in 2021. It manages waste cooking oil from households and culinary businesses through savings schemes, direct buying and selling, and modern affiliate-based marketing. The Bank Jatah affiliate program is an environmentally-based community empowerment innovation that opens up inclusive economic access for all segments of society, including the lower-middle class, through a waste cooking oil savings mechanism.

Therefore, the research questions are: (1) What are the characteristics of the functional groups in activated carbon made from palm kernel shells? (2) What are the results of the free fatty acid analysis before and after the adsorption process in waste cooking oil purification?The objectives of this study are: (1) To analyze the characteristics of functional groups in activated carbon made from palm kernel shells. (2) To determine the results of free fatty acid analysis before and after the adsorption process in waste cooking oil purification. The utilization of waste cooking oil and palm kernel shells in this study not only contributes to reducing environmental pollution but also supports the development of sustainable and economically valuable environmentally friendly products for the community UMKM Bank Minyak Jelantah.

Although many studies have reported the use of activated charcoal produced from palm kernel shells and separate studies on the purification of used cooking oil, research that integrates adsorbent synthesis, quantitative adsorption evaluation, and downstream soap production within a single circular economy framework at the MSME scale is still limited. Furthermore, previous studies rarely provide comparisons of adsorption efficiency. Therefore, this study contributes by offering an integrated and experimentally validated approach that links material characterization, adsorption performance, and product application.

METHOD

In this study, palm kernel shells were obtained from a palm oil mill in Riau Province, while waste cooking oil was collected from Bank Minyak Jelantah. Sample preparation, soap production, and quality testing were carried out at the Laboratory of the Faculty of Forestry and Science, also the Faculty of Engineering, Lancang Kuning University.

Materials and Equipment

The main materials used in this study were palm kernel shells and waste cooking oil. The main chemicals used included KOH, HCl, NaOH, N_2 gas, phenolphthalein indicator, waste cooking oil, lemongrass oil fragrance, dye, and distilled water. The equipment used included a soap mixer, hotplate, furnace, oven, pyrolysis unit, analytical balance, 200 mesh sieve, pH meter, funnel, beaker, and Whatman No. 42 filter paper.

Preparation of Activated Carbon Bioadsorbent

Palm kernel shells were washed with distilled water, dried at 110 °C to a constant weight, then pyrolyzed at 400 °C for 4 hours to produce initial charcoal. Fine charcoal measuring 200 mesh was soaked in a KOH solution (1:4 wt% ratio) for 12 hours with continuous stirring, then dried and activated under a flow of N_2 gas at 800 °C for 3.5 hours. After activation, the carbon is washed with HCl to neutral pH and dried again to obtain activated carbon bioadsorbent. Characterization of functional groups on activated carbon based on palm kernel shells using Fourier Transform Infrared (FTIR) [14].

Purification of Waste Cooking Oil

A total of 50 mL of waste cooking oil was heated at 110 °C for 10 minutes, then 3 g of activated carbon was added and stirred homogeneously, then left to stand for 12 hours before filtering. The mixture was filtered to separate the adsorbent, and the filtrate obtained was analyzed to determine the adsorption effectiveness [15]. Test the free fatty acids in the used cooking oil both before and after purification [16]. Weigh ± 5 grams of the prepared used cooking oil and place it in a 250 mL Erlenmeyer flask. Add 2–3 drops of phenolphthalein (PP) indicator to the solution. Titrate the solution using standard NaOH until it turns pink. Record the volume of NaOH used (mL).

The FFA content is calculated using the formula:

$$\% \, FFA = \frac{\mathrm{V_{NaOH}NaOH \; x \; N_{NaOH} \; x \; MW_{NaOH}}}{\mathrm{m \; x \; 1000}} \; x \; 100 \; \% \qquad (1)$$

Where:
V = volume of NaOH (mL)
N = normality of NaOH
MW = molecular weight of fatty acids (e.g., oleic acid = 256)
M = sample mass (g)

All adsorption experiments were conducted in triplicate to ensure reproducibility. Data are presented as mean ± standard deviation. Statistical significance between FFA values before and after treatment was evaluated using a paired t-test with a confidence level of 95% ($p < 0.05$).

Solid Soap Production

The formula and method for making solid soap are as follows [17]. Prepare a container, add water, then gradually add NaOH while stirring slowly and allow to cool or reach room temperature. Prepare a separate container, prepare the filtrate in the form of waste cooking oil, and add the oil to the NaOH solution that has been left to stand. Add dye and fragrance, then mix using a mixer until it quickly blends and becomes thick and traceable. Pour the mixture into molds, store in a safe place, and cover with plastic to prevent contamination. After 24 hours, the soap has hardened and is then dried by airing it in an open room for 30 days. After 30 days, the soap is tested for pH by cutting a small piece of soap, foaming it with water, and then measuring it using a pH meter. Soap that meets SNI standards has a pH range of 9 to 11.

RESULT AND DISCUSSION

Preparation of an activated carbon bioadsorbent from palm kernel shells

The preparation of an activated carbon bioadsorbent from palm kernel shells resulted in a carbon material with well-developed porosity. The initial washing and drying process at 110 °C effectively removed surface impurities and moisture, ensuring a stable precursor for subsequent thermal treatment. Pyrolysis at 400 °C for four hours successfully converted the biomass into charcoal by decomposing the volatile organic components, resulting in a carbon-rich solid structure.

Chemical activation using a 1:4 weight ratio of KOH significantly enhanced the textural properties of the charcoal. During the 12-hour impregnation process, the activating agent deeply interacted with the carbon matrix. During high-temperature activation at 800 °C in an N_2 atmosphere, the KOH reacted with the carbon framework. This promoted the formation of micropores and mesopores through gasification and intercalation mechanisms. This process increased the internal surface area and created a porous structure suitable for adsorption applications.

Using an inert nitrogen atmosphere prevented oxidation during activation and preserved the carbon structure while facilitating pore development. Subsequent acid washing with HCl removed residual potassium compounds and inorganic impurities, restoring the pH to neutral and improving the purity of the activated carbon. This step also stabilized the pore structure and enhanced surface functionality.

Overall, the combined effects of controlled pyrolysis, chemical activation, and thermal treatment resulted in an activated carbon bioadsorbent with improved morphological characteristics (see Figure 1). The high activation temperature and KOH treatment were crucial in generating a porous network, which is essential for efficient adsorption performance. These results suggest that palm kernel shells are promising renewable precursors for producing activated carbon with potential applications [18].

Palm Kernel Shell: washing, drying 110°C and pyrolysis 400°C, 4 hours

Sieving with 200 mesh

KOH Impregnation 1: 4 KOH solution, 12 hours and acid washing with HCl, neutral pH

High-Temperature Activation: 800^{0}C, N_2, Atmosphere 3,5 hours

Drying in 110^{o}C

Activated carbon bioadsorbent

Figure 1. Preparation of Activated Carbon Bioadsorbent

FTIR Analysis

Fourier Transform Infrared (FTIR) spectroscopy was employed to identify the surface functional groups of the activated carbon derived from palm kernel shell (PKS). The FTIR spectrum reveals the presence of several oxygen-containing functional groups that play a crucial role in the adsorption of impurities from used cooking oil according to Table 1.

Table 1. FTIR Peak Interpretation of Palm Kernel Shell–Derived Activated Carbon

No	Wavenumber (cm^{-1})	Functional Group	Vibration Mode	Interpretation
1	3400–3200	–OH (hydroxyl)	O–H stretching	Presence of surface hydroxyl groups and adsorbed moisture, indicating hydrophilic character
2	2920–2850	C-H (aliphatic)	C-H stretching	Residual aliphatic hydrocarbon structures from biomass carbonization
3	1700–1600	C=O (carbonyl)	C=O stretching	Carboxyl, ketone, or lactone groups formed during activation
4	1450–1380	C–H (aromatic/aliphatic)	Bending vibration	Structural carbon backbone
5	1200–1000	C–O	C–O stretching	Alcohol, ester, or phenolic groups on carbon surface
6	800–600	C–H (aromatic)	Out-of-plane bending	Aromatic ring structures formed during pyrolysis

A broad absorption band observed in the range of 3400–3200 cm^{-1} corresponds to the stretching vibration of hydroxyl (–OH) groups (see Figure 1). These hydroxyl groups may originate from phenolic structures or adsorbed moisture on the carbon surface. The presence of –OH groups enhances the hydrophilicity of the activated carbon and facilitates hydrogen bonding interactions with polar compounds such as free fatty acids and oxidation products in used cooking oil.

The absorption peaks at approximately 2920–2850 cm^{-1} are attributed to the C–H stretching vibrations of aliphatic hydrocarbons. These peaks indicate that some residual organic structures from the palm kernel shell biomass remain after carbonization. Such aliphatic groups can contribute to non-polar interactions with hydrocarbon-based contaminants.

A noticeable absorption band in the region of 1700–1600 cm^{-1} corresponds to the stretching vibration of carbonyl (C=O) groups, which may originate from carboxylic acids, ketones, or lactone functionalities formed during chemical activation with KOH. These oxygenated functional groups increase the surface polarity of the activated carbon, enhancing its affinity for oxidized compounds such as aldehydes and peroxides present in used cooking oil.

The absorption peaks around 1450–1380 cm^{-1} are associated with bending vibrations of C–H groups in aromatic and aliphatic structures, reflecting the carbon backbone formed during pyrolysis. Meanwhile, the strong absorption in the range of 1200–1000 cm^{-1} is attributed to C–O stretching vibrations, indicating the presence of alcohol, ester, or phenolic groups. These functional groups further support the adsorption of polar contaminants through dipole–dipole interactions.

Additionally, the peaks observed in the region of 800–600 cm^{-1} correspond to out-of-plane bending vibrations of aromatic C–H bonds, confirming the formation of aromatic carbon structures, as shown in Figure 2. Aromaticity contributes to the structural stability of the activated carbon and provides a high surface area for physical adsorption via van der Waals forces.

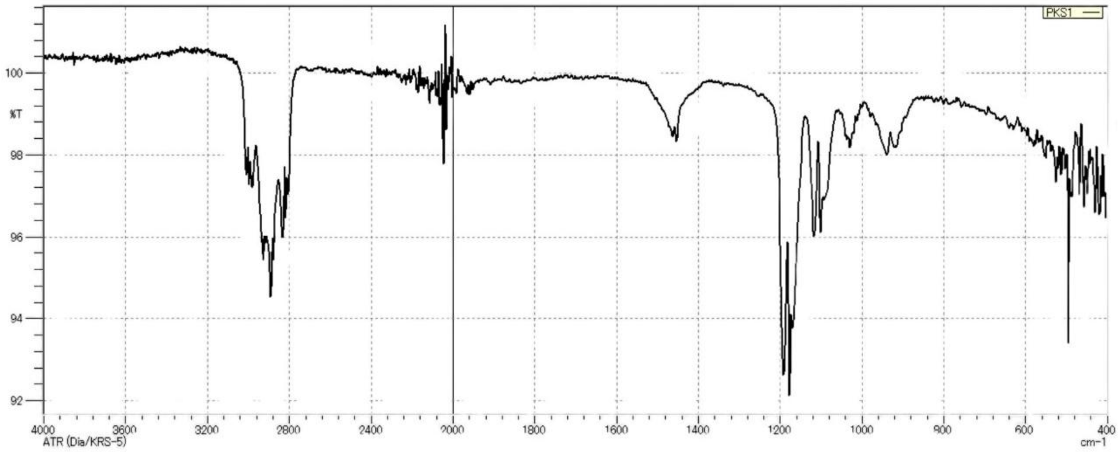

Figure 2. IR spectrum of of palm kernel shell–derived activated carbon

Overall, the FTIR results confirm that the palm kernel shell–derived activated carbon contains a variety of oxygenated functional groups, including –OH, C=O, and C–O, along with aromatic carbon structures. These surface characteristics promote both physical and chemical adsorption mechanisms, making the activated carbon highly effective for the purification of used cooking oil. The presence of polar functional groups enhances interactions with oxidized and acidic compounds, while the aromatic carbon framework provides a stable and porous adsorption matrix.

The successful surface modification achieved through KOH activation is consistent with the improved quality of the purified oil and the acceptable physicochemical properties of the resulting soap product. Therefore, palm kernel shell–based activated carbon represents a sustainable and efficient bioadsorbent for waste oil purification applications.

Analysis of Free Fatty Acid (FFA) Level Reduction in Used Cooking Oil After Treatment with Palm Kernel Shell Activated Carbon

The free fatty acid (FFA) content of the waste cooking oil was determined before and after purification using acid-base titration with phenolphthalein as the indicator. Approximately 5 g of each oil sample was titrated with a standardized sodium hydroxide (NaOH) solution until a stable pink endpoint was observed, and the volume of NaOH consumed was recorded (see Figure 3).

50 ml waste cooking oil was heated at 110 °C for 10 minutes

3 g of activated carbon was added, stirred homogeneously, and filtered

Titrate the waste cooking oil before and after the adsorption process using standard NaOH

Figure 3. Analysis of Free Fatty Acid (FFA) before and after the adsorption process

The Figure 4 shows a clear difference between the FFA levels before and after the adsorption process. The FFA value decreased from 2.35% to 0.43%, which is equivalent to a decrease of approximately 81.7%. This decrease indicates that activated carbon based on palm kernel shells has a high adsorption capacity for free fatty acids and oil degradation compounds.

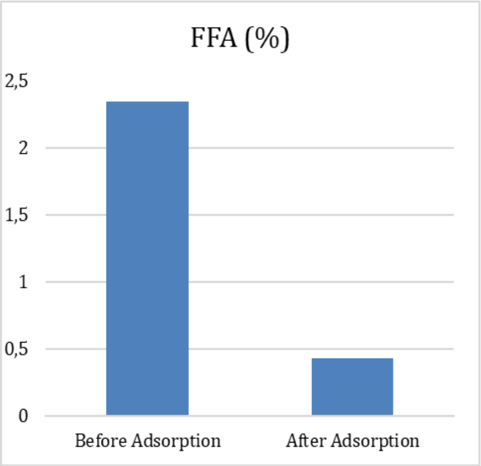

Figure 4. The FFA levels before and after the adsorption process

The test results show that the free fatty acid (FFA) content of used cooking oil before adsorption treatment was 2.35%, which indicates a relatively high level of oil degradation due to repeated frying. This value exceeds the quality limit for usable oil, because high FFA levels are generally correlated with the occurrence of hydrolysis and triglyceride oxidation reactions during heating, which produce free fatty acids, aldehydes, and compounds that cause rancid odors.

After treatment with activated carbon based on palm kernel shells, the FFA level decreased significantly to 0.43%. This decrease indicates the high effectiveness of activated carbon in adsorbing free fatty acids and other oil degradation products. Quantitatively, the adsorption process successfully reduced FFA by ±81.7%, reflecting a substantial improvement in oil quality. This effectiveness can be explained by the physicochemical characteristics of palm kernel shell activated carbon, which has a high surface area and the presence of oxygen functional groups such as –OH, C=O, and C–O. These groups enable interactions between the adsorbent surface and free fatty acid molecules through hydrogen bonding, electrostatic interactions, and van der Waals forces. In addition, the microporous structure of activated carbon facilitates the diffusion of FFA molecules into the pores of the adsorbent, thereby increasing the adsorption capacity.

The reduction in FFA levels to close to those of fresh oil indicates that the purified used oil meets the requirements as a more stable saponification raw material. Low FFA levels contribute to improved soap quality, particularly in terms of hardness, foam stability, and aroma. Oil with low FFA also reduces the need for excess base in the saponification process, resulting in soap with a more controlled pH that is safe for the skin.

Overall, these results confirm that activated carbon from palm kernel shells is an effective, economical, and sustainable bioadsorbent for used cooking oil purification. These findings support the application of biomass waste-based adsorption technology on a small business scale as an environmentally friendly solution to increase the added value of cooking oil waste.

Compared with previous studies reporting FFA reduction efficiencies ranging from 60–75% using biomass-based adsorbents, the 81.7% reduction achieved in this study indicates competitive adsorption performance. The improved efficiency may be attributed to the high-temperature KOH activation (800 °C), which promotes micropore development and increases active surface sites.

Solid Soap Production

The successful formation of solid soap confirms that used cooking oil can be effectively converted into a functional cleaning product through alkaline saponification (see Figure 5). This reaction produces sodium salts of fatty acids from the triglycerides in the oil; these salts act as the main cleansing agents. Adding NaOH to water gradually and controlling the mixing process contributes to a stable reaction, preventing excessive heat generation and ensuring safe, efficient soap formation.

Waste cooking oil that has been treated with bioadsorbent

Waste cooking oil filtered, and add the oil to the NaOH solution, add dye and fragrance, then mix

Soap molding Product solid laundry soap

Figure 5. Solid laundry soap production steps

The 30-day curing period was crucial for improving the soap's quality. During this time, excess water evaporated, and any remaining free alkali was neutralized. This resulted in a harder, gentler soap. This process also enhanced the soap's durability and utility. The alkaline pH observed after curing is consistent with that of typical solid soaps, which generally have a pH level of 8.89. This level effectively removes dirt, making the soap ideal for washing. However, this alkalinity also indicates that the soap is better suited for cleaning applications. Stable foam formation shows that the fatty acid composition of the used cooking oil mainly palmitic, oleic, and linoleic acids supports good surfactant performance [19][20]. These compounds contribute to cleansing efficiency and lather stability.

From an environmental perspective, converting waste cooking oil into solid soap provides a sustainable waste management solution. Instead of being improperly disposed of, which can cause water and soil pollution, the oil is transformed into a valuable product. This approach supports the principles of the circular economy by reducing waste and promoting the reuse of resources.

However, advanced surface characterization such as BET surface area analysis and SEM morphology observation was not performed in this study, representing a limitation. Future research should incorporate detailed textural analysis and adsorption isotherm modeling (Langmuir and Freundlich) to better understand adsorption mechanisms quantitatively [21-23].

CONCLUSION

Activated carbon made from palm kernel shells has been shown to be effective as a bioadsorbent in the purification process of waste cooking oil. FTIR characterization results indicate the presence of oxygen functional groups such as –OH, C=O, and C–O, which play an important role in the adsorption mechanism of impurities, including free fatty acids and oil oxidation products. The adsorption process significantly reduced the FFA content of waste cooking oil from 2.35% to 0.43%, thereby improving the quality of the oil as a raw material for saponification. The solid laundry soap produced from purified oil has good physical characteristics, marked by a solid form and optimal cleaning power. The utilization of waste cooking oil and palm kernel shells in this study not only contributes to reducing environmental pollution but also supports the development of sustainable and economically valuable environmentally friendly products for the community. This study demonstrates an integrated waste-to-value model combining biomass-derived activated carbon synthesis, quantitative adsorption validation, and solid soap production within a UMKM circular economy framework. This study demonstrates an integrated waste-to-value model combining biomass-derived activated carbon synthesis, quantitative adsorption validation, and solid soap production within a UMKM circular economy framework. The statistically validated FFA reduction of 81.7% confirms the adsorption effectiveness, while the downstream soap performance verifies practical applicability. The novelty lies in the integration of material characterization, adsorption quantification, and socio-economic implementation at the small-enterprise scale.

REFERENCES

[1] M. Ulfah, C. N. Tamanampo, and S. Sunardi, "The Refining Capability of Palm Shell Activated Carbon for Waste Cooking Oil," *Food ScienTech Journal*, vol. 5, no. 1, p. 37, Jul. 2023, doi: 10.33512/FSJ.V5I1.16644.

[2] B. E. G. Perdana, "Circular Economy of Used Cooking Oil in Indonesia: Current Practices and Development in Special Region of Yogyakarta," *Journal of World Trade Studies*, vol. 6, no. 1, pp. 28–39, Sep. 2021, doi: 10.22146/JWTS.V6I1.1541.

[3] C. L. Lee, K. L. Chin, P. S. H'ng, M. S. Hafizuddin, and P. S. Khoo, "Activation Temperature and Particle Size of Palm Kernel Shell vs. the Surface Properties of Activated Carbon," *Bioresources*, vol. 18, no. 1, pp. 1714–1730, 2023, doi: 10.15376/BIORES.18.1.1714-1730.

[4] T. D. Hoang, Y. Liu, and M. T. Le, "Synthesis and Characterization of Biochars and Activated Carbons Derived from Various Biomasses," *Sustainability 2024, Vol. 16, Page 5495*, vol. 16, no. 13, p. 5495, Jun. 2024, doi: 10.3390/SU16135495.

[5] N. Ngatirah, M. T. Dariyo, S. Suhardi, and E. Setiawan, "Activated Carbon from Palm Kernel Shell for Biogas Purification," *KnE Life Sciences*, vol. 9, no. 1, pp. 1–12, Aug. 2025, doi: 10.18502/KLS.V9I1.19340.

[6] L. Abubakar, M. M. Aliyu, H. Tukur, A. A. Yahaya, and H. Abubakar, "Palm kernel shell-derived nanoporous carbon materials: A review on preparation, modification and application," *Caliphate Journal of Science and Technology*, vol. 7, no. 1, pp. 73–99, May 2025, doi: 10.4314/CAJOST.V7I1.9.

[7] M. C. F. da Silva *et al.*, "KOH activated carbons from Brazil nut shell: Preparation, characterization, and their application in phenol adsorption," *Chemical Engineering Research and Design*, vol. 187, pp. 387–396, Nov. 2022, doi: 10.1016/J.CHERD.2022.09.012.

[8] H. Song *et al.*, "Supercapacitor Performance of Activated Carbon from Eucommia Ulmoides Oliver Wood Optimized by the Activation Method," *ACS Omega*, vol. 10, no. 15, pp. 15368–15380, Apr. 2025, doi: 10.1021/ACSOMEGA.4C11529.

[9] X. Su, S. Jiang, X. Zheng, X. Guan, P. Liu, and Z. Peng, "Hierarchical porous carbon materials from bio waste-mango stone for high-performance supercapacitor electrodes," *Mater. Lett.*, vol. 230, pp. 123–127, Nov. 2018, doi: 10.1016/J.MATLET.2018.07.096.

[10] M. Deng, J. Wang, and Q. Zhang, "Effect of freezing pretreatment on the performance of activated carbon from coconut shell for supercapacitor application," *Mater. Lett.*, vol. 306, p. 130934, Jan. 2022, doi: 10.1016/J.MATLET.2021.130934.

[11] A. Khdour and M. Nawaj'a, "Recycling of Waste Cooking Oil to Produce Soaps and Detergents: Technical and Economic Feasibility Study," Jan. 2017, Accessed: Nov. 18, 2025. [Online]. Available: http://scholar.ppu.edu/handle/123456789/6303

[12] D. H. Nugroho, L. Ekawati, S. K. Wardana, A. Kalista, and Y. Yuliansyah, "Pembuatan Sabun Padat Dari Minyak Jelantah Sebagai Solusi Limbah Cair Domestik Pada Pesantren Zaadul Ma'ad Kota Palembang," *Jurnal Abdimas Indonesia*, vol. 4, no. 3, pp. 959–970, Sep. 2024, doi: 10.53769/JAI.V4I3.749.

[13] S. Hartini, Y. Widharto, S. R. Indarto, and G. Murdikaningrum, "Eco-efficiency analysis of waste cooking oil recycling into liquid dish soap using life cycle assessment," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing Ltd, Nov. 2021. doi: 10.1088/1755-1315/896/1/012066.

[14] H. Yuvendius, I. Garniwa Mk, R. Setiabudy, A. Verdianto, and C. Hudaya, "The Impact of Freezing Treatment on Physicochemical Characteristics of Oil Palm Kernel Shell-Derived Activated Carbon," *J. Phys. Conf. Ser.*, vol. 3139, p. 12033, 2025, doi: 10.1088/1742-6596/3139/1/012033.

[15] Wahyudi, A. Kurniawan, and Mustafa, “Pemurnian Minyak Jelantah Menggunakan Metode Adsorpsi Dengan Arang Aktif Serbuk Gergaji Kayu Sebagai Adsorben,” *Majalah Teknik Industri*, vol. 30, no. 2, pp. 84–91, Jun. 2023, doi: 10.61844/MAJALAHTEKNIKINDUSTRI.V30I2.471.

[16] M. Onn, K. Muniandy, S. N. ’ Zaiton, and M. U. Wahit, “Free Fatty Acid Reduction in Used Frying Oil via Bio Adsorbent: A Short Review,” *Chem. Eng. Trans.*, vol. 106, pp. 139–144, 2023, doi: 10.3303/CET23106024.

[17] Y. Yelmiza, W. Widya, and H. Yuvendius, “IbM Pelatihan Pembuatan Sabun Padat Berbasis Minyak Atsiri Pada Siswa SMKS Islam Inayah Ujung Batu,” *Jurnal Pengabdian Masyarakat Bangsa*, vol. 2, pp. 3110–3115, Oct. 2024, doi: 10.59837/jpmba.v2i8.1127.

[18] H. Yuvendius, M. Iwa Garniwa, R. Setiabudy, A. Verdianto, and C. Hudaya, “The Impact of Freezing Treatment on Physicochemical Characteristics of Oil Palm Kernel Shell-Derived Activated Carbon,” *J. Phys. Conf. Ser.*, vol. 3139, no. 1, p. 012033, Nov. 2025, doi: 10.1088/1742-6596/3139/1/012033.

[19] E. H. Ernest, A. J. Widagdo, S. Ismadji, S. P. Santoso, and F. Gosal, “Inovasi Pengolahan Minyak Bekas: Peningkatan Kualitas Melalui Adsorpsi FFA dan Produksi Sabun Cair,” *Widya Teknik*, vol. 24, no. 1, pp. 28–31, Feb. 2025, doi: 10.33508/WT.V24I1.6089.

[20] D. R. Al Qory, Z. Ginting, S. Bahri, and S. Bahri, “Pemurnian Minyak Jelantah Menggunakan Karbon Aktif dari Biji Salak (Salacca Zalacca) Sebagai Adsorben Alami dengan Aktivator H2SO4,” *Jurnal Teknologi Kimia Unimal*, vol. 10, no. 2, pp. 26–36, Nov. 2021, doi: 10.29103/JTKU.V10I2.4727.

[21] B. T. Danat, R. A. Wuana, H. F. Chahul, and M. S. Iorungwa, “Review of adsorption isotherms models,” *Applied Water Science 2026 16:3*, vol. 16, no. 3, pp. 72-, Feb. 2026, doi: 10.1007/s13201-025-02682-0.

[22] D. Damayanti, S. Arita, and P. L. Hariani, “Modification of Activated Carbon from Palm Kernel Shells with Fe_3O_4 Magnetic for Water Treatment of Enim River,” *IJFAC (Indonesian Journal of Fundamental and Applied Chemistry)*, vol. 10, no. 3, pp. 176–185, Oct. 2025, doi: 10.24845/ijfac.v10.i3.176.

[23] M. Zakir, P. Taba, N. U. Permatasari, M. Nurdin, and Muliadi, “Palm kernel shell based hydrothermal carbon for methylene blue removal in wastewater treatment: application of dual adsorption isothermal models,” *Journal of Ecological Engineering*, vol. 26, no. 7, pp. 394–407, 2025, doi: 10.12911/22998993/203741.

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