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Eco-Friendly Adsorbent Derived From Palm Kernel Shell Waste As Activated Carbon For Crude Palm Oil (CPO) Purification

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Abstract

Indonesia, as the world's largest palm oil producer, generates significant amounts of biomass waste, including palm kernel shells that remain underutilized. This study aims to develop eco-friendly activated carbon from palm kernel shell waste through carbonization and chemical activation using NaCl and $ZnCl_2$*, and to evaluate its performance in Crude Palm Oil (CPO) purification. Carbonization was conducted at high temperatures under limited oxygen conditions, followed by chemical activation to enhance surface area and pore structure. The resulting materials were characterized using SEM, FTIR, XRD, and XRF to determine morphology, functional groups, crystal structure, and elemental composition. The adsorption performance was evaluated based on the reduction of free fatty acids, peroxide value, saponification value, and moisture content in CPO. The results indicate that* $ZnCl_2$ *activation produces a more developed pore structure and higher adsorption capacity compared to NaCl. This study demonstrates that palm kernel shell waste can be effectively utilized as a low-cost, sustainable, and environmentally friendly adsorbent, contributing to improved CPO quality and supporting circular economy practices in the palm oil industry.*

Keywords: Activated Carbon; Palm Kernel Shell; Ecofriendly Adsorbent; Crude Palm Oil (CPO) Purification; Chemical Activation.

INTRODUCTION

Indonesia is one of the leading agrarian countries and the world's largest producer of palm oil, resulting in substantial biomass waste generation from plantation activities. Palm oil is a major national commodity that has shown significant growth over the years. Data indicate that the total area of oil palm plantations in Indonesia reached 16.83 million hectares with a production of 46.82 million tons in 2022, and it continues to dominate global production in subsequent years. This high level of production is directly proportional to the amount of waste generated, including solid, liquid, and gaseous waste (Kurniawan et al., 2023).

One of the major solid wastes produced in large quantities is palm kernel shell. This waste is abundantly available in major production regions such as Jambi, Riau, and South Sumatra; however, its utilization remains suboptimal. Palm kernel shell is characterized by its hard physical structure, grayish-black color, and resistance to natural degradation. Its high lignocellulosic content, consisting of approximately 45% cellulose and 26% hemicellulose, makes it a promising raw material for activated carbon with high adsorption capacity (Hikmawan and Naufa, 2022; Saleh et al., 2023).

Activated carbon is a porous material widely used as an adsorbent in various purification processes, including in the palm oil industry. Its production involves carbonization and activation processes, either chemical or physical, aimed at increasing surface area and pore structure. Chemical activation commonly employs acidic or basic agents; however, salt-based activators such as NaCl and $ZnCl_2$ are being developed as more environmentally friendly alternatives. These activators are known to enhance the porosity and structural stability of activated carbon, thereby improving its adsorption capacity (Primastiyaningayu et al., 2024).

In the purification of Crude Palm Oil (CPO), oil quality is influenced by several parameters, including free fatty acid (FFA) content, peroxide value, saponification value, and moisture content. High FFA levels can reduce oil quality due to oxidation and hydrolysis processes, leading to the formation of peroxide compounds and rancid odors. The use of activated carbon as an adsorbent can reduce FFA levels through physical adsorption mechanisms, where FFA molecules are bound to the surface of activated carbon via Van der Waals forces and diffuse into the pores of the material (Jondra et al., 2022).

The utilization of palm kernel shell waste as a raw material for activated carbon not only provides a solution to waste management issues but also contributes to improving CPO quality. This approach aligns with the concept of sustainable industry and circular economy, in which waste is converted into value-added products. Therefore, this study aims to investigate the potential of palm kernel shell as an eco-friendly adsorbent through carbonization and activation processes using NaCl and $ZnCl_2$, as well as to evaluate its effectiveness in CPO purification. The results are expected to provide an applicable, economical, and sustainable technological alternative for the palm oil industry in Indonesia.

RESEARCH METHODS

Materials and Equipment

The equipment used in this study included laboratory glassware (beakers and Erlenmeyer flasks), filter paper, separating funnel, mortar and pestle, furnace with a limited air system, pH indicator, burette, clamp and stand, forced convection oven, desiccator, sieve (150 mesh), magnetic stirrer, hot plate, vial bottles, and characterization instruments including Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Diffraction (XRD), and X-Ray Fluorescence (XRF).

The materials used in this study included palm kernel shell waste, sodium chloride (NaCl), zinc chloride ($ZnCl_2$), distilled water, Crude Palm Oil (CPO), phenolphthalein (PP), saturated potassium iodide (KI), sodium thiosulfate ($Na_2S_2O_3$), chloroform, acetic acid, 10% phosphoric acid, 95–98% ethanol, 1% starch solution, sodium hydroxide (NaOH), potassium hydroxide (KOH), and hydrochloric acid (HCl).

Preparation of Activated Carbon

Palm kernel shells were first washed to remove impurities, then dried under sunlight for approximately ±3 days to reduce moisture content. The shells were then carbonized at 500°C for 3 hours under limited oxygen conditions to prevent excessive oxidation. The resulting carbon was cooled to room temperature, then ground using a mortar and pestle into fine powder. The carbon powder was sieved using a 150 mesh sieve to obtain uniform particle size.

Activation Process

Chemical Activation

The carbon obtained from carbonization was chemically activated using two types of salt-based activators, namely 15% NaCl and 2 M $ZnCl_2$ with a carbon-to-solution ratio of 1:2. The mixture was soaked for 24 hours to allow the activator to penetrate into the carbon structure. After soaking, the sample was washed with distilled water until neutral pH (~7) was achieved, then filtered. The resulting activated carbon was dried in an oven at 110°C for 1 hour.

Physical Activation

Physical activation was carried out using a furnace with gradual heating, namely at 200°C for 1 hour, followed by 400°C for 1 hour, and continued at 600°C for 1.5 hours to enhance porosity and surface area of the activated carbon.

Adsorbent Characterization

Fourier Transform Infrared (FTIR)

FTIR analysis was conducted to identify functional groups in the adsorbent. Samples were prepared using the KBr pellet method and analyzed within the wavenumber range of 400–4000 cm^{-1}.

Scanning Electron Microscopy (SEM)

SEM analysis was performed to observe surface morphology and pore structure of the adsorbent. Samples were placed on a specimen holder and analyzed under vacuum conditions.

X-Ray Fluorescence (XRF)

XRF analysis was used to determine the elemental composition of activated carbon before and after activation.

X-Ray Diffraction (XRD)

XRD analysis was carried out to identify the crystal structure of the produced activated carbon.

Crude Palm Oil (CPO) Purification Process

CPO purification was conducted through a degumming process by mixing 100 grams of CPO with 10% phosphoric acid at 80°C. Then, 0.9 grams of activated carbon was added and stirred using a magnetic stirrer at 400 rpm for 3 hours. After that, the oil was washed with distilled water at 60°C until neutral pH was reached, resulting in clearer CPO free from impurities.

CPO Quality Analysis

Free Fatty Acid (FFA)

A total of 2.5 grams of CPO sample was dissolved in 50 mL ethanol and heated to 50°C. After adding phenolphthalein indicator, the solution was titrated with 0.1 N NaOH until a color change occurred.

$$\text{FFA (\%)} = \frac{25{,}6 \text{ x N x V}}{\text{w}} \text{ x } 100$$

N = Normality of NaOH
V = Volume of NaOH (ml)
w = Weight of CPO (gr)

Peroxide Value

A total of 1 gram of CPO was added with an acetic acid–chloroform solution (3:2), saturated KI, and distilled water. After standing, 1% starch indicator was added, then titrated with 0.01 N $Na_2S_2O_3$ until the yellow color disappeared.

$$\text{Peroxide value} = \frac{\text{Meg}}{\text{kg}} = \frac{(S - B) \text{ x N x } 1000}{\text{sample mass}}$$

B = Blank titrant volume (ml)
S = Sample titrant volume (ml)
N = Normality (N) of sodium thiosulfate

Saponification Value

A total of 1.5 grams of sample was mixed with 50 mL of 0.5 N alcoholic KOH and heated for 30 minutes. After adding phenolphthalein indicator, the solution was titrated with 0.5 N HCl until the pink color disappeared.

$$\text{Saponification value (\%)} = \frac{(\text{Vb-Vs}) \text{ x N x } 56{,}1}{\text{m}}$$

Vb = Volume of HCl for blank titration (mL)
Vs = Volume of HCl for sample titration (mL)
N = Normality of HCl solution (eq/L)
56,1 = Equivalent weight of KOH (mg/mmol)
m = Mass of oil/fat sample (g)

Moisture Content

A total of 5 grams of sample was heated in an oven at 130°C until constant weight was achieved. Moisture content was determined based on the difference in weight before and after heating.

$$\text{Moisture content (\%)} = \frac{\text{initial weight (g) - final weight (g)}}{\text{sample weight (g)}} \text{ x } 100\%$$

RESULTS AND DISCUSSION

Characterization of Activated Carbon

SEM Characterization

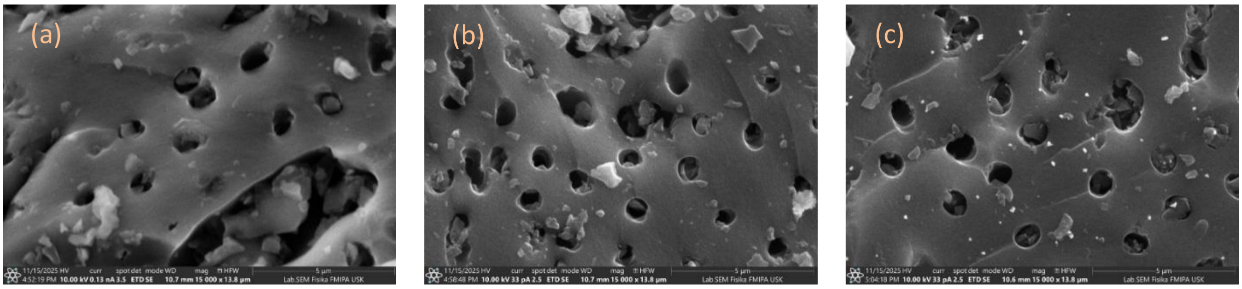


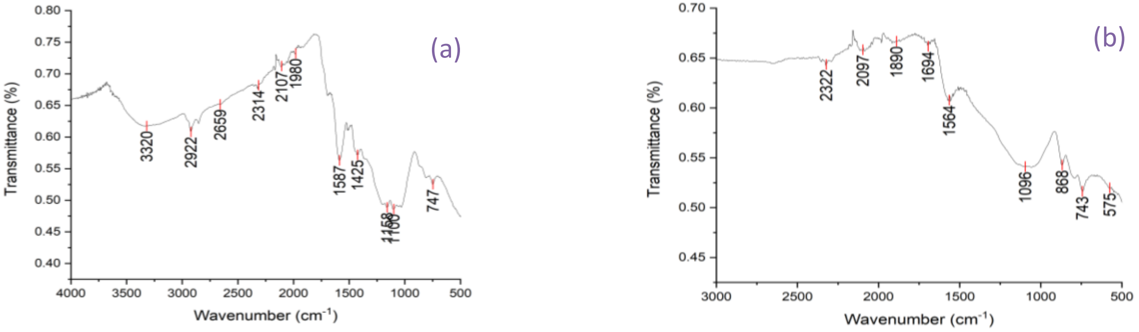
Figure 1. SEM Characterization Results of Activated Carbon (a) Unactivated Carbon (b) NaCl-Activated Carbon (c) ZnCl2-Activated Carbon

The SEM analysis results (Figure 1) show that carbon before activation has a relatively dense surface with pores that have not yet developed optimally. This structure indicates that the carbonization process only produces initial cavities with a limited pore distribution. After activation using NaCl, an increase in the number of pores with a more uniform distribution is observed. The formed pores reflect micro- to mesoporous structures, which contribute to an increase in the surface area of the activated carbon (Pujiono and Mulyati, 2014).

Meanwhile, activation using $ZnCl_2$ results in more significant morphological changes. The pores appear more open, well-defined, and interconnected, indicating a more optimal development of the porous structure. This suggests that $ZnCl_2$ plays a more effective role in pore formation and development, thereby potentially enhancing the adsorption capacity of activated carbon compared to NaCl.

FTIR Characterization

The FTIR spectrum of carbon before activation shows the dominance of –OH and aliphatic C–H functional groups, indicating the presence of lignocellulosic residues and volatile compounds. In addition, the presence of aromatic C=C bands indicates the initial formation of carbon structure, although it is not yet fully developed. After activation using NaCl, there is a decrease in the intensity of –OH and C–H groups, accompanied by an increase in aromatic C=C bands. This indicates that the activation process promotes aromatization and enhances the structural stability of carbon. Activation using $ZnCl_2$ results in more significant changes, characterized by a sharp decrease in hydroxyl groups and an increase in aromatic structure intensity. This condition indicates that $ZnCl_2$ acts as an effective dehydrating agent in accelerating the formation of a more mature and stable carbon structure.



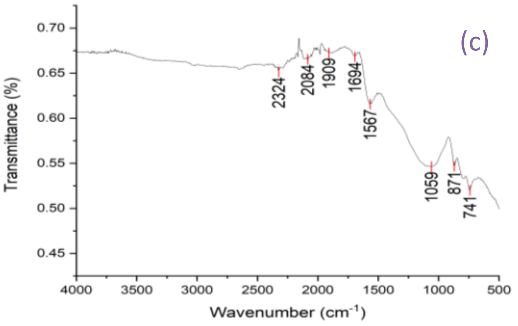


Figure 2. FTIR Characterization Results of Activated Carbon (a) Unactivated Carbon (b) NaCl-Activated Carbon (c) ZnCl2-Activated Carbon

XRD Characterization

The XRD analysis results show that all activated carbon samples exhibit diffraction patterns with broad peaks in the 2θ range of approximately 20–25°, indicating the dominance of an amorphous structure. This structure is a common characteristic of biomass-based carbon materials with low crystallinity. Activation using NaCl does not produce new crystalline phases but causes changes in peak intensity, indicating restructuring within the carbon matrix. Meanwhile, $ZnCl_2$ activation shows slightly more defined diffraction peaks, suggesting an increase in structural order, although the material remains predominantly amorphous. The absence of peaks related to activating agent residues indicates that the washing process was effective.

XRF Characterization

The XRF analysis results show that non-activated carbon is dominated by CaO (±43.6%) and SiO_2 (±22%), indicating a high ash content that may block pores and reduce adsorption capacity. NaCl-activated carbon still shows dominance of mineral oxides such as CaO (±36.5%) and SiO_2 (±29%), with a low ZnO content. This suggests that NaCl activation has a moderate effect, being able to modify the carbon structure but not yet optimal in reducing mineral impurities. In contrast, $ZnCl_2$-activated carbon shows an increase in ZnO content (±7.1%) and a decrease in CaO (±21.7%), indicating that $ZnCl_2$ is more effective in reducing mineral content and ash fraction.

CPO Quality Analysis

Free Fatty Acid (FFA)

Table 1. CPO FFA Analysis Results

Analysis	CPO sample without activated carbon	CPO Sample with ZnCl2 Activated Carbon	CPO Sample with NaCl Activated Carbon
FFA (%)	5,92	4,03	4,14

Free fatty acid (FFA) is a key parameter in determining CPO quality as it is related to the hydrolysis of triglycerides. Based on the analysis results, untreated CPO has an FFA value of 5.92%, exceeding the Indonesian National Standard (SNI) limit (≤5%). After adsorption treatment, the FFA value decreased to 4.03% for $ZnCl_2$-activated carbon and 4.14% for NaCl-activated carbon. This reduction indicates that activated carbon is capable of effectively adsorbing free fatty acids. Activation, particularly using $ZnCl_2$, increases the surface area and number of active sites, resulting in more optimal interaction between the adsorbent and FFA molecules (Harahap et al., 2021).

Peroxide Value Analysis

Table 2. CPO Peroxide Number Analysis Results

Analysis	CPO sample without activated carbon	CPO Sample with ZnCl2 Activated Carbon	CPO Sample with NaCl Activated Carbon
Bilangan Peroksida (meq O_2/kg)	16,19	6,07	6,07

The peroxide value indicates the level of primary oxidation in oil. Untreated CPO shows a value of 16.19 meq O_2/kg, indicating the occurrence of initial oxidation. After treatment with activated carbon, this value significantly decreased to 6.07 meq O_2/kg for both types of activators. This decrease demonstrates that activated carbon is effective in adsorbing peroxide and hydroperoxide compounds. The absence of a significant difference between $ZnCl_2$ and NaCl suggests that both adsorbents have relatively similar effectiveness toward oxidation compounds with small molecular sizes (Husnah and Nurlela, 2020).

Saponification Value Analysis

Table 3. CPO Saponification Number Analysis Results

Analysis	CPO sample without activated carbon	CPO Sample with ZnCl2 Activated Carbon	CPO Sample with NaCl Activated Carbon
Bilangan Penyabunan	201,67	198,78	199,77

The saponification value of untreated CPO is 201.67, which then decreases to 198.78 ($ZnCl_2$) and 199.77 (NaCl). This decrease indicates that activated carbon is able to adsorb components that react with KOH, such as free fatty acids and other polar compounds. The absence of a significant difference between the two activators indicates that adsorption of components contributing to the saponification value is relatively similar. This is likely due to the large molecular size of triglycerides, which is less affected by differences in pore structure (Kurniati and Susanto, 2015).

Moisture Content Analysis

Table 4. CPO Water Content Analysis Results

Analysis	CPO sample without activated carbon	CPO Sample with ZnCl2 Activated Carbon	CPO Sample with NaCl Activated Carbon
Kadar Air (%)	0,30 %	0,08 %	0,10 %

Moisture content is an important parameter affecting oil stability and shelf life. Untreated CPO has a moisture content of 0.30%, which is still below the SNI limit (≤0.50%). After treatment, the moisture content decreased to 0.08% for $ZnCl_2$-activated carbon, indicating good water adsorption capability. In contrast, the moisture content for NaCl-activated carbon slightly increased to 0.10%. This is likely due to the hygroscopic nature of activated carbon, which allows it to absorb moisture from the surrounding environment or retain water within its pore structure (Aldi et al., 2024).

CONCLUSION

Based on the results of this study, palm kernel shell waste has been successfully utilized as activated carbon with potential as an eco-friendly adsorbent for the purification of Crude Palm Oil (CPO). The activation process was proven to have a significant effect on the characteristics of the activated carbon, including its morphology, chemical structure, and elemental composition. The characterization results indicate that activation using $ZnCl_2$ produces more optimal pore development, a more stable aromatic structure, and lower mineral impurity content compared to NaCl and non-activated carbon. The application of activated carbon in CPO purification shows an improvement in oil quality, as indicated by the reduction of FFA value from 5.92% to 4.03%, peroxide value from 16.19 to 6.07 meq O_2/kg, and moisture content to 0.08%. Meanwhile, NaCl-activated carbon also demonstrates effectiveness, although not as optimal as $ZnCl_2$. Therefore, $ZnCl_2$-activated carbon exhibits the best performance and has strong potential to be developed as an environmentally friendly adsorbent in the palm oil industry, while also supporting waste utilization based on circular economy principles.

REFERENCES

De Smedt, Gertjan, Hammami, Rym, Snijkers, Frank, Ruysschaert dan Greetje. 2025. "Comparative study on the effect of ZnCI, a 60:20 mol eutectic of ZnCI--NaCl and CO, during activation of pinewood". *Journal Research Chem.* Vol 1(1): 2-15.

De Smedt, Gertjan, Hammami, Rym, Snijkers, Frank, Ruysschaert dan Greetje. 2025. "Improving micro- and mesoporosity of carbon from seaweed by eutectic activation". *Journal Biblio UGent.* Vol 2 (4) : 5- 10.

Diniaty, D., F.Haunn dan M.I. Hamdy. 2019. "Analisis Pengendalian Mutu (Quality Control) CPO (Crude Palm Oil) pada PT. XYZ." *Jurnal Teknik lndustri*, Vol. 5 (2): 92- 99.

Hapsari, L., Arifin, B., dan Setyawan, H. 2019. "Pemanfaatan Cangkang Sawit Sebagai Adsorben Dalam Pemurnian CPO". *Jurnal Teknologi Pertanian Tropis*, 10(1), 45-52.

Haryono., M. Ali dan Wahyuni.2012. "Pemucatan Minyak Sawit Mentah Menggunakan Arang Aktif". *Jurnal Teknik Kimia.* Vol 6(2): 41-45.

Hermanti, M., H. Mahmudah, U. M. Hasyim dan I. Kurniaty. 2019. "Pemanfaatan Limbah Batang Pisang Sebagai Bioadsorbent Dalam Pengolahan Minyak Mentah (CPO) Untuk Menurunkan Free Fatty Acid (FFA) Dengan Variabel Massa Bioadsorbent". *Jurnal UMY SEMNASTEK.* Vol 1(1): 1-6.

Hikmawan, 0. dan M. Naufa. 2022. "Perbandingan Efektivitas Bioadsorben Limbah Tandan Kosong Dan Cangkang Kelapa Sawit Pada Purifikasi Minyak Jelantah". *Jurnal Teknik Kimia.* 8(1):1-6.

Jondra, A., Azhari, Sulhatun, Zulnazri dan Meriatna. (2022). "Penurunan Kadar FFA *(Free Fatty Acid)* pada CPO dengan Menggunakan Adsorben dari Karban Aktif Cangkang Buah Ketapang". *Chemical EngineeringJournal.1(4):* 99-110.

Kochaniec, M., dan Lieder, M. (2024). "Molten salt template synthesis of highly porous carbon from chitosan using NaCl and ZnCI". *Scientific Reports.* Vol 1(1): 114-118.

Kurniawan, R., S. F. Azzarah dan N. T. Yohaningsih. 2023. "Pengaruh Jenis Adsorben pada Proses Bleaching di Pemurnian *Crude Palm Oil* (CPO) Sebagai Bahan Baku pada Proses Green Fuel". *Jurnal Teknologi Ramah Lingkungan.* 7(2):102-111.

Marfitania,T., Yunianto, Hariyanto, K. P. Saragih dan R. Januarti. 2024. "Sintesis Zeolit Karban Aktif Berbasis Abu Boiler Pabrik Kelapa Sawit sebagai Adsorben Asam Lemak Be bas dan Karoten pada CPO". *Jurnal Sains Dan Teknologi.* Vol 5(1): 1-11.

Meriatna., N. Sylvia, Suryati, F. S. Siregar, L. Maulinda dan Zulmiardi. 2020. "Optimasi Kondisi Proses Adsorbsi untuk Meningkatkan Kualitas Cpo Menggunakan Adsorben Karban Aktif Sisa Pembakaran Cangkang Kelapa Sawit pada Batch Column". *Jurnal Teknologi Kimia Unimal.* Vol 9(1): 14-23.

Nasution dan Chairunnisa. 2021. "Analisis Pemasaran Kelapa Sawit Di Desa Sampeyan Kecamatan Sungai Kanan Kabupaten Labuhan Batu SeIatan Provinsi Sumatera Utara". *Wahana lnovasi Jurnal Penelitian dan Pengabdian Masyarakat UISU.* Vol. 10(1) : 234 - 244.

Nugroho, A.S. 2019 "Pemanfaatan Limbah Tempurung Kelapa Sawit". *Jurnal Teknologi.* Vol 19(2): 21-26.

Permana, E., I.L. Tarigan, D.R. Gusti dan I.Lestari. (2020). "Analisis Mutu Karban Aktif dari Cangkang Kelapa Sawit Menggunakan Larutan Aktivator ZnCI,." *Jurnal Teknologi.* Vol 12 (12); 170-175.

Primastiyaningayu, A., E. I. Rismala dan N. W. Triana. (2024). "Sintesa dan Karakteristik Karban Aktif dari Batang Pisang Kepok (Musa *acuminata)* Sebagai Adsorben pada Penjernihan Minyak Goreng Bekas". *Jurnal 1/miah Teknik Kimia.* 8(2): 83-90.

Raja, P. M. dan Giyanto. 2020. "Aplikasi Karban Aktif Dari Cangkang Kelapa Sawit Sebagai Adsorben Pada Minyak Jelantah Bahan B Sabun". *Jurnal Agro Fabrica.* 2(2): 49-57.

Rosa, A. A., E. Ariyanto, M. Mardwita dan G. Abriansyah .2023. "lnvestigasi Uji Nilai Warna dan Persentase Free Fatty Acid dalam Meningkatkan Mutu Crude Palm Oil." *Jurnal lndustri.* 8(1): 29-34.

Saleh, M., J. Doi dan Y. Pasae. 2023. Pembuatan Arang Aktif dari Cangkang Kelapa Sawit, Tempurung Kelapa, dan Cangkang Kakao dengan Proses Torefaksi. *Chem Engineering Journal.* 1(1): 1-15.

Setiawan, Ab. A., Anis, S., & lntan, S. (2017). "Pemanfaatan Limbah Daun Nanas *(Ananas* comosus) sebagai Bahan Dasar Arang Aktif Untuk Adsorpsi Fe (11)". *JKK.* Vol 6(3), 66-74.

Taufik, M.,T. S. D. Kasih, dan M. Khair. 2021. "Pembuatan Karban Aktif Cangkang Kelapa Sawit (Elaeis guineensis) Dengan Aktivator Gelombang Microwave." *Chemistry Journal of Universitas Negeri Padang,* Vol. 10 (1): 40-44.

Wulandari, N., Prihastanti, E., dan Nurhadi, A. 2021."Efektivitas Karban Aktif dalam Proses Bleaching Minyak Sawit Mentah". *Jurnal lndustri Pangan,* 12(4), 211-220.