Indonesian Journal of Chemical Science and Technology (IJCST)
State University of Medan, https://jurnal.unimed.ac.id/2012/index.php/aromatika

IJCST-UNIMED 2026, Vol. 09, No. 1, Page; 158 – 167
Received : Jan 21st, 2026 Accepted : Jan 29th, 2026 Web Published : Jan 31st, 2026

Utilization of Coconut Shell Activated Carbon as an Eco-Friendly Adsorbent for Cu(II) Remediation in a Continuous Column System

Isma Uly Maranggi [1*], Syariful Maliki [2], Linda Ekawati [1], Dwi Indah Lestari [1], Zeolita Prabu Putri [2]

[1] *Study Program of Diploma IV Industrial Chemical of Technology, Department of Chemical Engineering, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara, Bukit Lama, Palembang 30128, Indonesia*
[2] *Study Program Diploma III Chemical Engineering, Department of Chemical Engineering, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara, Bukit Lama, Palembang 30128, Indonesia*

**Corresponding author : ismauly@polsri.ac.id*

ABSTRACT

Copper (II) contamination in aquatic environments poses severe toxic risks. This study investigates the use of coconut shell-activated carbon as an eco-friendly adsorbent for Cu(II) remediation in a continuous column system. Coconut shell was prepared via carbonization at 400–500°C, followed by 0.1 M NaOH activation. FTIR and SEM analysis confirmed the presence of active functional groups (O–H, C=O, C–O) and a porous morphology suitable for ion diffusion. Continuous adsorption trials, conducted at a flow rate of 25 mL/min with 100 mg/L Cu(II), showed that performance increased with contact time. The system achieved a maximum adsorption capacity of 2.390 mg/g and 15.948% effectiveness at 25 minutes. Consequently, coconut shell-activated carbon demonstrates significant potential as a cost-effective adsorbent for continuous heavy-metal wastewater treatment.

Keywords: Activated Carbon, Coconut Shell, Adsorption, Continuous Column System

1. INTRODUCTION

Heavy metal contamination in aquatic environments is a serious problem that requires immediate attention. One of the heavy metals commonly found and requiring further treatment is copper (Cu) in the form of Cu(II) ions. Elevated concentrations of copper (Cu) exceeding established tolerance thresholds can lead to copper-induced toxicity in biological organisms.[1] The toxic effects of Cu occur only after it enters the organism's body.[2] The presence of this heavy metal can inhibit growth and ultimately lead to mortality in aquatic biota and humans. Therefore, this condition highlights the urgent need for effective, low-cost, and environmentally friendly remediation methods to reduce Cu(II) ion concentrations before wastewater is discharged into the environment.

Various methods have been applied to remove heavy metals from wastewater; however, adsorption is considered one of the most efficient, economical, and simple approaches. The adsorption process requires a solid material (adsorbent) to bind metal ions onto its surface via attractive forces between atoms or molecules on the solid surface.[3] In this study, coconut shell was selected as the adsorbent material. Coconut shell is a waste product of the coconut industry and has significant biomass potential for use as activated carbon or an adsorbent. Its high hardness facilitates processing and yield low ash content and high carbon purity.[4] This adsorbent was chosen due to its superior diffusion properties compared to other materials.[5] Furthermore, the utilization of coconut shell as an adsorbent not only provides economic value but also supports green technology principles and sustainable biomass waste management.

In this research, activated carbon derived from coconut shell was first subjected to pyrolysis and subsequently characterized for its physicochemical properties, including surface area, pore distribution, and surface functional groups. The novelty of this study lies in the application of a continuous column system, in which wastewater is continuously passed through an adsorption column. Continuous column systems offer more stable adsorption efficiency, more effective contact time, and easier integration into wastewater treatment facilities. In general, adsorbates in continuous adsorption processes are effectively removed until the breakthrough point is reached, while continuous influent flow enhances the driving force for mass transfer.[6] Therefore, further investigation of Cu(II) ion remediation using an environmentally friendly coconut shell–based adsorbent in a continuous column system is warranted.

This study is expected to provide important data on the characterization of coconut shell activated carbon through FTIR and SEM analyses, as well as on adsorption capacity and Cu(II) removal efficiency under continuous flow conditions. The results are anticipated to serve as a basis for the development of practical, low-cost, and environmentally friendly adsorption technologies for heavy metal wastewater treatment, particularly for small- and medium-scale industries.

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

The primary materials used in this study are categorized into three groups: the raw material for the adsorbent, chemicals for activation and analysis, and the test solution. Dry coconut shells were employed as the eco-friendly raw material, serving as the carbon precursor. For activation, a 0.1 M NaOH solution was used as the chemical activating agent to develop the pore structure of the activated carbon. Distilled water was used to wash the activated carbon and dilute the solution. Meanwhile, the Cu(II) ion test solution, serving as the adsorbate, was prepared using analytical grade (p.a.) copper salt, specifically $CuSO_4 \cdot 5H_2O$. The initial concentration was adjusted to simulate wastewater conditions. The equipment used in this study included an analytical balance, standard laboratory glassware (beakers, funnels, stirring rods, and filtration flasks), a vacuum filtration setup, and a continuous adsorption column system. Characterization was performed using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM), while the concentration of Cu(II) was measured using UV-Vis Spectrophotometry.

2.2. Research Procedure

e-ISSN : 2622-4968, p-ISSN : 2622-1349

2.2.1. Coconut Shell Carbonization

The coconut shells were thoroughly washed to remove impurities, sun-dried, and subsequently dried in an oven at 105°C for 12 hours to eliminate residual moisture. Following the drying process, carbonization was performed in a furnace at temperatures ranging from 400°C to 500°C for 1–2 hours to produce coconut shell char.

2.2.2. Chemical Activation of Carbon

The char produced from the carbonization process underwent chemical activation. However, since the initial char size was coarse and non-uniform, it was first crushed using a crusher to obtain a smaller and more uniform particle size. The char was then chemically activated by immersing it in a 0.1 M NaOH solution for 24 hours. Activation using NaOH enhances carbon porosity, resulting in high surface area, micropore volume, and adsorption capacity.[7] A high particle surface area determines the magnitude of adsorption, thereby optimizing the ability to adsorb Cu(II) ions.

Following activation, the adsorbent was washed repeatedly with distilled water and separated using vacuum filtration until the resulting filtrate reached a pH of 7–8. The separated adsorbent was subsequently dried in an oven at 110°C for 6 hours and stored in an airtight container as ready-to-use Coconut Shell Activated Carbon.

2.2.3. Adsorbent Characterization

Adsorbent characterization was conducted using FTIR in the wavenumber range of 4000–400 cm^{-1}. This analysis was performed to identify functional groups and chemical bonds present in the coconut shell–derived adsorbent based on the interaction between infrared radiation and sample molecules. In addition to FTIR analysis, Scanning Electron Microscopy (SEM) was employed to examine the surface structure and morphology of the coconut shell activated carbon at high resolution.

2.2.4. Preparation of Cu(II) Solution

The Cu(II) stock solution was prepared by dissolving a calculated amount of $CuSO_4 \cdot 5H_2O$ in distilled water. The solution was diluted to obtain the required initial concentration of 100 mg/L for the continuous column adsorption experiments.

2.2.5. Column Adsorption System

The adsorption process was carried out using a laboratory-scale column with an internal diameter of 21 mm and a column height of 50 cm. The Cu(II) solution was introduced from the top of the column in a down-flow mode using a peristaltic pump to control the flow rate. The flow rate was maintained at 25 mL/min to ensure sufficient contact time between the adsorbent and adsorbate and to prevent channelling (non-uniform flow). Effluent samples were collected at regular intervals of 5 minutes to evaluate the temporal profile of Cu(II) concentration reduction.

2.2.6. Chemical Activation of Carbon

e-ISSN : 2622-4968, p-ISSN : 2622-1349

Effluent samples containing Cu(II) were analyzed using a UV–Vis spectrophotometer at a wavelength range of approximately 800–810 nm. Based on the measured concentrations, the adsorption capacity (q) was calculated using the following equation[8]:

$$q = \frac{(C_0 - C_e)V}{m}$$

where:

Q = adsorption capacity (mg/g)

C_0 = initial Cu(II) concentration (mg/L)

C_e = final Cu(II) concentration (mg/L)

V = volume of the solution (L)

m = mass of the adsorbent (g)

In addition to adsorption capacity, the adsorption efficiency was determined to evaluate the percentage of Cu(II) ions removed by the adsorbent. The adsorption efficiency was calculated as the ratio of the amount of Cu(II) adsorbed to the initial concentration, as expressed by the following equation[8]:

$$\text{Adsorption Efficiency (\%)} = \frac{[C_0 - C_s]}{C_0} x100\%$$

Given:

Co = Cu(II) concentration before adsorption (mg/L)

Cs = Cu(II) concentration after adsorption (mg/L)

3. RESULTS AND DISCUSSION

3.1. Analysis of Raw Material Characterization Results

In this section, chemical activation was performed by immersing (macerating) the coconut shell powder in a 0.1 M NaOH solution to enlarge the pore diameter and increase the pore volume of the adsorbent. The prepared activated carbon raw material was subsequently characterized to determine its chemical composition and surface structure using FTIR and SEM analyses.

e-ISSN : 2622-4968, p-ISSN : 2622-1349

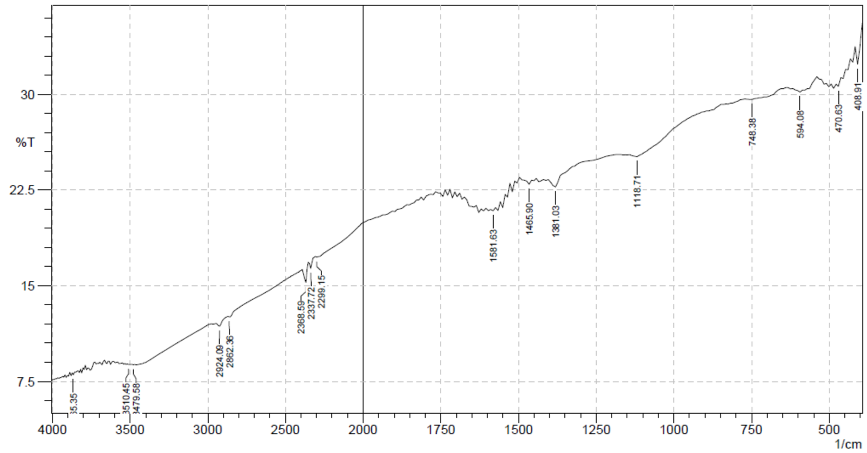


Figure 1. FTIR Spectrum of Coconut Shell Char Activated Carbon

The results of the functional group analysis using the FTIR instrument are presented in Figure 1. The FTIR spectrum exhibits several significant absorption bands within the wavenumber range of 4000–400 cm^{-1}. These bands indicate the presence of oxygen-containing surface functional groups, which play a crucial role as active sites for the adsorption of Cu(II) metal ions.[9]

The O–H functional group appearing at wavenumbers 3479.58–3510.45 cm^{-1} represents the primary active sites capable of releasing protons (H^+) and interacting directly with Cu(II) ions through ion exchange and complexation.[10] The wavenumber at 1581.63 cm^{-1} indicates the C=C aromatic stretch associated with the lignin content of the coconut shell, serving as a strong metal ion trapping site.[11] The C–O bond is observed at wavenumber 1118.71 cm^{-1}, reflecting the degree of carbon surface oxidation occurring during activation, while the C–H bond of aromatic rings with medium intensity appears at wavenumber 2924.09 cm^{-1}.[12] The bands at 748–750 cm^{-1} indicate aromatic (C–H) functional groups resembling graphite, which reinforce the fundamental structure of the activated carbon.[13] Furthermore, the C=O functional group is observed at 2368.59 cm^{-1}, consistent with previous research findings.[14]

The peaks at 594.08 cm^{-1}, 470.63 cm^{-1}, and 408.09 cm^{-1} can be attributed to metal-oxygen bond vibrations.[10] This confirms that the activation process was successful. However, the chemically activated carbon still retains certain infrared-sensitive functional groups, specifically the C–O group. The FTIR spectrum effectively verifies that the treated coconut shell activated carbon possesses oxidized surface functional groups, primarily O–H and C=O. These functional groups, which exhibit O–H, C=O, and C–O stretching vibrations, play a crucial role as adsorbents for pollutants. The adsorption mechanism involves the active sites identified at wavenumbers 3479.58–3510.45 cm^{-1}, where the functional groups interact within the surface structure of the coconut shell activated carbon.

e-ISSN : 2622-4968, p-ISSN : 2622-1349

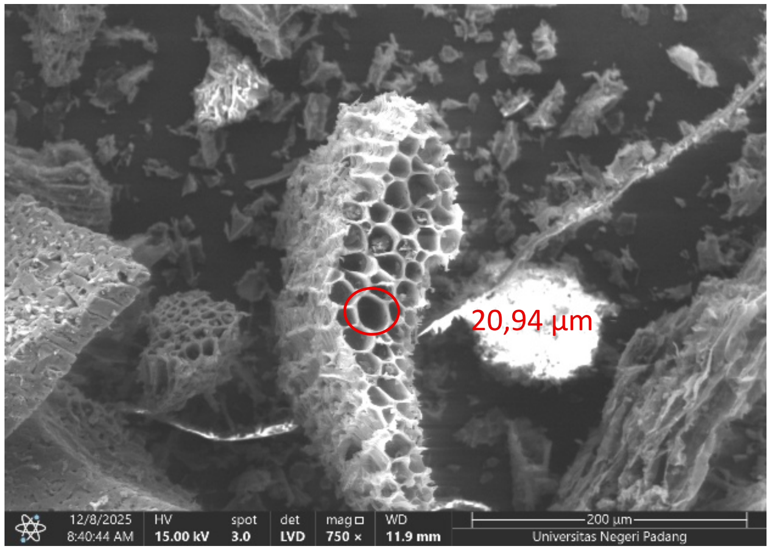


Figure 2. SEM Results of Coconut Shell Char Activated Carbon

The SEM characterization results presented in Figure 2 indicate that the material (activated carbon) surface is not smooth but rather characterized by numerous cavities, voids, and crevices. The pore sizes of the coconut shell activated carbon vary, ranging from approximately 8.45 to 20.94 µm. This texture results from the carbonization and chemical activation processes using NaOH. The presence of a rough surface and irregular pores provides evidence that the activation process successfully etched the carbon walls and released volatile substances (such as tar and hydrocarbons), thereby opening and developing the adsorbent's pore structure. Although pores in the µm range are strictly classified as macropores, they play a vital role in adsorption. Large macropores function as access channels, allowing Cu(II) ions (adsorbate) to rapidly diffuse from the external surface into the smaller internal pore structures (micropores and mesopores).[15]

The characterization results reveal a surface pattern that is layered or heterogeneously structured, reflecting the remnants of the natural cellulose structure of the coconut shell. During carbonization, this organic matrix collapses, leaving thin carbon layers that form partition walls between pores, thereby enhancing the adsorption capacity. This SEM analysis validates that the coconut shell activated carbon possesses a highly favorable surface morphology for application as an adsorbent. Furthermore, the presence of thin layers and rudimentary pores indicates that this material holds significant potential for a high internal surface area, serving as the primary active sites for Cu(II) ion capture.

3.1. Analysis of Cu(II) Reduction

The reduction of Cu(II) metal ion levels in the test solution was conducted using 5 g of coconut shell activated carbon in a continuous column system. The operating principle of this column involves continuously contacting the test solution with the adsorbent within the column at a constant flow rate of 25 mL/min. The absorbance data and the corresponding reduction in Cu(II) concentration over time, measured using UV-Vis Spectrophotometry, are presented in Table 1.

Table 1. Analysis of Cu(II) Metal Adsorption Filtrate

e-ISSN : 2622-4968, p-ISSN : 2622-1349

Contact Time (Minute)	Absorbance	Concentration (mg/L)
0	0.919	99.912
5	0.912	99.143
10	0.902	98.044
20	0.889	96.615
25	0.774	83.978

Table 1 presents the changes in the absorbance values of the Cu(II) solution as a function of adsorption contact time using coconut shell activated carbon. Absorbance values are directly proportional to the Cu(II) metal concentration in the solution; thus, a decrease in absorbance indicates a reduction in Cu(II) concentration due to the adsorption process, as depicted in Figure 3. In the initial sample, an absorbance of 0.919 indicates a high Cu(II) concentration prior to the adsorption process. After 5 minutes, the absorbance decreased slightly to 0.912, indicating that Cu(II) ions began to be adsorbed onto the activated carbon surface. A gradual decrease in absorbance was also observed at 10 minutes (0.902) and 20 minutes (0.889), demonstrating that the adsorption process continued with increasing contact time.

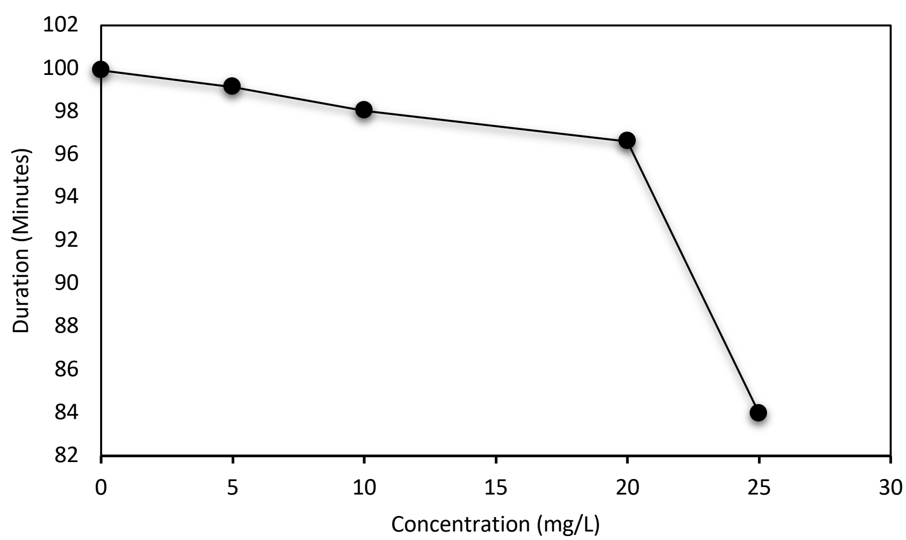


Figure 3. Reduction of Cu (II) Concentration Versus Time by Continuous Column Adsorption System

The most significant reduction in absorbance occurred at 25 minutes, dropping to 0.774. This indicates that as contact time increases, a greater amount of Cu(II) ions are bound to the activated carbon. At this stage, adsorption approaches the optimum condition, where the majority of pores and active functional groups have interacted with the Cu(II) ions.

Based on Table 2, it is evident that the adsorption contact time significantly influences the adsorption capacity and effectiveness of Cu(II) metal removal using coconut shell activated carbon. At an adsorption time

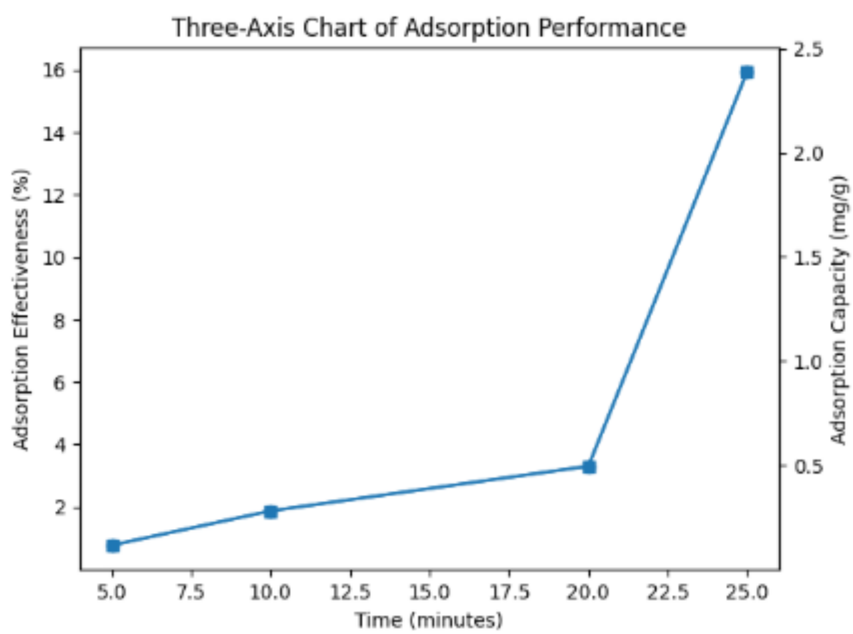
e-ISSN : 2622-4968, p-ISSN : 2622-1349

of 5 minutes, the adsorption capacity remained low at 0.115 mg/g with an effectiveness of 0.770%, indicating that the interaction between Cu(II) ions and the adsorbent active sites was still limited. As the contact time increased to 10 and 20 minutes, the adsorption capacity rose to 0.280 mg/g and 0.495 mg/g, respectively, followed by an increase in adsorption effectiveness to 1.870% and 3.300%. This indicates that a longer contact time allows more Cu(II) ions to diffuse into and bind onto the pores and active functional groups of the activated carbon. The presence of fine pores increases the surface area, thereby facilitating greater interaction between the adsorbate solution and the adsorbent.[16]

Table 2. Cu(II) Metal Adsorption Capacity and Efficiency

Contact Time (Minute)	Adsorption Capacity (mg/g)	Adsorption Efficiency (%)
5	0.115	0.770
10	0.280	1.870
20	0.495	3.300
25	2.390	15.948

The most significant improvement occurred at an adsorption time of 25 minutes, where the adsorption capacity reached 2.390 mg/g with an effectiveness of 15.948%. This phenomenon is attributed to the availability of a large adsorbent surface area.[17] This result in Figure 4 is consistent with adsorption theory, which states that increasing contact time enhances the amount of bound adsorbate until a near-equilibrium condition is reached.[18] Furthermore, this finding is supported by the characteristics of the coconut shell activated carbon, which possesses a porous structure and active functional groups that play a crucial role in heavy metal adsorption.



e-ISSN : 2622-4968, p-ISSN : 2622-1349

Figure 4. Cu(II) Adsorption Efficiency and Capacity as a Function of Contact Time

4. CONCLUSION

Coconut shell–based activated carbon produced via carbonization and chemical activation with 0.1 M NaOH demonstrates effective physicochemical properties for Cu(II) adsorption. FTIR and SEM analyses confirm the presence of oxygen-containing functional groups and a porous surface structure that facilitates metal ion binding. Continuous column adsorption results indicate that contact time significantly influences adsorption performance, with increasing time enhancing both adsorption capacity and removal efficiency. A maximum adsorption capacity of 2.390 mg/g and an adsorption efficiency of 15.948% at 25 minutes highlight the potential of coconut shell activated carbon as a sustainable and environmentally friendly adsorbent for Cu(II) removal.

REFERENCES

1. Samosir, A. F., Yulianto, B., & Suryono, C. A. **(2019)**. *Arang Aktif dari Ampas Kopi sebagai Absorben Logam Cu Terlarut dalam Skala Laboratorium*. *8*(3), 237–240.
2. Anggriani, U. M., Hasan, A., & Purnamasari, I. **(2021)**. *Kinetika Adsoprsi karbon Aktif dalam Penurunan Konsentrasi Logam Tembaga (Cu) dan Timbal (Pb)*. *12*(02), 29–37.
3. Maranggi, I. U., Rahadianto, W. T., Chandra, Y., & Sugesti, H. **(2025)**. Pengaruh Variasi Massa Bentonit dan Suhu Pemanasan Terhadap Efektivitas Penjernihan Minyak Jelantah Secara Fisika dan Kimia. *Jurnal Teknologi Kimia Unimal*, *1*(Mei), 78–88.
4. Masriatini, R., Fatimura, M., Pengajar, S., Teknik, F., Studi, P., & Kimia, T. **(2019)**. *Penggunaan Arang Tempurung Kelapa yang Diaktifkan untuk Menyerap Zat Warna Limbah Cair Industri Kain Tradisional*. *4*, 37–40. https://doi.org/https://doi.org/10.31851/redoks.v4i2.3508
5. Budi, E. **(2011)**. *Tinjauan Proses Pembentukan dan Penggunaan Arang Tempurung Kelapa Sebagai Bahan Bakar Bahan Komponen Kandungan Sifat termal*. *14*(C), 25–29.
6. Hariyanti, Y. **(2017)**. *Analisis Kinerja Kolom Adsorpsi Kontinu untuk Pengolahan Larutan Zat Warna Strawberry Red Menggunakan Adsorben Karbon Aktif*. Universitas Katolik Parahyangan.
7. Toprak, A., & Kopac, T. **(2017)**. Carbon Dioxide Adsorption Using High Surface Area Activated Carbons from Local Coals Modified by KOH, NaOH and ZnCl2 Agents. *International Journal of Chemical Reactor Engineering*. https://doi.org/10.1515/ijcre-2016-0042
8. Tasanif, R., Isa, I., & Kunusa, W. R. **(2020)**. Potensi Ampas Tebu Sebagai Adsorben Logam Berat Cd , Cu dan Cr. *Jambura Journal of Chemistry*, *2*(01), 33–43. https://ejurnal.ung.ac.id/index.php/jjc/article/view/2608/pdf
9. Bandosz, T. J., & Jagiello, J. **(2007)**. Activated Carbon: Surface Chemistry, Structure, and Applications. *CRC Press*.
10. Ojo, D. T., Amuda, O. S., Salam, K. K., Oyediran, O. F., & Yekini, B. B. **(2025)**. Preparation and Characterization of Steam-Activated and Green Alkali-Activated Carbon from Coconut Shells. *Next Nanotechnology*, *8*(May), 100198. https://doi.org/10.1016/j.nxnano.2025.100198
11. Bani, M., & Santjojo, D. H. **(2013)**. *Pengaruh Suhu Reaksi Reduksi Terhadap Pemurnian Karbon Berbahan Dasar Tempurung Kelapa*. *2*(2), 159–163. https://natural.ub.ac.id/index.php/natural-b/article/viewFile/221/185
12. Nurdin, M., Salamba, R., Hikmawati, Wibowo, D., & Maulidiyah. **(2015)**. Preparation and Characterization of Activated Carbon from Coconut Shell – Doped Tio2 in Water Solution. *Oriental Journal of Chemistry*, *4*. https://doi.org/http://dx.doi.org/10.13005/ojc/310462
13. Mendame, L. L., Silangen, P., & Rampengan, A. **(2021)**. Perbandingan Karakteristik Karbon Aktif Arang Tempurung Kelapa dan Arang Tempurung Kemiri Menggunakan Scanning Electron Microscopic dan Fourier Transform Infra Red. *Jurnal Fista: Fisika Dan Terapan*, *2*, 105–108.
14. Sujiono, E. H., Zabrian, D., Zharvan, V., & Humairah, N. A. **(2022)**. Results in Chemistry Fabrication and Characterization of Coconut Shell Activated Carbon Using Variation Chemical Activation for Wastewater Treatment Application. *Results in Chemistry*, *4*(January), 100291. https://doi.org/10.1016/j.rechem.2022.100291
15. Rouquerol, F., Rouquerol, J., & Sing, K. **(2014)**. Adsorption by Powders and Porous Solids: Principles, Methodology

and Applications. *Academic Press*.

16. Indah, S., Helard, D., & Lathifatuzzahrah, S. **(2022)**. Penyisihan Fosfat dari Air Limbah Artifisial Laundry Memanfaatkan Kulit Jagung Sebagai Adsorben. *Jurnal Litbang Industri*, *12*, 33–40. https://doi.org/http://dx.doi.org/10.24960/jli.v12i1.7504.33-40
17. Simanjuntak, G. R. **(2012)**. *Pengaruh Massa Adsorben dan Waktu Kontak terhadap Adsorpsi Fosfat Menggunakan Adsorben Kitosan- Ferrihidrit dengan Sistem Batch* [Universitas Brawijaya]. https://repository.ub.ac.id/id/eprint/153136/1/SKRIPSI.pdf
18. Anwar, N. A. F., Meicahayanti, I., & Rahayu, D. E. **(2022)**. Pengaruh Variasi Waktu Kontak dan Massa Adsorben Kulit Jeruk Siam (Citrus Nobilis) Terhadap Penyisihan Kadmium (Cd) dan Merkuri (Hg). *Jurnal Teknologi Lingkungan UNMUL*, *6*(1), 35–43.

e-ISSN : 2622-4968, p-ISSN : 2622-1349