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Comparative Adsorption Performance of Coconut Coir and Coconut Coir-Derived Activated Carbon toward Chromiums Ions

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Abstract

Chromium contamination in aqueous systems commonly occurs as Cr(VI) and Cr(III), both of which pose environmental risks. This study comparatively evaluates the adsorption performance of raw coconut coir and sulfuric acid-activated carbon derived from coconut coir toward chromium ions. Activated carbon was characterized according to SNI 06-3730-1995 based on moisture and ash content, and adsorption capacity was determined using Atomic Absorption Spectrophotometry at an initial concentration of 50 ppm and pH 2. Raw coconut coir exhibited no measurable adsorption capacity for either Cr(VI) or Cr(III). In contrast, the activated carbon demonstrated adsorption capacities of 14.677 ± 0.367 mg/g for Cr(VI) and 26.923 ± 0.370 mg/g for Cr(III), with corresponding removal efficiencies of 29.355 ± 0.750% and 53.846 ± 0.739%, respectively. The adsorption capacity for Cr(III) was approximately 1.8 times higher than that for Cr(VI), indicating stronger interactions between cationic chromium species and oxygen-containing functional groups on the activated carbon surface. These findings confirm that sulfuric acid activation substantially enhances the adsorption capability of coconut coir, particularly for Cr(III) removal under acidic conditions.

Keywords: activated carbon, coconut coir, chromium, Cr(VI), Cr(III), cdsorption capacity

1. INTRODUCTION

Heavy metal contamination is one of the most critical environmental issues worldwide, particularly in industrial wastewater containing chromium. Chromium contamination occurs primarily in the hexavalent (Cr(VI)) and trivalent (Cr(III)) oxidation states in aqueous systems (Mohanty et al., 2023). Hexavalent chromium **(**Cr(VI)**)**, the most toxic oxidation state of chromium, is widely generated from industries such as leather tanning, textile dyeing, agricultural processing, wood preservation, and mining activities (Xie, 2024). According to Hossini et al., 2022 Cr(VI) is one of the most hazardous heavy metal pollutants due to its high solubility, ability to exist as mobile anionic species such as $HCrO_4^-$, CrO_4^{2-}, and $Cr_2O_7^{2-}$, and its strong oxidizing power, which allows it to penetrate biological membranes and induce severe health effects

(Hossini et al., 2022). Numerous studies have shown that exposure to Cr(VI) can lead to severe health complications, including reproductive effects, kidney damage, nephrotoxic effect, hepatotoxic effect, gastrointestinal effect, hematologic disorder, skin and respiratory problems (Xie, 2024).

The increasing levels of chromium pollution highlight the need for effective and economical treatment technologies. Various methods have been employed to address chromium pollution, including chemical precipitation (Kismolo et al., 2002) (Tarigan et al., 2021), membrane filtration (Kevin Sutanto, 2017), electrocoagulation (Purnata et al., 2025), and adsorption (Rahayu, 2023). Adsorption systems are generally easier to operate and scale compared to other treatment technologies (Qasem et al., 2021). Consequently, adsorption has emerged as one of the most widely researched and applied methods due to its simplicity, high efficiency, cost-effectiveness, and environmental friendliness.

Adsorbent methods use solid materials (adsorbents) to capture dissolved chromium species from water by surface interactions (Islam et al., 2023). Modern research focuses on designing low-cost, high-surface-area materials for chromium metal ions, such as zeolite (Isharyanti, 2024), metal-oxide nanoparticles (Ghosh et al., 2022), functional polymers (Sánchez et al., 2020), composites (Juturu et al., 2024), engineered carbon (Saxena et al., 2024), biochar (Ambika et al., 2022), and activated carbon. (Wijaya et al., 2024) The use of activated carbon as an adsorbent for chromium removal is due to its high surface area, well-developed porous structure, and abundance of oxygen-containing functional groups, which facilitate strong interactions with metal ions (Ghosh et al., 2022). Chemical activation, such as with sulfuric acid, introduces functional groups like hydroxyl, carbonyl, and carboxyl, thereby enhancing surface polarity and promoting metal ion adsorption via ion exchange and complexation mechanisms (Pet et al., 2024). These properties enable the efficient adsorption of cationic Cr(III) through electrostatic attraction and surface complexation. Anionic Cr(VI) species can be removed via electrostatic interaction under acidic conditions or reduced to become the less toxic Cr(III) form on the carbon surface (Wijaya et al., 2024). In addition, activated carbon made from low-cost biomass precursors can be regenerated for repeated use and easily applied in various treatment configurations, making it a cost-effective and versatile option for chromium remediation in wastewater systems (Ziemińska & Doczekalska, 2024) (Kamel et al., 2025).

Earlier studies reported that activated carbon made from biomasses such as coconut shells (Deng et al., 2021), banana peels (Mkilima et al., 2024), and cassava peels (Che Ismail et al., 2025) has a significant heavy metal adsorption capacity. Nevertheless, commercial activated carbon remains relatively expensive, prompting researchers to explore low-cost adsorbents derived from agricultural wastes. Coconut coir, an abundant agricultural by product in tropical countries such as Indonesia, is rich in lignin and cellulose, making it a promising precursor for activated carbon production (Lubis et al., 2023). Its lignocellulosic structure allows the development of pore networks suitable for adsorption applications (Zhang & Zuo, 2024).

Previous studies have extensively reported chromium adsorption using activated carbon derived from various biomass sources such as coconut shells (Deng et al., 2021), banana peels (Mkilima et al., 2024), and corncob (Kamel et al., 2025**).** However, most studies primarily focus on a single chromium species, predominantly Cr(VI), without comparative evaluation against Cr(III). In addition, investigations on coconut coir have largely emphasized its conversion into activated carbon, while the inherent adsorption capability of raw coconut coir has not been systematically assessed under identical experimental conditions.

Therefore, a direct and quantitative comparison between raw coconut coir and its acid-activated carbon toward both Cr(VI) and Cr(III) adsorption remains insufficiently explored.

To the best of our knowledge, a systematic side-by-side comparison between raw coconut coir and acid-activated coir carbon toward both Cr(VI) and Cr(III) adsorption has not been comprehensively reported. The present study addresses this gap by quantitatively evaluating adsorption enhancement and speciation-dependent adsorption behavior.

2. MATERIAL AND METHODS

2.1 Material

Coconut coir is taken from coconut peeling waste around the FMIPA UNIGA campus. Chromium standard solution (1000 mg/L Cr, traceable to SRM from NIST, $Cr(NO_3)_3$ in 0.5 mol/L HNO_3, Certipur®, Supelco/Merck, Germany), potassium dichromate ($K_2Cr_2O_7$, analytical grade, Merck, Germany), and sulfuric acid (H_2SO_4, 95–97%, analytical grade, Merck, Germany) were used in this work. All reagents were of analytical grade and were used without further purification.

2.2 Methods

2.2.1. Preparation of Coconut Coir Adsorbent

The coconut coir is separated and then dried in the sun. The fiber is ground into powder and sieved through a 100-mesh sieve. The powder is oven-dried at 105°C for 4 hours. The fiber is stored in a container with a silk gel bag before use to maintain its dryness. A total of 1 kg of fresh coconut coir yielded approximately 600 g of dried coir after the drying process, corresponding to a mass reduction due to moisture removal.

2.2.2. Preparation of coconut-coir activated carbon

The carbonization process of **coconut-coir** with direct combustion in a closed metal container. Carbonization was conducted at 500°C for 30 min with a heating rate of 10°C/min in a limited-oxygen condition. The resulting char was impregnated with 1 M H_2SO_4 at a ratio of 1:4 (w/v) for 24 h. The chemically activated charcoal was thoroughly washed with distilled water until the filtrate reached neutral pH, then dried in an oven at 105 °C for 4 hours. After cooling it in a desiccator for 15 minutes, the resulting charcoal was sieved through a 100-mesh sieve.

2.2.3.The Characterization of activated carbon

After the charcoal has undergone physical and chemical activation, we characterize it by testing its moisture and ash content. The moisture content test begins by placing 1 g of activated carbon into a crucible and heating it in an oven at 105°C for 1 hour. After we put it in a desiccator for 30 minutes, we weighed the crucible and the cooled carbon to determine the mass of the activated carbon. We repeat the moisture content determination at least three times to obtain a consistent mass, with a mass difference of less than 0.3%. The ash content test begins by placing 1 g of activated carbon into a crucible and heating it in a furnace at 800°C for 2 hours. After we put it in a desiccator for 30 minutes, we weighed the crucible and the cooled carbon to determine the mass of the activated carbon. We repeat the moisture content determination at least three times to obtain a consistent mass, with a mass difference of less than 0.3%.

2.2.4. The adsorption capacity analysis

The adsorption capacity was determined using an Avanta Sigma A 6525 Atomic Absorption Spectrophotometer (AAS), with a detection limit range of 0–15 ppm for chromium analysis. For the first step, we created a standard curve of AAS with concentration variations of 0, 2, 5, 10, and 15 ppm of the 1000 ppm of chromium standard solution. For the adsorption of the sample, we prepared a solution from a 50 ppm Cr(VI) solution by dissolving 50 mg of $K_2Cr_2O_7$ (Merck) in 1 liter of distilled water. We prepared a 10 mL solution of Cr(VI) and 0.1 g of the synthesized sample in a 100 mL Erlenmeyer flask. The adsorption process mixture was shaken for 1 hour using an orbital shaker at 150 rpm at pH 2. The solution was then transferred to the centrifuge tube and centrifuged for 15 minutes at 150 rpm. The mixture was then filtered using Whatman 42 paper before the measurement using an AAS instrument. We counted the adsorption capacity (q) using equation 1(Kaushal & Singh, 2017).

$$\boldsymbol{q = \frac{(C_i - C_f)V_s}{m_a}} \tag{1}$$

Where q is the equilibrium adsorption capacity (mg adsorbate/g adsorbent), C_i is the initial concentration, C_f is the final concentration, V_s is the volume of the solution (liters), and m_a is the mass of the adsorbent (g) used.

3. RESULTS AND DISCUSSION

The adsorption capacity of coconut fiber against chromium ions was tested qualitatively by observing the direct color changes in a 50 ppm $K_2Cr_2O_7$ solution. **Fig. 1a** shows the color of the solution before the adsorption process. **Fig. 1b** shows the color of the solution after absorption. The results of the observations in the figure indicate that the color of the solution remained unchanged. This minimal color change indicates that the decrease in Cr(VI) concentration in the solution was not significant.1 The results of the AAS analysis test on the solution after the adsorption process with coconut fiber showed that coconut fiber had no adsorption capacity. The low adsorption effectiveness of raw coconut fiber prompted efforts to modify it into activated carbon. We modified the material into activated carbon through a carbonization process and chemical activation. Coconut fiber activated carbon is produced by combustion and activated using sulfuric acid (H_2SO_4). Acidic agents, such as H_2SO_4, contribute to pore formation through chemical reactions with the precursor material (Pet et al., 2024). The characterization of activated carbon produced from coconut fiber aims to determine the physical and chemical properties of the adsorbent prior to its use in subsequent adsorption processes. This stage is crucial because physical and chemical characteristics, such as ash and moisture content, directly affect the adsorption capacity and storage stability of the activated carbon. Good characterization will ensure that the adsorbent used performs optimally in binding heavy metal ions.

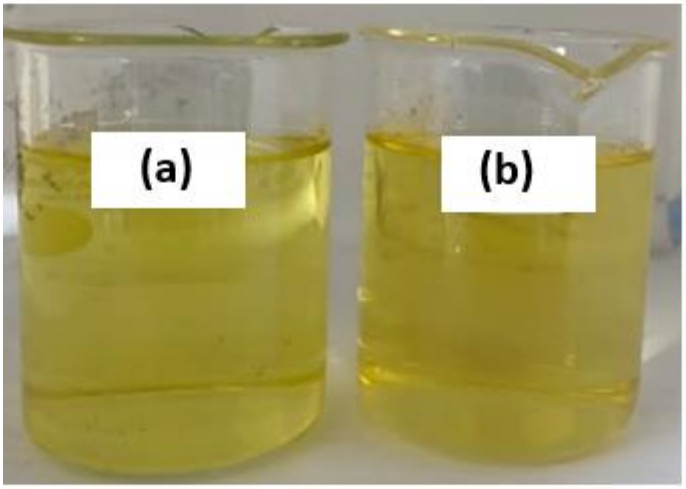

Figure 1. The Colour of the solution **(a)** before adsorption, **(b)** after adsorption of simplicial of coconut coir.

Moisture content testing aims to determine the water content in coconut fiber activated carbon samples. The moisture content measurement data, which were 15.00 ± 0.00%, are presented in **Table 1**. Moisture content is an important parameter for determining the quality of activated carbon. The lower the water content, the better the adsorption properties of activated carbon because water can occupy the active pores of coconut coir by 15.00%. This value still meets the maximum water content standard according to SNI 06-3730-1995, which is a maximum of 15%. This data shows that the drying process carried out is optimal enough to achieve a constant weight. Consistent results in the three repetitions also show that the test procedure is meticulous and reproducible. The initial sample weight is approximately 1 gram for each test, and the identical water content results strengthen the validity of the data. A water content that is too high can cause activated carbon to degrade quickly.

Table 1. Characterization of Activated Carbon of Coconut Coir

Parameters	**Value (%)**	**SNI 06-3730-1995 (%)**
Moisture content	15.00 ± 0.00	Max. 15
Ash content	10.00 ± 0.27	Max. 10

The results of the ash content of the activated carbon sample in **Table 1** were 10.00 ± 0.27%. The Indonesian National Standard (SNI) stipulates that the maximum ash content in activated carbon is 10%. The ash content of the activated carbon sample from coconut fiber meets SNI standards and is suitable for use as a test sample. This data indicates that the carbonization and activation process of coconut fiber has successfully converted organic materials into activated carbon with a balanced amount of inorganic residue.

The adsorption experiments were conducted at pH 2 to optimize chromium speciation and surface interaction with the activated carbon. At highly acidic conditions (pH ≈ 2), Cr(VI) predominantly exists as hydrogen chromate ions ($HCrO_4^-$), which are more readily adsorbed due to enhanced electrostatic interactions with positively charged adsorbent surfaces. Under acidic conditions, the surface of activated carbon becomes protonated, increasing the availability of positively charged functional groups that facilitate the attraction of anionic Cr(VI) species (Rout & Jena, 2023). A contact time of 60 minutes was applied to allow sufficient interaction between chromium ions and the adsorbent surface and to ensure that the system approached adsorption equilibrium under the studied conditions (Nurjaibah & Fauziah, 2025).

The adsorption capacity of activated carbon was studied using an atomic absorption spectrophotometer (AAS). We use the Cr(VI) and Cr(III) test solution at a concentration of 50 ppm. We triplicate the test with the resulting data shown in **Table 2**. The standard deviation values for both Cr(III) (±0.370 mg/g) and Cr(VI) (±0.367 mg/g) are relatively small, indicating good reproducibility and uniform adsorption behavior across replicates. The low standard deviation indicates that the synthesized activated carbon exhibits consistent and stable adsorption toward Cr(III) and Cr(VI) ions. This consistency suggests that the activation and synthesis processes produced adsorbents with homogeneous structural and chemical properties.

Table 2. The adsorption capacity and removal efficiency of coconut fiber activated carbon toward Cr(III) and Cr(VI).

Metal ion	**Adsorption Capacity (mg/g)**		**Removal efficiency (%)**	
Cr(III)	27.349 26.686 26.734	26.923± 0,370	54.698 53.372 53.468	53.846 ± 0.739
Cr(VI)	14.996 14.759 14.277	14,677± 0,367	29.992 29.518 28.554	29.355 ± 0.750

In general, the adsorption mechanism of chromium ions on solid adsorbents is through the transfer of metal ions from the water system to the surface of the adsorbent, followed by the transfer of mass of chromium ions from the surface of the adsorbent to the pores of the adsorbent. Then, the adsorption of chromium ions occurs at the active sites of the adsorbent's pores (Rahayu, 2023). The adsorption capacity values obtained for Cr(III) were 27.349 mg/g, 26.686 mg/g, and 26.734 mg/g, yielding an average adsorption capacity of 26.923 ± 0.370 mg/g with a removal efficiency reaching 53.846 ± 0.739%. Cr(III) gives a good adsorption capacity due to Cr(III) exists as cations, which are more easily adsorbed by activated carbon (Hossini et al., 2022). Cr(III) is a cationic species that binds strongly to oxygen-containing functional groups on adsorbents (Krawic & Zhitkovich, 2023).

The adsorption capacities for Cr(VI) were 14.996 mg/g, 14.759 mg/g, and 14.277 mg/g, giving an average value of 14.677 ± 0.367 mg/g. This value is substantially lower than that obtained for Cr(III), indicating less efficient uptake of Cr(VI) species by the adsorbent. However, if we compare it with the adsorption capacity of activated carbon from Coconut shell (Tolkou et al., 2022), Coconut tree (Selvi et al., 2001), and Corncob-Derived Activated Carbon (Kamel et al., 2025) which are in the range of 1–18 mg/g. Our Cr(VI) value exceeds this typical range; moreover, our removal efficiency of Cr(VI) is better than that of tamarin wood activated carbon (28%) (Mkilima et al., 2024).

The results show that the adsorption capacity for Cr(III) (26.923 mg/g) is approximately 1.8 times higher than that of Cr(VI) (14.677 mg/g). The performance difference shows that activated carbon more easily adsorbs positively charged Cr(III) than negatively charged Cr(VI) anions (Rivera-Utrilla & Sánchez-Polo, 2003). Cr(III) exists as cations, making it more easily adsorbed by activated carbon than Cr(VI) (Hossini et al., 2022). In the adsorption process onto solid surfaces, the electrostatic interactions play a crucial role (Pet et al., 2024). Oxygen-containing groups on the adsorbent surface form stronger coordinate bonds with Cr(III) ions. Cr(III) and Cr(VI) exhibit different adsorption mechanisms. Specifically, Cr(III) undergoes chemisorption and surface complexation, whereas Cr(VI) undergoes physisorption and potential reduction-dependent uptake (Mohanty et al., 2023) (Krawic & Zhitkovich, 2023). Overall, these findings demonstrate that coconut-coir-based activated carbon is significantly more effective for Cr(III) removal. At the same time, its efficiency for Cr(VI) may require enhancement through oxidation–reduction pretreatment or functional surface modification.

4. CONCLUSION

Coconut coir did not exhibit measurable adsorption toward Cr(VI) and Cr(III) under the studied conditions. In contrast, sulfuric acid activation substantially improved its adsorption performance. The activated carbon showed higher affinity toward Cr(III) compared to Cr(VI), indicating stronger interactions between cationic chromium species and oxygen-containing functional groups introduced during activation. These findings demonstrate that chemical activation is essential to enhance the adsorption capability of coconut coir and confirm its effectiveness as a modified biomass-based adsorbent, particularly for Cr(III) removal under acidic conditions.

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BIBLIOGRAPHY

Ambika, S., Kumar, M., Pisharody, L., Malhotra, M., Kumar, G., Sreedharan, V., Singh, L., Nidheesh, P. V., & Bhatnagar, A. (2022). Modified biochar as a green adsorbent for removal of hexavalent chromium from various environmental matrices: Mechanisms, methods, and prospects. *Chemical Engineering Journal*, *439*(January). https://doi.org/10.1016/j.cej.2022.135716

Che Ismail, N. H., Zurizam, N. A. F., & Hashim, F. (2025). Performance of Activated Carbon from Cassava Peel for the Removal of Pb(II) in Pb Solution. *Journal of Academia*, *13*(1), 34–42. https://doi.org/10.24191/joa.v13i1.4582

Deng, Z., Sun, S., Li, H., Pan, D., Patil, R. R., Guo, Z., & Seok, I. (2021). Modification of coconut shell-based activated carbon and purification of wastewater. *Advanced Composites and Hybrid Materials*, *4*(1), 65–73. https://doi.org/10.1007/s42114-021-00205-4

Ghosh, N., Das, S., Biswas, G., & Haldar, P. K. (2022). Review on some metal oxide nanoparticles as effective adsorbent in wastewater treatment. *Water Science and Technology*, *85*(12), 3370–3395. https://doi.org/10.2166/wst.2022.153

Hossini, H., Shafie, B., Niri, A. D., Nazari, M., Esfahlan, A. J., Ahmadpour, M., Nazmara, Z., Ahmadimanesh, M., Makhdoumi, P., Mirzaei, N., & Hoseinzadeh, E. (2022). A comprehensive review on human health effects of chromium: insights on induced toxicity. *Environmental Science and Pollution Research*, *29*(47), 70686–70705. https://doi.org/10.1007/s11356-022-22705-6

Isharyanti, Sriatun, & Azmiyawati, C. (2024). Adsorpsi ion Cr(III) menggunakan zeolit alam termodifikasi dietanolamin. *Greensphere: Journal of Environmental Chemistry*, *4*(1), 8–13.

Islam, M. M., Mohana, A. A., Rahman, M. A., Rahman, M., Naidu, R., & Rahman, M. M. (2023). A Comprehensive Review of the Current Progress of Chromium Removal Methods from Aqueous Solution. *Toxics*, *11*(3), 1–43. https://doi.org/10.3390/toxics11030252

Juturu, R., Selvaraj, R., & Murty, V. R. (2024). Efficient removal of hexavalent chromium from wastewater using a novel magnetic biochar composite adsorbent. *Journal of Water Process Engineering*, *66*(July). https://doi.org/10.1016/j.jwpe.2024.105908

Kamel, M., Bastaweesy, A. M., & Hefny, R. A. (2025). Optimized Removal of Cr (VI) and Ni (II) From Wastewater Using Corncob-Derived Activated Carbon. *Water, Air, and Soil Pollution*, *236*(2), 1–22. https://doi.org/10.1007/s11270-024-07711-3

Kaushal, A., & Singh, S. K. (2017). Critical analysis of adsorption data statistically. *Applied Water Science*, *7*(6), 3191–3196. https://doi.org/10.1007/s13201-016-0466-4

Kismolo, E., Prayitno, & Nurimaniwathy. (2002). Pengelolaan Limbah Khrom Residu Proses Recovery Khorm Menggunakan Kalsium Karbonat. *Prosiding Pertemuan Dan Presentasi Ilmiah Penelitian Dasar Ilmu Pengetahuan Dan Teknologi Nuklir*, *1*(1), 153–158.

Krawic, C., & Zhitkovich, A. (2023). Chemical mechanisms of DNA damage by carcinogenic chromium(VI). *Advances in Pharmacology*, *96*(0), 25–46. https://doi.org/10.1016/bs.apha.2022.07.003

Lubis, R. Y., Sirait, R., & Fahmijal, I. (2023). Pembuatan Karbon Aktif dari Sabut Kelapa dengan Aktivasi menggunakan H3PO4 untuk Adsorpsi Air Gambut. *Journal Online of Physics*, *8*(2), 23–28.

Mkilima, T., Zharkenov, Y., Abduova, A., Sarypbekova, N., Kudaibergenov, N., Sakanov, K., Zhukenova, G., Omarov, Z., Sultanbekova, P., & Kenzhaliyeva, G. (2024). Utilization of banana peel-derived activated carbon for the removal of heavy metals from industrial wastewater. *Case Studies in Chemical and Environmental Engineering*, *10*(May), 100791. https://doi.org/10.1016/j.cscee.2024.100791

Mohanty, S., Benya, A., Hota, S., Kumar, M. S., & Singh, S. (2023). Eco-toxicity of hexavalent chromium and its adverse impact on environment and human health in Sukinda Valley of India: A review on pollution and prevention strategies. *Environmental Chemistry and Ecotoxicology*, *5*(November 2022), 46–54. https://doi.org/10.1016/j.enceco.2023.01.002

Nurjaibah, A., & Fauziah, N. (2025.). *Synthesis of Polyaniline Using the Rapid Mixing Method and Its Utilization as an Adsorbent for Chromium Metal Ions*. *NPCB*, 1–9.

Pet, I., Sanad, M. N., Farouz, M., ElFaham, M. M., El-Hussein, A., El-sadek, M. S. A., Althobiti, R. A., & Ioanid, A. (2024). Review: Recent Developments in the Implementation of Activated Carbon as Heavy Metal Removal Management. *Water Conservation Science and Engineering*, *9*(2), 1–15. https://doi.org/10.1007/s41101-024-00287-3

Purnata, H., Rahmat, S., Ilahi, N. A., & Triwuri, N. A. (2025). Room of Civil Society Development Pengolahan Limbah Cair Batik dengan Elektrokoagulasi dan Filtrasi- Adsorbsi untuk

Keberlanjutan. *Room of Civil Society Development*, *4*(1), 197–210.

Qasem, N. A. A., Mohammed, R. H., & Lawal, D. U. (2021). Removal of heavy metal ions from wastewater: a comprehensive and critical revifile:///C:/Users/Windows 11/Downloads/referensi NPCB sabut kelapa/Isharyanti 2024.pdfew. *Npj Clean Water*, *4*(1). https://doi.org/10.1038/s41545-021-00127-0

Rahayu, A. (2023). Review : Biomassa Sebagai Adsorbent untuk Pengolahan Logam Berat Pada Air Limbah Industri. *Prosiding Seminar Nasional Teknik Kimia "Kejuangan,"* 1–6.

Rivera-Utrilla, J., & Sánchez-Polo, M. (2003). Adsorption of Cr(III) on ozonised activated carbon. Importance of Cπ—cation interactions. *Water Research*, *37*(14), 3335–3340. https://doi.org/10.1016/S0043-1354(03)00177-5

Rout, D. R., & Jena, H. M. (2023). Synthesis of graphene oxide-modified porous chitosan cross-linked polyaniline composite for static and dynamic removal of Cr(VI). *Environmental Science and Pollution Research*, *30*(9), 22992–23011. https://doi.org/10.1007/s11356-022-23774-3

Sánchez, J., Rodriguez, C., Oyarce, E., & Rivas, B. L. (2020). Removal of chromium ions by functional polymers in conjunction with ultrafiltration membranes. *Pure and Applied Chemistry*, *92*(6), 883–896. https://doi.org/10.1515/pac-2019-1103

Saxena, V., Singh, A. K., Srivastava, A., & Srivastava, A. (2024). Eco-Engineered Low-Cost Carbosorbent Derived from Biodegradable Domestic Waste for Efficient Total Chromium Removal from Aqueous Environment: Spectroscopic and Adsorption Study. *Nature Environment and Pollution Technology*, *23*(2), 979–989. https://doi.org/10.46488/NEPT.2024.v23i02.032

Selvi, K., Pattabhi, S., & Kadirvelu, K. (2001). Removal of Cr(VI) from aqueous solution by adsorption onto activated carbon. *Bioresource Technology*, *80*(1), 87–89. https://doi.org/10.1016/S0960-8524(01)00068-2

Sutanto, K. (2017). *Penyisihan kromium (Cr) dalam limbah cair industri pelapisan logam dengan proses filtrasi menggunakan membran*. Jurnal Teknik Kimia, 12(2), 45–52.

Tarigan, B. S., Rukiah, & Rostika Noviyanti, A. (2021). *Komposisi Polialuminium Klorida Dengan Hidroksiapatit Dan Aplikasinya Untuk Pemisahan Ion Kromium Heksavalen*. *30*(Vi), 26–34.

Tolkou, A. K., Trikalioti, S., Makrogianni, O., Xanthopoulou, M., Deliyanni, E. A., Kyzas, G. Z., & Katsoyiannis, I. A. (2022). Lanthanum Modified Activated Carbon from Coconut Shells for Chromium (VI) Removal from Water. *Nanomaterials*, *12*(7), 1–18. https://doi.org/10.3390/nano12071067

Wijaya, R. A., Nakagoe, O., Sano, H., Tanabe, S., & Kamada, K. (2024). Superior comprehensive performance of modified activated carbon as a hexavalent chromium adsorbent. *Heliyon*, *10*(15), e35557. https://doi.org/10.1016/j.heliyon.2024.e35557

Xie, S. (2024). Water contamination due to hexavalent chromium and its health impacts: exploring green technology for Cr (VI) remediation. *Green Chemistry Letters and Reviews*, *17*(1), 1–19. https://doi.org/10.1080/17518253.2024.2356614

Zhang, L., & Zuo, S. (2024). The Significance of Lignocellulosic Raw Materials on the Pore Structure of Activated Carbons Prepared by Steam Activation. *Molecules*, *29*(13), 1–13. https://doi.org/10.3390/molecules29133197

Ziemińska, N., & Doczekalska, B. (2024). Biomass derived activated carbons in wastewater treatment – The aim of metallurgical industry. *Desalination and Water Treatment*, *318*(March), 100320. https://doi.org/10.1016/j.dwt.2024.100320