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Original Research Article

Effectiveness of Sugarcane Bagasse Adsorbents for Chromium Removal from Industrial Metal Plating Wastewater

Iffah Nabila[1], Siti Rachmawati[1]*, Mohammad Masykuri[2], Siti Nurlita[3]
[1] Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Sebelas Maret University, Jalan Sutami 36A, Kentingan, Jebres, Surakarta, Indonesia 57126
[2] Master Program of Environmental Science, Sebelas Maret University, Jalan Sutami 36A, Kentingan, Jebres, Surakarta, Indonesia 57126
[3] Graduate School of Engineering, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan
* Corresponding Author, email: siti.rachmawati@staff.uns.ac.id

Abstract

Wastewater from metal plating businesses contains hazardous heavy metals, including chromium (Cr), which must be properly treated to avoid environmental contamination. Adsorption utilizing natural materials, such as sugarcane bagasse, is a promising option. This study compared the effectiveness of H2SO4-activated sugarcane bagasse with sugarcane bagasse-based activated carbon in removing total chromium (Cr-T) from metal plating wastewater and analyzed the effects of adsorbent mass and contact time. Atomic absorption spectrophotometry (AAS) was used to measure the final chromium concentrations after batch adsorption was conducted with different masses and contact periods. The findings revealed that the adsorption effectiveness increased as the adsorbent mass and contact duration increased, reaching an ideal point. While activated carbon achieved its peak at 12 g and 120 min (95% and 47.6% efficacy, respectively), activated bagasse performed best at 15 g and 150 min (51.9% and 43% effectiveness, respectively). Activated carbon performed better because of its increased surface area and pore structure resulting from carbonization. These results demonstrate that sugarcane bagasse is a potential, affordable, and sustainable natural adsorbent for lowering total chromium in industrial effluents, particularly when transformed into activated carbon.

Keywords: Adsorption; chromium; sugarcane bagasse; wastewater treatment

1. Introduction

The industrial sector significantly contributes to Indonesia's economic expansion. The expansion and advancement of industries have the potential to greatly enhance societal well-being. The metal coating sector is currently expanding rapidly (Sitorus et al., 2024). However, liquid waste, including heavy metals, is produced during its production (Mardiyono et al., 2023). The main sources of this waste are metal rinsing procedures and leftover electroplating solutions (Rahman et al., 2021). Untreated disposal of such waste can damage the environment and disrupt ecosystem equilibrium (Pande et al., 2022). The Bedadung River in Jember was originally contaminated by metal plating waste; according to Indonesian Government Regulation Number 22 of 2021, the chromium concentration at four sampling locations was higher than the river water quality requirement. The local population utilizes the river for daily activities; however, itching and eye discomfort are common complaints (Amri et al., 2020).

One of the metal plating companies in Surakarta, is situated in Ngringo Village, Jaten District, and employs copper, nickel, and chromium in its manufacturing process. In practice, this industry does not have adequate wastewater treatment plants; therefore, the liquid waste generated flows directly into the environment without undergoing any treatment. Heavy metals pose a serious threat to humans, living organisms, and the environment because of their hazardous nature, particularly their high toxicity levels and strong accumulation ability (Amri et al., 2020). Additionally, chromium has a negative impact on the environment because it can kill aquatic organisms, inhibit the growth of biota, and accumulate in the food chain (Ao et al., 2025). Contamination of the soil in humid and dry subtropical regions can lead to a decline in the quality of soil biological characteristics (Rachmawati et al., 2025). The presence of heavy metals in vegetation, soil, and water sources has the potential to negatively impact human health (Rachmawati et al., 2023). Initial testing revealed that the liquid waste produced contained the heavy metal chromium at a concentration of 12.0774 ppm. Therefore, an effective waste treatment method is needed to reduce the concentration of heavy metals before they are discharged into the environment. An effective and efficient method for clarifying wastewater containing heavy metals is adsorption (Somyanonthanakun et al., 2023). This method works by binding heavy metals to the surface of the adsorbent, allowing the metals to degrade (Czikkely et al., 2018). Adsorption is an effective method for removing heavy metals because of its simplicity, efficiency, and ability to utilize low-cost adsorbent materials (Saputro and Dwiprigitaningtias, 2022). In this study, natural materials were used as adsorbents, namely sugarcane bagasse, which has enormous potential owing to its high lignocellulose content. The use of these natural materials is also in line with efforts to convert agricultural waste into valuable and environmentally friendly products.

Indonesia, one of the largest sugar producers, contributes significantly to the global sugar market (Kurniati et al., 2024). In addition to producing sugar, Indonesia's high sugarcane output generates a significant quantity of trash in the form of sugarcane bagasse. According to BPS statistics, the country’s white crystal sugar output reached 2,271,009 metric tons in 2023. This technique generates approximately 90% sugarcane bagasse, 5% sugar, and the remaining molasses and water (Khumla et al., 2024). The amount of waste sugarcane bagasse poses a unique challenge for environmental management; however, it also presents an opportunity to employ it as a natural adsorbent material.

Sugarcane bagasse, a lignocellulosic substance, has a complex structure including extractives, polysaccharides, lignin, and other organic components (Nurdiani et al., 2021). Sugarcane bagasse can be used as an affordable and sustainable natural adsorbent for treating heavy metal pollution, especially total chromium in metal plating industrial wastewater, because its primary constituents, cellulose and lignin, can be transformed into activated carbon that can bind heavy metals (Kumar et al., 2017). H2SO4 was chosen for chemical activation because it can improve the pore structure and functional groups of lignocellulosic materials, increasing their potential to adsorb heavy metals. Commercial activated carbon, natural zeolite, modified clay, chitosan, charcoal, and agricultural waste-based materials, including rice husks, sawdust, and coconut shells, have been used as adsorbents to extract chromium from wastewater. Although some of these adsorbents exhibit good absorption capacity, the availability of materials, production costs, and the need for relatively expensive activation processes are often obstacles to large-scale applications. For example, commercial activated carbon is effective but expensive, whereas chitosan requires a complicated chemical preparation process. Therefore, the use of abundant, easily obtainable, and low-cost agricultural waste has become an increasingly developed alternative as a more economical and sustainable solution. Based on these gaps, this study offers a novel approach through the use of H2SO4-activated bagasse as an economical and environmentally friendly alternative adsorbent and evaluates the effect of variations in adsorbent mass and contact time on the efficiency of total chromium adsorption. Additionally, this study compares the adsorption effectiveness between activated sugarcane bagasse biomass and sugarcane bagasse-based activated carbon. Additionally, this study compares the adsorption effectiveness between activated sugarcane bagasse biomass and sugarcane bagasse-based activated carbon. The findings of this research are expected to contribute to the development of agricultural waste-based adsorbents and serve as a reference for the sustainable management of industrial wastewater in metal plating.

2. Methods

2.1. Research Time and Location

The research sample was obtained from a metal plating industry located in Karanganyar Regency, Central Java, and liquid waste samples were collected from the metal washing tank. Pulp waste was obtained from the Mojo Sugar Factory located in Sragen Kulon Village, Sragen District, Sragen Regency. Laboratory analyses were conducted at the Central Laboratory of Sebelas Maret University. The sampling process and data analysis will be conducted from September to October 2025.

2.2. Research Design

This study conducted a laboratory experiment using the batch method to evaluate the effectiveness of sugarcane bagasse waste as an adsorbent for heavy metal chromium in liquid waste from the metal plating industry. Liquid waste samples were collected from the washing water tank in accordance with SNI 8990:2021 regarding the method for collecting wastewater samples for physical and chemical testing. Grab sampling was used, in which wastewater samples were collected directly at a specific point and time to obtain an instantaneous representation of wastewater characteristics. The adsorption process was conducted by varying the mass of the adsorbent on both types of biomass (3, 6, 9, 12, 15, 18, 21, and 24 g) and activated carbon (3, 6, 9, 12, and 15 g), as well as by varying the contact time for both types of adsorbents (60, 90, 120, 150, and 180 min) against liquid waste solutions containing chromium. Each treatment was performed in duplicate to increase the accuracy of the results. The standard deviation (SD) was calculated from these repetitions to describe the level of variation or spread of the data with respect to its mean value (Martinez and Bartholomew, 2017). The graph showing the findings of the study indicates the computed SD value as error bars. The dependability of the reported mean value and the uncertainty of the data are shown by these error bars. Atomic absorption spectrophotometry (AAS) was used to determine the total chromium concentration after the adsorption procedure. To examine the efficacy of sugarcane bagasse activated carbon and activated biomass adsorbents and to identify the ideal mass and contact duration, the collected data were subjected to both descriptive and quantitative analyses.

The limitations of this study lie in the scope of the experiment, which focused on determining the effectiveness of absorption and adsorption capacity. Calculations of the isotherm, kinetic, and thermodynamic parameters were not possible because the experimental design did not include variations in the initial concentration of the adsorbate, measurements of equilibrium values at different concentration ranges were not performed, and testing at the temperature range required for thermodynamic parameter calculations was not conducted.

2.3. Data Collection

The research process began by collecting 2 L of liquid waste samples according to SNI 8990:2021 standards for the method of collecting wastewater test samples. Sugarcane bagasse waste from the Mojo Sugar Mill was cleaned and then subjected to oven drying until its moisture content was reduced.

Figure 1. Workflow for producing activated biomass adsorbents (left) and activated carbon (right)

The production of activated sugarcane bagasse biomass with 10% H_2SO_4 begins with cleaning the bagasse of impurities, followed by dehydration in an oven at 105–110°C for 8 h to reduce the moisture content. After drying and grinding, the biomass is soaked in a 10% H_2SO_4 solution for 24 h in a closed container for the chemical activation process. Thereafter, the biomass is filtered, washed with distilled water until a neutral pH is reached, and then dried again at 105–110°C for 2 h. The final step is sieving using a 100-mesh sieve to ensure a uniform particle size, thereby optimizing the surface area of the adsorbent. The final product of this activated biomass was ready for direct use as an adsorbent for liquid waste containing heavy metals. The first type of adsorbent application was carried out with variations in mass of 3, 6, 9, 12, 15, 18, 21, and 24 grams with a contact time of 120 minutes, as well as time variations of 60, 90, 120, 150, and 180 minutes with a mass variation of 9 grams. All variations were stirred at a speed of 100 rpm for the specified contact time. Thereafter, the sample was filtered to separate the adsorbent from the solution. The tested solution was then destroyed so that the final chromium content could be analyzed using atomic absorption spectroscopy (AAS).

Activated carbon with 10% H2SO4 was produced in two main stages: carbonization and activation. The cleaned and dried sugarcane bagasse was carbonized in a furnace at 500°C for 2 h to produce charcoal. After this treatment, the original pores of the charcoal were clogged with inorganic minerals. To remove the remaining minerals and completely open the pores, a 10% H2SO4 solution was used for 24 h. After activation, the charcoal was filtered, washed until a neutral pH was achieved, dried again at 105–110°C for 2 h, and sieved through a 100-mesh sieve. The activated carbon produced was tested for quality based on SNI 06-3730-1995 standards to ensure that the moisture and ash contents met the quality requirements before being used as an adsorbent in liquid waste. Ready-to-use activated carbon was applied to the solution with varying masses of 3, 6, 9, 12, and 15 grams, with a contact time of 120 minutes, and with varying times of 60, 90, 120, 150, and 180 minutes, with a constant mass of 9 grams. All variations were stirred at a speed of 100 rpm for the specified contact time. Thereafter, the sample was filtered to separate the adsorbent from the solution. The tested solution was then destroyed to analyze the final chromium metal content using AAS.

2.4. Data Analysis

The research to be conducted is experimental research. Data were obtained from laboratory test results and analyzed to determine the effectiveness of using sugarcane bagasse as an adsorbent. The experiment was conducted twice with the same variations. The heavy metal concentrations were calculated using the linear regression formula from the standard calibration curve. The formula is described as follows:

$$y = mx + c$$

In this equation, y denotes the sample absorbance read by the instrument, m is the slope value indicating the instrument's sensitivity to changes in metal concentration, and c is the constant or y-intercept, which represents the baseline absorbance when the metal concentration is zero. Lab results were analyzed to determine the effectiveness of using sugarcane bagasse as an adsorbent. According to Pratiwi et al. (2023), the adsorption effectiveness can be determined using the following formula:

$$Adsorption\ Effectiveness\ (\%) = \frac{C_o - C_t}{C_o} x\ 100\%$$

In this formula, C_o denotes the initial concentration of the metal in the solution before the adsorption process, whereas Ct denotes the final concentration of the metal after the adsorption process. The difference between C_o and C_t indicates the amount of metal successfully adsorbed by the adsorbent. The effectiveness value is expressed as a percentage (%) to show the performance of the adsorbent in reducing the metal content from the test solution.

Then, the adsorption capacity was calculated to determine the adsorbent's ability to absorb chromium per unit mass. According to Ishak and Kunusa (2020), the adsorption capacity can be calculated using the following formula:

$$Adsorption\ Capacity (mg/g) = \frac{(C_o - C_t) x\ V}{M}$$

In this equation, C_o and C_t represent the initial and final concentrations of the metal, respectively (mg/L), V is the volume of the sample solution in liters (L), and M is the mass of the adsorbent in grams (g). The adsorption capacity value (mg/g) indicates the amount of metal ions adsorbed by each gram of the adsorbent. After calculating the effectiveness and adsorption capacity of each variation, the most effective mass and contact time of the adsorbent for adsorbing total chromium heavy metals in liquid waste can be determined.

3. Result and Discussion

3.1. Liquid Industrial Waste from Metal Plating and the Potential of Sugarcane Bagasse as an Adsorbent

The metal coating industry provides protection for base metals against corrosion, increases resistance to friction, slows down damage, and enhances the aesthetic value of the metal surface. Wang et al., 2023). In this study, the plating process was carried out using nickel and copper as the initial layers and chromium as the main final layer, and the use of chromium solution was the main cause of the formation of liquid waste containing total chromium (Cr-T) heavy metals. Based on field results, the main source of total chromium was the final plating stage in the industry, with chromic acid being the main component of the chromium plating solution. According to SNI 6989.17:2009, total chromium includes all dissolved and suspended forms of chromium in wastewater. The liquid waste samples taken from this industry originated from the runoff water after metal washing after being dipped in the coating solution. The metal coated with a chromium plating solution for approximately 15 min was immediately immersed in the metal washing rinse water. In the metal plating process, after the metal was plated in a chromium plating solution, its surface still contained residues of the metal plating solution. If the coated metal is not soaked in plain water, the remaining coating material can dry and form stains, and it can also cause the coated metal to lose its shine. Runoff water was used as the main liquid waste in this industry. Waste samples taken from the metal washing runoff water showed a total chromium content of 12.0774 ppm. The test results indicate that the total chromium content exceeds the quality standard set in the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.16/MenLHK/SetJen/Kum.1/4/2019 Concerning the Second Amendment to the Minister of Environment Regulation Number 5 of 2014 Concerning Wastewater Quality Standards. The wastewater quality standard for metal plating and galvanizing industrial businesses or activities is 0.5 mg/L for total chromium (Cr-T).

Figure 2. Sugarcane bagasse biomass

To reduce chromium levels, this study utilized sugarcane bagasse from the Mojo Sugar Mill as a natural adsorbent. The type of sugarcane used by this sugar factory is Bulubalang sugarcane or BL sugarcane. Sugarcane bagasse contains cellulose, hemicellulose, and lignin, which belong to the lignocellulosic materials group (Azizah and Marziah, 2022). In addition, sugarcane bagasse has a porous fiber structure with high potential as an adsorbent material in heavy metal absorption (Ahmed et al., 2023).

3.2. Adsorbent Activation

The activation of the adsorbent opens the pores and forms active functional groups on the material's surface, thereby increasing the heavy metal adsorption capacity (Li et al., 2022). In this study, H_2SO_4 (sulfuric acid) was used as an acid activator because it is effective for lignocellulosic materials, such as sugarcane bagasse (Okokpujie et al., 2024). The use of H_2SO_4 dissolves non-carbon components, such as lignin and hemicellulose, which can clog pores, while also increasing the effective surface area of the adsorbent. According to Ramadhani et al. (2020), H_2SO_4 has advantages such as chemical stability and high availability compared with other activator materials. Through this activation process, lignin and hemicellulose are degraded, the fiber structure becomes more open, the number of active sites increases, and the efficiency of heavy metal adsorption also increases (Zheng et al., 2022). In this study, two types of adsorbents were created: activated biomass and activated carbon. The activated carbon adsorbent type requires testing the quality of the activated carbon according to SNI 06-3730-1995.

Table 1. Results of quality requirements analysis for technical activated carbon SNI 06-3730-1995

No	Description	Requirements (%)	Analysis Results (%)
1	Moisture content	Maximum 15	8
2	Ash content	Maximum 10	9

Activated carbon demonstrates strong potential for pollutant removal because of its high adsorption capacity and wide applicability across various treatment systems (Yudha, 2025). The moisture content of activated carbon indicates the amount of water present in the sample, and the higher the moisture content, the lower the adsorption capacity of the carbon because its pores are filled with water molecules (Sholikhah et al., 2021). In this study, the moisture content was measured by weighing 2 grams of activated charcoal, then heating it in an oven at 115°C for 3 hours, resulting in a final weight of 1.84 grams. Based on calculations, the moisture content was found to be 8%, which is still below the maximum limit of SNI 06-3730-1995 at 15%, thus meeting the quality standards for activated charcoal. This result is slightly higher than that obtained by Imani et al. (2021), who obtained a moisture content of 6.09%. This difference is likely due to variations in the activation process used. In addition to water content, the quality of activated charcoal is also influenced by ash content, as excessive ash can cause pore blockage (Karume et al., 2023). The ash content test was conducted by incinerating 2 g of charcoal until it was completely reduced to ash, resulting in a final weight of 0.18 g and an ash content of 9%. This value is below the SNI maximum limit of 10%, indicating that the charcoal meets the technical quality requirements. This result is slightly higher than that obtained by Imani et al. (2021), who obtained an ash content of 5.11%, likely due to differences in carbonization temperature, where higher temperatures can reduce ash content because inorganic compounds decompose during the heating process (Oktaviansyah et al., 2024).

3.3. Adsorption of Total Chromium Metal on Liquid Waste

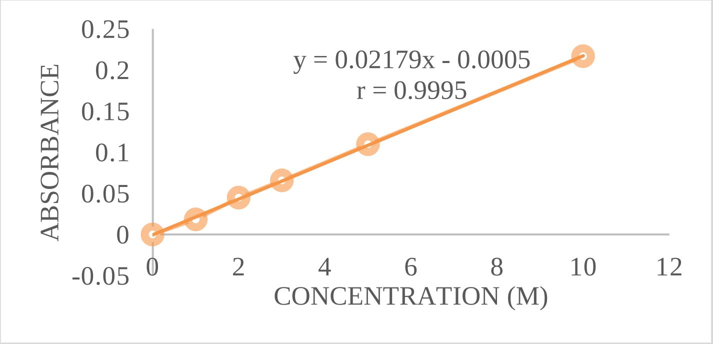

Figure 3. Graph of absorbance vs. concentration for chromium metal

A calibration curve was created using a series of chromium standards with graded concentrations, for example, 0, 1, 2, 3, 5, and 10 ppm. Each standard solution was analyzed using. The absorbance measurement results showed a linear relationship between increasing chromium concentration and the resulting absorbance value. This effect is indicated by a correlation coefficient (r) value > 0.9995, which indicates that the relationship between the two variables is strong and meets the requirements for the suitability of the calibration curve (Ngibad, 2023). The absorbance values consistently increased with increasing concentration, with the lowest value at 0 ppm and the highest at a concentration of 10 ppm. This is consistent with the basic principle of spectrophotometry, wherein the higher the concentration of chromium ions in the solution, the more light is absorbed by the chromium complex, resulting in an increase in absorbance.

Table 2. Reduction in chromium content and biomass adsorption capacity for varying mass

Variation	Initial Concentration (ppm)	Contact time (minute)	Mass (grams)	Final Concentration (ppm)	Adsorption Capacity (mg/g)
Activated biomass	12.077	120	3	8.964	0.104
Activated biomass	12.077	120	6	7.877	0.070
Activated biomass	12.077	120	9	7.467	0.051
Activated biomass	12.077	120	12	6.754	0.044
Activated biomass	12.077	120	15	5.812	0.042
Activated biomass	12.077	120	18	6.380	0.032
Activated biomass	12.077	120	21	7.641	0.021
Activated biomass	12.077	120	24	9.421	0.011
Activated carbon	12.077	120	3	7.856	0.141
Activated carbon	12.077	120	6	6.053	0.084
Activated carbon	12.077	120	9	4.524	0.084
Activated carbon	12.077	120	12	0.609	0.096
Activated carbon	12.077	120	15	0.798	0.075

Based on the data listed in Table 2, both types of adsorbents, activated biomass and activated carbon, were able to reduce the concentration of total chromium in liquid waste. For activated biomass, the difference in chromium concentration reduction for each variation was 3.113 mg/L for a mass of 3 g, 4.201 mg/L for 6 g, 4.610 mg/L for 9 g, 5.323 mg/L for 12 g, and 6.266 mg/L for 15 g. After the optimum mass was exceeded, there was a decrease in adsorption effectiveness, resulting in a decrease in the difference in reduction as well, namely 5.697 mg/L at 18 grams, 4.436 mg/L at 21 grams, and the lowest at 2.657 mg/L at 24 grams. Based on the adsorption capacity calculations in the table, it is known that the adsorption capacity decreases as the adsorbent mass increases, with the highest value at a mass of 3 grams (0.1038 mg/g) and the lowest at 24 grams (0.0111 mg/g). Meanwhile, for the activated carbon adsorbent, the difference in chromium concentration reduction for each variation was 4.221 mg/L for the 3-g mass variation, 6.025 mg/L for 6 g, 7.554 mg/L for 9 g, 11.467 for 12 g, and 11.279 for the 15-g variation. Based on these differences, the greatest reduction occurred with the 12-g variation.

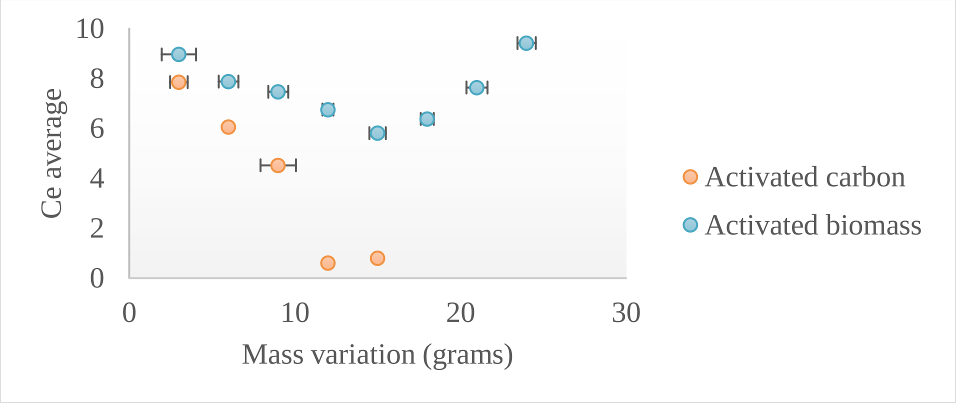

Figure 4. Error bar graph of activated biomass and activated carbon

As shown in the error bar graph in Figure 4, the mass variations of 6, 9, 12, 15, 18, 21, and 24 g resulted in relatively small standard deviation values: 0.59, 0.60, 0.33, 0.50, 0.39, 0.63, and 0.55, respectively. The small standard deviation values indicate that the adsorption process remained stable and consistent across most mass variations. However, at a mass variation of 3 g, the standard deviation reached a value of 1.0, indicating instability in the adsorption system. A similar pattern was also observed in the activated carbon graph, where mass variations of 3, 6, 12, and 15 g resulted in standard deviations of 0.53, 0.04, 0.07, and 0.17, respectively, reflecting satisfactory data stability and replication. In contrast, the standard deviation increased to 1.0 with a mass variation of 9 g. In addition to operational factors, such as uneven mixing and measurement fluctuations, which caused variations between repetitions and possibly led to instability in the adsorption system under those conditions, this increase may have been caused by physical factors of the adsorbent, such as limited active sites or particle agglomeration. Although there were some higher SD values at certain points, overall, the SD values remained within a low and acceptable range; therefore, the data remained reliable and did not disrupt the consistency of the adsorption trends.

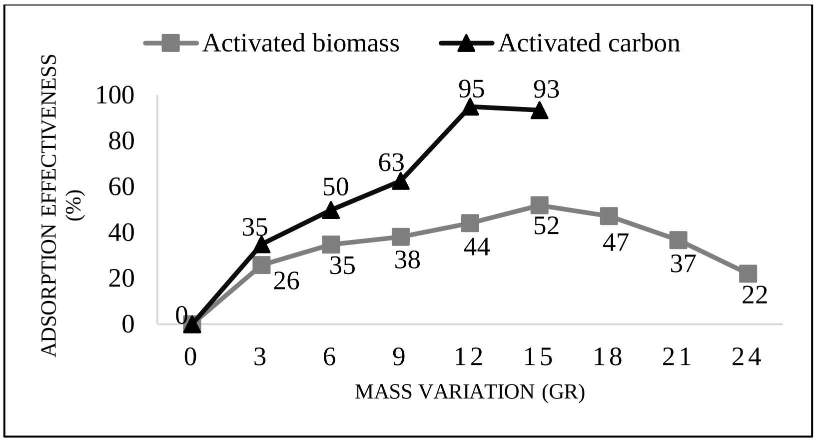

Figure 5. Graph of adsorption effectiveness mass variation

Variations in the mass of the adsorbent for both types of adsorbents were proven to play a significant role in influencing the reduction of heavy metal chromium concentration in liquid waste. In activated biomass, an increase in the adsorbent mass showed a direct relationship with a decrease in chromium concentration until it reached an optimum point. The optimum mass was obtained at 15 g, with a final concentration of 5.812 mg/L. However, the highest adsorption capacity was found at a mass of 3 g (0.104 mg/g), while the lowest capacity was at a mass of 24 g (0.0111 mg/g). This phenomenon indicates that the adsorption capacity per gram tends to decrease as the mass of the adsorbent increases. This difference is because the capacity is calculated based on the amount of metal ions adsorbed per unit mass of adsorbent. Because the number of accessible metal ions is proportional to the number of active sites, each unit of mass functions more efficiently at low masses, leading to a high capacity. In contrast, because of particle overlap, partial pore blockage, and restricted availability of metal ions to active sites, the capacity per gram actually declines with higher masses, even if the total number of adsorbed ions increases. Three primary stages of adsorption are depicted in the graph pattern of Figure 3: the equilibrium phase, the saturation or efficiency drop phase, and the fast adsorption phase (Ismadji et al., 2021). Excessive addition of adsorbent mass can lead to agglomeration, lower the active surface area, and restrict interaction with metal ions, as seen by the decline in efficacy after reaching the optimal mass (Neolaka et al., 2022). Therefore, to achieve efficient adsorption processes, the appropriate ratio between the adsorbent and adsorbate must be considered.

In contrast to activated biomass, the adsorption performance of activated carbon derived from sugarcane bagasse carbonized and chemically activated using 10% H_2SO_4 was better. With a final concentration of 0.609 mg/L, the chromium content decreased dramatically and reached its peak at a mass of 12 g. Once this threshold was crossed, increasing the mass to 15 g resulted in a higher final concentration and a lower adsorption capacity of 0.075 mg/g. The buildup of adsorbent particles that blocked the pores and restricted the passage of metal ions, as well as the saturation of active sites, caused this condition. When compared to activated biomass, activated carbon had a more effective ability to remove chromium metals per unit mass. The highest adsorption capacity value for activated carbon was recorded at a mass of 3 g, with a value of 0.141 mg/g. The graph pattern indicates that an optimal equilibrium point between the number of active sites and the concentration of metal ions in the solution was reached when the capacity increased to an optimum mass of 12 g and then slightly decreased. Thus, the most efficient adsorbent mass for the adsorption process using activated carbon is 12 g, because at this point, the number of active sites, surface area, and metal ion interactions are in the most ideal condition. This condition allows metal ions to have a balanced opportunity to interact with the active groups without excess adsorbent hindering the adsorption process.

Table 3. Chromium concentration reduction and adsorption capacity at varying times

Variation	Initial Concentration (ppm)	Contact time (minute)	Mass (grams)	Final Concentration (ppm)	Adsorption Capacity (mg/g)
Activated biomass	12.077	60	9	8.681	0.038
Activated biomass	12.077	90	9	7.923	0.046
Activated biomass	12.077	120	9	7.009	0.056
Activated biomass	12.077	150	9	6.885	0.058
Activated biomass	12.077	180	9	7.073	0.056
Activated carbon	12.077	60	9	7.596	0.050
Activated carbon	12.077	90	9	5.846	0.069
Activated carbon	12.077	120	9	5.512	0.073
Activated carbon	12.077	150	9	6.323	0.064
Activated carbon	12.077	180	9	7.124	0.055

As shown in Table 3, extending the contact time between the adsorbent and solution significantly affected the reduction of chromium concentration for both activated biomass and activated carbon adsorbents. For activated biomass, the final chromium concentration decreased from 8.681 ppm at a contact time of 60 min to 6.885 ppm at 120 min, indicating that a longer contact time increased the interaction and binding of metal ions to the active sites on the adsorbent surface. Nevertheless, the highest adsorption capacity was achieved at a contact time of 150 min (0.058 mg/g), after which the capacity decreased to 0.056 mg/g at 180 min and the final concentration increased to 7.078 ppm. This pattern indicates that the adsorption process reached its optimum point at a contact time of 150 min, after which the system approached equilibrium conditions, in which some active sites became saturated and desorption began (i.e., the release of metal ions from the adsorbent surface).

Similar phenomena were also observed with activated carbon adsorbents, which exhibited higher adsorption performance. At a contact time of 60 min, the final chromium concentration was 7.596 ppm and decreased to its lowest value of 5.512 ppm at the optimum contact time of 120 min. The highest adsorption capacity was also obtained at 120 min (0.073 mg/g), indicating that the adsorption rate was most effective at that point. However, after passing the optimum time, the adsorption capacity decreased to 0.064 mg/g at 150 min and 0.055 mg/g at 180 min, along with an increase in the final concentration to 6.323 ppm and 7.124 ppm. This conclusion indicates that excessive contact time can lead to saturation of active sites, a decrease in the slope of the concentration gradient, and desorption due to weakened interactions between metal ions and the adsorbent's active sites. Because the mass of the adsorbent used was the same (9 g) for all variations, the change in adsorption capacity fully reflects the change in the final concentration of the solution.

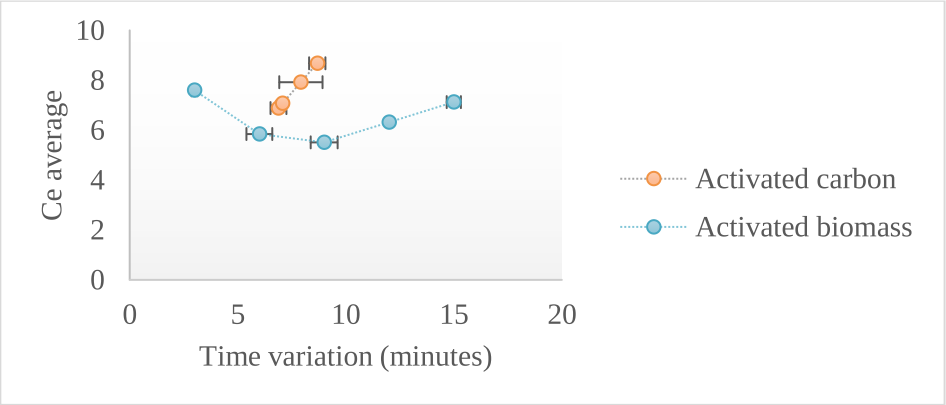

Figure 6. Error bar graph of activated biomass and activated carbon

As shown in the error bar graph in Figure 6, for activated biomass, contact time variations of 60, 120, 150, and 180 min resulted in small standard deviation values: 0.38, 0.16, 0.37, and 0.11, respectively. These low standard deviation values indicate that the adsorption process was stable and consistent. However, at a contact time variation of 90 min, the graph shows a high standard deviation of 1, which may indicate instability in the adsorption system. In the data obtained for activated carbon, all contact time variations produced small standard deviations, with values of 0.14, 0.60, 0.62, 0.04, and 0.33, respectively, reflecting differences in the stability level of the adsorption system under each condition.

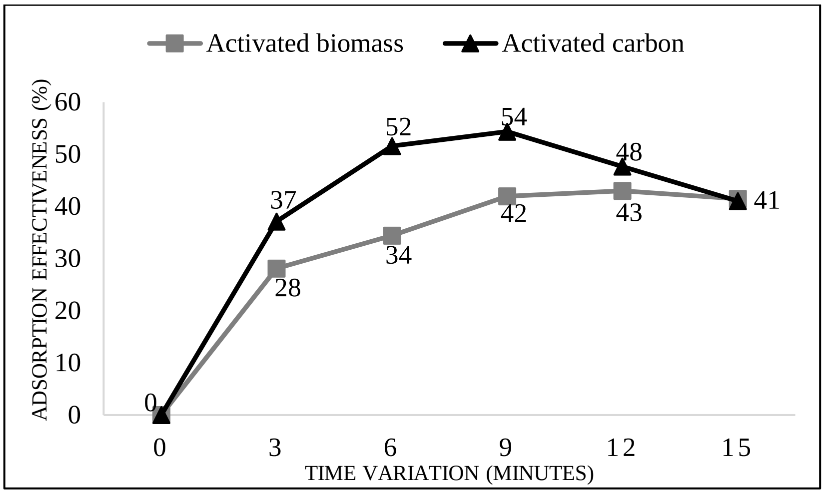

Figure 7. Graph of adsorption effectiveness time variation

As shown by the adsorption effectiveness graph in Figure 5, increasing the contact time significantly affects the reduction of heavy metal chromium levels, both in activated biomass and activated carbon. In activated biomass, the adsorption effectiveness increased from 28% at 60 min to 34% at 90 min, then gradually increased to 42% at 120 min and reached 43% at 150 min before decreasing again to 41% at 180 min. The greatest decrease in chromium concentration was achieved at 150 min, with a final concentration of 6.885 mg/L. The active adsorption phase occurred at 60–90 min, when the availability of active sites was still high and the concentration difference between the adsorbent and adsorbate was still large. The adsorption process started to approach equilibrium conditions, indicated by a drop in the rate of adsorption, after reaching the 120–150 min range, at which point part of the active sites were already filled. This condition also shows that when the system has reached its optimal point, longer contact times are not always correlated with higher adsorption efficacy. The capacity reached only 5.005 mg/L at 180 min, suggesting desorption or the return of chromium ions to the solution as a result of the adsorbent surface being saturated. The highest adsorption capacity was achieved at 150 min, reaching 0.058 mg/g, and decreased to 0.056 mg/g after passing the optimum point because the adsorption effectiveness also decreased. Under a constant adsorbent mass (9 g), changes in adsorption capacity are entirely influenced by changes in the final solution concentration, making the adsorption ability highly reflective of the effectiveness of metal concentration reduction in the solution.

A similar pattern was also observed with activated carbon, but with higher effectiveness and adsorption capacity. The adsorption effectiveness increased from 37% at a contact time of 60 min to 52% at 90 min, and reached its optimum at 120 min, with a highest effectiveness of 54.4%. After passing the optimum point, the adsorption effectiveness decreased to 48% at 150 min and further decreased to 41% at 180 min. The lowest final concentration was achieved at a contact time of 120 min, which was 5.512 mg/L, indicating that this time range is the most effective condition for the adsorption process. The highest adsorption capacity value also occurred at a contact time of 120 min (0.073 mg/g), which is consistent with the highest adsorption effectiveness value. The capacity decreased to 0.064 mg/g at 150 min and 0.055 mg/g at 180 min after reaching the optimal threshold. Because the adsorbent began to become saturated and some metal ions started to desorb, this drop suggests that extending the contact duration no longer improves metal adsorption. Aggregation of activated carbon particles also began to occur with excessive contact times, leading to a reduction in the active surface area and blocking of some active sites, thus limiting the interaction with metal ions. In this experiment, the mass of the activated carbon adsorbent was also constant at 9 g; therefore, the changes in adsorption capacity fully reflected the changes in the final concentration of the solution.

3.4. Comparison of the Effectiveness of Activated Biomass Adsorption and Activated Carbon with H_2SO_4

A comparison of the effectiveness of 10% H_2SO_4-activated biomass and 10% H_2SO_4-activated activated carbon is presented in Table 6. The research results reveal that the two types of adsorbents have different characteristics and performances in terms of total chromium (Cr-T) metal ion adsorption. Activated carbon showed higher effectiveness than activated biomass, regardless of variations in mass or contact time.

Table 6. Effectiveness comparison

Comparison Aspects	Activated Biomass	Activated Carbon
Optimum Mass	15 grams (BM5)	12 grams (AM4)
Optimum Time	150 minutes (BW4)	120 minutes (AW3)
Adsorption Mass Effectiveness	52%	95%
Adsorption Time Effectiveness	43%	54%

Based on the test results, the optimum mass indicates the most effective amount of adsorbent ffor reducing heavy metal concentration. Activated biomass reached its optimum mass at 15 g, while activated carbon did so at 12 g. This difference suggests that activated carbon has more active sites per unit mass than activated biomass. The greatest decrease in chromium concentration in activated biomass was 6.266 mg/L, while in activated carbon,,,, it reached 11.469 mg/L. A comparison of adsorption capacity at the same mass showed significant differences, with activated biomass at a mass ofg producing a capacity of 0.042 mg/g, while activated carbon at the same mass reached 0.075 mg/g. Therefore, activated carbon has a greater metal adsorption capacity at the same mass owowing to differences in the final concentration of the test solution produced. Based on the test results, the optimum mass indicates the most effective amount of adsorbent ffor reducing heavy metal concentration. Activated biomass reached its optimum mass at 15 g, while activated charcoal did so at 12 g. This difference indicates that activated charcoal has a higher number of active sites per unit mass than activated biomass. The greatest decrease in chromium concentration in activated biomass was 6.266 mg/L, while in activated carbon it reached 11.469 mg/L. A comparison of adsorption capacity at the same mass showed significant differences, with activated biomass at a mass of 15 grams producing a capacity of 0.042 mg/g, while activated carbon at the same mass reached 0.075 mg/g. Therefore, activated carbon has a greater metal adsorption capacity at the same mass due to differences in the final concentration of the test solution produced.

In terms of adsorption effectiveness, activated carbon also has a higher value compared to activated biomass. The adsorption effectiveness itself describes the ability of the adsorbent to reduce the concentration of heavy metals from the solution (Alrowais et al., 2024). The calculation results indicate that the adsorption effectiveness based on mass variation for activated biomass reaches 52%, while for activated carbon it reaches 95%. Meanwhile, the adsorption effectiveness based on time variation shows a result of 43% for biomass and reaches 54% for activated carbon. Based on the calculation of its adsorption effectiveness, activated carbon has a higher value compared to activated biomass for both mass and time variations. The difference in effectiveness between the two types of adsorbents is also related to their manufacturing process. Activated biomass is only activated through a chemical activation process using 10% H_2SO_4 for 24 hours without a carbonization stage, while activated charcoal goes through two stages: carbonization and chemical activation. Carbonization produces microporous and mesoporous structures that expand the adsorbent's surface area. During the carbonization process, there is a gradual decomposition of the lignocellulosic components, namely hemicellulose, cellulose, and lignin (Chen et al., 2022). During pyrolysis, volatile compounds are released, leaving behind a rearranged carbonaceous matrix. As a result, the surface area increases and the pore structure becomes more developed. The next step is activation by a chemical activator, which serves to open clogged pores (Takarani et al., 2019) Chemical activation using H_2SO_4 plays a dual role in improving the characteristics of bagasse-based activated carbon. Physically, H_2SO_4 removes tar residues and volatile compounds covering the surface, thus reopening the micropores and mesopores formed during the carbonization stage. Chemically, H_2SO_4 causes sulfonation and oxidation processes on the carbon surface, resulting in functional groups $-SO_3H$, $-COOH$, and $-OH$ as active sites for the adsorption of chromium (Cr) metal ions. The combination of pore opening and the formation of these active groups increases the specific surface area and the affinity of activated carbon surfaces toward Cr ions in metal plating wastewater, thus leading to higher adsorption capacity compared to biomass that has only undergone carbonization. By increasing the surface area and number of active sites, these two processes work together to improve activated carbon's ability to absorb heavy metals. With an ideal mass of 12 grams, contact duration of 120 minutes, and efficacy of up to 95%, activated carbon with 10% H_2SO_4 therefore emerged as the most effective adsorbent. Activated carbon derived from sugarcane bagasse waste was shown to be successful in lowering the amount of the heavy metal chromium (Cr-T) in liquid waste, with the best results obtained at a mass of 12 grams and a contact duration of 120 minutes. This activated carbon has the potential to be applied in the field as an adsorbent medium in a simple wastewater treatment system based on an adsorption column. The application is carried out through a two-stage mini wastewater treatment plant, consisting of an initial holding tank and a parallel adsorption column containing activated carbon. Liquid waste is first collected to separate solid particles, then it is flowed into an adsorption column where metal absorption occurs. This system can operate continuously throughout the metal plating process by adjusting the flow rate and volume according to the results of laboratory research. This simple wastewater treatment plant can be applied to small and medium-sized businesses because of its simple design, the fact that it doesn't require much land, and its relatively low operational costs.

In this study, the remaining adsorbent that had been used to absorb chromium metal was categorized as hazardous and toxic waste (B3 waste) because it contained a certain amount of heavy metals. This refers to Government Regulation 22 of 2021 concerning the Management of Hazardous and Toxic Waste, which states that waste containing heavy metals is categorized as hazardous waste. All remaining adsorbent is collected in a special container. Then it was handed over to the officers to be managed according to the applicable B3 waste management regulations. This handling was done to prevent the potential release of chromium back into the environment and to ensure that every process in the research met the standards.

4. Conclusions

Based on the research results, it can be concluded that variations in the adsorbent mass and contact time significantly affect the adsorption capacity of heavy metal chromium (Cr). The greater the adsorbent mass and the longer the contact time, the higher the adsorption capacity, reaching an optimum point. Activated biomass reaches its optimum condition at a mass of 15 g and a contact time of 150 min, with an effectiveness of 52% and 43%, while activated charcoal reaches its optimum point at a mass of 12 g and a contact time of 120 min with an effectiveness of 95% and 48%. Overall, sugarcane bagasse has proven to be a potentially environmentally friendly natural adsorbent material for reducing total chromium (Cr-T) levels in industrial metal plating wastewater.

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Ethics Statement

This study did not involve human participants, animals, or sensitive data; therefore no ethical approval was required.

CrediT Author Statement

Iffah Nabila: Conceived and Designed Analysis, Collected Data, Performed Analysis, Wrote Paper. **Siti Rachmawati**: Conceived and Designed Analysis, Collected Data, Contributed and Analysis Tools, Performed Analysis. **Mohammad Masykuri**: Conceived and Designed Analysis, Contributed and Analysis Tools, Performed Analysis. **Siti Nurlita**: Conceived and Designed Analysis, Contributed and Analysis Tools, Performed Analysis.

References

Ahmed, R., Block, I., Otte, F., Günter, C., Duarte-Rodrigues, A., Hesemann, P., Banerji, A., and Taubert, A. 2023. Activated carbon from sugarcane bagasse: a low-cost approach towards cr(vi) removal from wastewater. Chemistry (Switzerland) 5(2), 1124–1137.

Alrowais, R., Bashir, M. T., Khan, A. A., Bashir, M., Abbas, I., and Daiem, M. M. A. 2024. Palm waste

Amri, I., Awalsya, F., and Irdoni, I. 2020. Pengolahan limbah cair industri pelapisan logam dengan proses elektrokoagulasi secara kontinyu. Chempublish Journal 5(1), 15–26.

Ao, M., Zhou, R., Meng, R., Bonaventure, L. A., Luo, B., Qian, X., Xu, X., Wang, S., and Wu, P. 2025. Chromium transformations and biological impacts in aquatic systems: From sediment-water interfaces to food web complexity. Ecotoxicology and Environmental Safety 303, 118850.

Azizah, Y., and Marziah, A. 2022. Hidrolisis ampas tebu (baggase) menggunakan HCl menjadi cellulosa powder. JIRL: Jurnal Inovasi Ramah Lingkungan 3(3), 11–15.

Chen, D., Cen, K., Zhuang, X., Gan, Z., Zhou, J., Zhang, Y., and Zhang, H. 2022. Insight into biomass pyrolysis mechanism based on cellulose, hemicellulose, and lignin: evolution of volatiles and kinetics, elucidation of reaction pathways, and characterization of gas, biochar and bio-oil. Combustion and Flame 242.

Czikkely, M., Neubauer, E., Fekete, I., Ymeri, P., and Fogarassy, C. 2018. Review of heavy metal adsorption processes by several organic matters from wastewaters. Water (Switzerland) 10(10), 1–15,

Imani, A., Sukwika, T., and Febrina, L 2021. Karbon aktif ampas tebu sebagai adsorben penurun kadar besi dan mangan limbah air asam tambang. Jurnal Teknologi 13(1), 33–42.

Ismadji, S., Soetaredjo, F. E., Santoso, S. P., Putro, J. N., Yuliana, M., Irawaty, W., Hartono, S. B., and Lunardi, V. B. 2021. Adsorpsi pada fase cair: Kesetimbangan, kinetika, dan termodinamika.

Karume, I., Bumba, S., Tewolde, S., Mukasa, I. Z. T., and Ntale, M. 2023. Impact of carbonization conditions and adsorbate nature on the performance of activated carbon in water treatment. BMC Chemistry 17(1), 1–12.

Khumla, N., Solomon, S., Manimekalai, R., and Misra, V. 2024. Prospects of diversification for sustainable sugar bioenergy industries in ASEAN countries. Sugar Tech 26(4), 951–971.

Kumar, S., Meena, R. S., Jinger, D., Jatav, H. S., and Banjara, T. 2017. Use of press mud compost for improving crop productivity and soil health. International Journal of Chemical Studies 5.

Kurniati, K., Ervina, V., Ainatasya, N., and Jailani, A. 2024. The efforts of implementing the 21st century learning in english education. Ainara Journal: Jurnal Penelitian dan PKM Bidang Ilmu Pendidikan 5(1), 32–35.

Li, Y., Chai, J., Wang, R., Zhang, X., and Si, Z. 2022. Utilization of sugarcane bagasse ash (SCBA) in construction technology: a state-of-the-art review. Journal of Building Engineering 56.

Mardiyono, Sajidan, Masykuri, M., and Setyono, P. 2023. Bioremediation of nickel heavy metals in electroplating 020084.

Martinez, M. N., and Bartholomew, M. J. 2017. What does it mean? A review of interpreting and calculating different types of means and standard deviations. Pharmaceutics 9(2).

Neolaka, Y. A. B., Lawa, Y., Naat, J., Riwu, A. A. P., Mango, A. W., Darmokoesoemo, H., Widyaningrum, B. A., Iqbal, M., and Kusuma, H. S. 2022. Efficiency of activated natural zeolite-based magnetic composite (ANZ-Fe3O4) as a novel adsorbent for removal of Cr(VI) from wastewater. Journal of Materials Research and Technology 18, 2896–2909,

Ngibad, K. 2023. Pengukuran kadar logam Hg, kadmium, arsen, dan kromium (valensi 6) dalam air sumur. Lantanida Journal 11(2), 118.

Nurdiani, I., Suwardiyono, S., and Kurniasari, L. 2021. Pengaruh ukuran partikel dan waktu perendaman ampas tebu pada peningkatan kualitas minyak jelantah. Jurnal Inovasi Teknik Kimia 6(1).

Okokpujie, I. P., Tartibu, L. K., Musa-Basheer, H. O., and Adeoye, A. O. M. 2024. Effect of coatings on mechanical, corrosion and tribological properties of industrial materials: a comprehensive review. Journal of Bio- and Tribo-Corrosion 10(1), 1–20.

Oktaviansyah, I., Hindriarsana, A. Y., and Wahyudi, A. 2024. Pengaruh karbon aktif tempurung kelapa dan karbon aktif industrial terhadap parameter ammonia pada Danau Sipin. 9, 137–146.

Pande, V., Pandey, S. C., Sati, D., Bhatt, P., and Samant, M. 2022. Microbial interventions in bioremediation of heavy metal contaminants in agroecosystem. Frontiers in Microbiology 13, 1–16,

Pratiwi, A. T., Widiatmono, B. R., and Wirosoedarmo, R. 2023. Adsorpsi minyak dan timbal (Pb) pada air limbah bengkel mobil menggunakan bentonit dan cangkang telur ayam sebagai adsorben. Jurnal Ilmu Lingkungan 22(1), 125–131.

R, T., Ishak, I., and Kunusa, W. R. 2020. Potensi ampas tebu sebagai adsorben logam berat Cd, Cu dan Cr. Jurnal Program Studi Kimia Universitas Negeri Gorontalo 2(01), 33–43.

Rachmawati, S., Hawali Abdul Matin, H., Khoiriyah Azzam, A., Meilana Arifiandita, D., Darma Nurcahyo, F., Hamonangan Manullang, R., and Susatio, R. 2025. Analysis of heavy metal pollution of chromium (Cr) and nickel (Ni) in soil at Putri Cempo Landfill, Indonesia. BIO Web of Conferences 155, 1–15.

Rachmawati, S., and Syafrudin, B. 2023. Potential to be Used for Paving Blocks. Jurnal Kesehatan Masyarakat 19(2), 312–318.

Rahman, M. L., Wong, Z. J., Sarjadi, M. S., Soloi, S., Arshad, S. E., Bidin, K., and Musta, B. 2021. Heavy metals removal from electroplating wastewater by waste fiber-based poly (Amidoxime) ligand. Water (Switzerland) 13(9), 1–20.

Ramadhani, L. F., Nurjannah, I. M., Yulistiani, R., and Saputro, E. A. 2020. Review: teknologi aktivasi fisika pada pembuatan karbon aktif dari limbah tempurung kelapa. 26(2), 42–53.

Saputro, H. D., and Dwiprigitaningtias, I. 2022. Penanganan pada limbah infeksius (sampah medis) akibat Covid 19 untuk kelestarian lingkungan hidup. Jurnal Dialektika Hukum 4(1), 1–18.

Sholikhah, H. I., Putri, H. R., and Inayati, I. 2021. Pengaruh konsentrasi aktivator asam fosfat (H3PO4) pada pembuatan karbon aktif dari sabut kelapa terhadap adsorpsi logam kromium. Equilibrium Journal of Chemical Engineering 5(1), 45.

Sitorus, A. L., Sihotang, S., and Nugraha, A. W. 2024. Analisis konsentrasi pelarut dan kuat arus terhadap kualitas pelapisan logam perak (Ag) pada logam tembaga (Cu). EDUPROXIMA: Jurnal Ilmiah Pendidikan IPA,6(1), 8–19,

Somyanonthanakun, W., Greszta, A., Roberts, A. J., and Thongmee, S. 2023. Sugarcane bagasse-derived activated carbon as a potential material for lead ions removal from aqueous solution and supercapacitor energy storage application. Sustainability (Switzerland) 15(6).

Takarani, P., Novita, S. F., and Fathoni, R. 2019. Pengaruh massa dan waktu adsorben selulosa dari kulit jagung terhadap konsentrasi penyerapan. Prosiding Seminar Nasional Teknologi V.

Wang, B., Lan, J., Bo, C., Gong, B., and Ou, J. 2023. Adsorption of heavy metal onto biomass-derived activated carbon: review. RSC Advances 13(7), 4275–4302.

Wibowo, Y. G. 2025. Carbon-Based adsorbents for heavy metal removal in wastewater: Green technology or environmental burden? Environmental Nanotechnology, Monitoring & Management 101051.

Zheng, Y., Zhang, Z., Chen, Y., An, S., Zhang, L., Chen, F., Ma, C., and Cai, W. 2022. Adsorption and desorption of Cd in reclaimed soil under the influence of humic acid: characteristics and mechanisms. 9(1), 1–11.