

Original Research

The Effect of Avocado Seed Charcoal and Bamboo Charcoal Filtration Model on Chromium Reduction in Tannery Wastewater

Sri Puji Ganefati*, Sri Haryanti, Sarjito Eko Windarsa, Haryono, Sugianto and Diah Setyo Rini

Department of Environmental Health, Poltekkes Kemenkes Yogyakarta, Yogyakarta, Indonesia

Article history

Received: 20 May 2026

Revised: 16 August 2026

Accepted: 18 August 2026

Published Online: 13 September 2026

***Correspondence:**

Sri Puji Ganefati

Address: Sukunan Hamlet No. 36, RT.7/RW. 19, Banyuraden Subdistrict, Gamping District, Sleman Regency, Yogyakarta City, Indonesia.

Email: sripuji_ganefati@yahoo.com

How to cite this article: Ganefati SP, Haryanti S, Windarsa SE, Haryono, Sugianto, Rini DS. The Effect of Avocado Seed Charcoal and Bamboo Charcoal Filtration Model on Chromium Reduction in Tannery Wastewater. *Health Dynamics*, 2026, 3(9), 372-378. <https://doi.org/10.33846/hd30902>



Copyrights: © 2026 by the author(s). This is an open access article under the terms and conditions of the Creative Commons Attribution – NoDerivatives 4.0 International (CC BY-ND 4.0) license (<https://creativecommons.org/licenses/by-nd/4.0/>).

ABSTRACT

Background: Industrial tanning wastewater contains high concentrations of total chromium (Cr) due to the use of chromium sulphate in the tanning process. This study aims to evaluate the effect of filtration using avocado seed charcoal, bamboo charcoal, and a combination of both in a multi-stage filtration device model on the reduction of total chromium in leather tanning wastewater. **Methods:** This study is a laboratory experiment with a pretest–posttest design using three treatment variations, involving 60 samples (30 pre-test, 30 post-test). The wastewater flowed through three filtration units (Tank I = avocado seed charcoal; Tank II = bamboo charcoal; Tank III = combination of avocado seed charcoal + bamboo) with a flow rate of 800 ml/minute, a media height of 9 cm, and a contact time of 1 hour. Data analysis included Kolmogorov–Smirnov normality test and one-way ANOVA test ($\alpha=0.05$) followed by LSD test. **Results:** The results showed that the highest Cr reduction occurred in Tank III with an average reduction of 22.72 ppm, compared to Tank I (19.14 ppm) and Tank II (14.46 ppm). The ANOVA test showed a significant difference between treatments ($p = 0.034$). The LSD test confirmed a significant difference between Tank II and Tank III ($p = 0.010$), with the best effectiveness in combination filtration (Tank III). **Conclusion:** The filtration model combining avocado seed charcoal and bamboo charcoal has the potential to be an efficient and environmentally friendly adsorption technology for reducing chromium in leather tanning wastewater.

Keywords: Total chromium; adsorption; avocado seed charcoal; bamboo charcoal; leather tanning waste

1. INTRODUCTION

The leather tanning industry is an industry. The leather tanning industry is an economic activity that processes raw materials, raw ingredients, semi-finished goods, and/or finished goods into raw materials for the manufacture of leather goods.⁽¹⁾ In its operations, the leather tanning industry generates liquid waste, solid waste, and gaseous emissions. Of these three types of waste, liquid waste is the most abundant.⁽²⁾ The leather tanning process is a method of preserving animal hides using chemicals as processing aids. The hides typically come from cattle, buffalo, goats, and other animals. The chemicals commonly used contain chromium compounds. In general, the leather tanning process includes pre-tanning, tanning, and post-tanning.⁽³⁾ The leather tanning industry is an industry that generates wastewater classified as “B3” (in Indonesia, “hazardous and toxic substances” are referred as *Bahan Berbahaya dan Beracun* or abbreviated as B3). If B3 waste is discharged directly into water bodies, it can pose a threat to the environment, human health, and other living organisms.

Industrial tanning wastewater contains pollutant parameters including Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD5), nitrogen as nitrogen sulfide, total chromium, and oils and fats. Chromium (Cr) compounds in liquid waste from the leather tanning industry originate from the production process, which uses chromium sulphate compounds at a percentage of 60%-70%. Not all of these compounds can be absorbed by the leather during the tanning process, so the rest is discharged in the form of liquid waste. Leather tanning industrial wastewater contains toxic and carcinogenic chemicals.⁽⁴⁾ Among these substances, the most prevalent heavy metal in leather tanning wastewater is chromium, which is considered the most toxic to human health and the environment.⁽⁵⁾

The chromium content in leather tanning waste comes from the chemical Chromosal B ($\text{Cr}_2\text{O}_7^{2-}$), which is an auxiliary agent used in the wetting-back process to increase the moisture content of the leather, making it more supple.⁽⁶⁾ Chromium is a heavy metal that is highly toxic and not needed by the human body. Chromium is carcinogenic because it can damage chromatin structure and cell function.⁽⁷⁾ Chromium compounds can cause eye and skin irritation as well as irritation of the nose and throat, which can lead to lung cancer.⁽⁸⁾

Most leather tanning industries are small-scale, so the wastewater generated from the production process has not been treated. Meanwhile, wastewater from large-scale leather tanning industries and clusters has been treated through Wastewater Treatment Plants (WWTPs), but the concentration of the wastewater produced is still quite high and exceeds quality standards. If this wastewater is discharged into water bodies, it has the potential to pollute the environment and have a negative impact on human life and other living creatures, especially aquatic biota. Given these problems, there is a need for appropriate treatment technology to treat wastewater generated from the leather tanning industry.⁽³⁾

The use of avocado seeds as an adsorbent for heavy metals such as chromium is based on their organic compound content, including cellulose, hemicellulose, and lignin, which can be converted into high-porosity activated carbon. This porous structure enables effective adsorption through both physical and chemical interactions between the adsorbent surface and heavy metal ions. Several studies over the past decade have shown that biomass-based activated carbon, including avocado seeds, has a sufficiently high adsorption capacity

for heavy metals due to the presence of active functional groups such as hydroxyl (-OH) and carboxyl (-COOH) groups.⁽⁹⁾

Furthermore, traditionally produced bamboo charcoal is also widely used as an adsorbent due to its well-developed microporous structure and large surface area. The carbonization process of bamboo produces a material with high adsorption capacity for various pollutants, including heavy metals such as chromium. Furthermore, the abundance of raw materials and relatively low production costs make bamboo charcoal an economical and environmentally friendly adsorbent alternative.⁽¹⁰⁾

Traditionally produced bamboo charcoal has been widely used as an adsorbent due to its excellent adsorption capacity. Its superior adsorption performance is attributed to several unique characteristics, including a well-developed microporous structure, distinctive biological properties, high density, and an extensive pore network. These characteristics provide a large specific surface area that enhances the adsorption of contaminants. Notably, bamboo charcoal has a specific surface area of approximately $300 \text{ m}^2/\text{g}$, which is substantially greater than that of conventional wood charcoal, with a surface area of around $30 \text{ m}^2/\text{g}$. This larger surface area provides more active adsorption sites, making bamboo charcoal a more effective adsorbent for the removal of pollutants from aqueous solutions.⁽¹¹⁾

In addition, the increasing demand for environmentally friendly and cost-effective wastewater treatment technologies has encouraged the exploration of natural adsorbents derived from biomass. These materials are not only renewable but also have high potential for modification to improve their adsorption performance. Therefore, the development of a filtration model using locally available materials such as avocado seeds and bamboo is expected to provide a practical and sustainable solution for reducing heavy metal pollution, particularly chromium, in industrial wastewater. Based on the background described above, it is necessary to process the wastewater using a combination of avocado seed charcoal and bamboo charcoal to reduce chromium levels more efficiently through a leather tanning wastewater treatment system.

2. METHODS

This study is a laboratory experiment with a pretest-posttest design using three treatment variations.

A sample of leather tanning wastewater from the same source was simultaneously fed into three filtration tanks with the same volume and flow rate but using different filtration media. Total chromium levels were measured before the filtration process (pre-test) and after the filtration process (post-test), and the effectiveness of each filtration model was then compared based on the magnitude of the reduction in total chromium levels.⁽¹²⁾

2.1 Materials

2.1.1 Preparation of research materials

This study began with the preparation of the research materials, namely avocado seed charcoal and bamboo charcoal. Avocado seed charcoal was produced by first drying the avocado seeds to reduce their moisture content, followed by carbonization using a distillation apparatus. In contrast, bamboo charcoal was produced through direct combustion (Figure 1). After the carbonization process, both types of charcoal were washed with clean water before use. The prepared avocado seed charcoal and bamboo charcoal were then ready for use in the study.



Figure 1. Avocado seed charcoal (left) and bamboo charcoal (right)

2.1.2 Filtration model design

The filtration system was constructed in a sequential configuration consisting of three storage tanks and three filter units. Each storage tank had a capacity of 60 L. The filter units were made of glass boxes measuring 30 cm in length, 20 cm in width, and 40 cm in height. The three filter units consisted of Filter I (avocado seed charcoal), Filter II (bamboo charcoal), and Filter III (a mixture of avocado seed charcoal and bamboo charcoal). The charcoal layer in each filter unit was 9 cm in height. The filtration system, including the storage tanks and filter units, is shown Figure 2.



Figure 2. Filter unit model with reservoir units and filter units

2.2 Research Sample

The sample of this study was liquid waste from the leather tanning industry, with samples taken using the grab sampling method, amounting to 30 liters.

2.3 Research Variables

The variables used in this study were independent variables in the form of filtration media, namely avocado seed charcoal and bamboo charcoal. Meanwhile, the dependent variables were the decrease in chromium levels before and after treatment with a leather tanning liquid waste treatment model using bamboo charcoal, avocado seeds, and a combination of both.

2.4 Research Procedure

This study was conducted at the Environmental Health Laboratory of the Yogyakarta Ministry of Health Polytechnic. The study was conducted over two days with one repetition. Liquid waste samples were collected from the leather tanning process at PT ASA. A total of 60 samples were used, comprising 30 samples before treatment (pre) and 30 samples after treatment (post).

The samples were stored in three reservoir tanks and flowed at a rate of 800 ml/minute into three filtration tanks. The samples were placed on the filtration media for one hour, and post-treatment samples were collected. Chromium level measurements were carried out by the

laboratory. The research procedure is illustrated in Figure 3.

2.5 Data Analysis

The data obtained were tested for normality using Kolmogorov-Smirnov. If the data were normally distributed, they were then tested using multivariate ANOVA with a significance level of 95% ($\alpha = 0.05$) to determine significant differences between the use of the Bak I filtration model, the Bak II filtration model, and the Bak III filtration model. Furthermore, the data were subjected to a Least Significant Difference (LSD) test to determine the effective filtration model in reducing chromium levels in leather tanning wastewater.

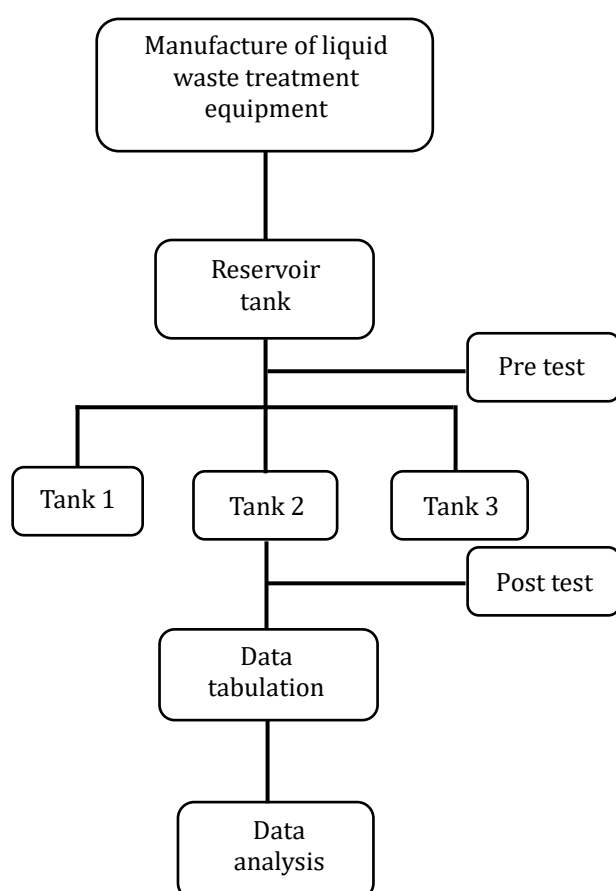


Figure 3. Research procedure scheme

3. RESULTS

3.1 Decrease in Chromium Levels

Based on the data processing results (Table 1), among the three filtration tanks, the one that can reduce the highest chromium level is Tank III (combined filtration of avocado seed charcoal and bamboo charcoal) with an average reduction of 22.72 ppm.

Table 1. Average decrease in chromium levels

Treatment	Pre-average (ppm)	Post-average (ppm)	Average difference in reduction (ppm)
Tank I	145.4	126.3	19.14
Tank II	146.1	131.7	14.46
Tank III	145.7	123.0	22.72

3.2 Findings of the Decrease in Chromium Levels

Based on the results of the data normality test, significant values greater than 0.05 were obtained, namely in the Bak I screening model with a value of 0.072, the Bak II screening model with a value of 0.123, and the Bak III screening model with a value of 0.55. This indicates that the data is normally distributed. Furthermore, a one-way ANOVA test was conducted and a significant value of less than 0.05 was obtained, namely 0.034. Thus, H_0 was rejected and H_a was accepted, so it can be stated that there is a significant difference in the reduction of chromium levels after using the Bak I filtration model, the Bak II filtration model, and the Bak III filtration model. Furthermore, the data was tested using the least significant difference (LSD) test to determine the effective filtration model in reducing chromium levels in leather tanning wastewater, and the results are as shown in Table 2.

Table 2. Least significant difference (LSD) test results

Dependent variable	Multiple comparisons		
Filtration model	Measurement results	Mean difference (I-J)	Sig.
Tank I	Tank II	4.93	0.129
	Tank III	-3.59	0.267
Tank II	Tank I	-4.93	0.129
	Tank III	-8.52	0.010
Tank III	Tank I	3.59	0.267
	Tank II	8.52	0.010

Among the Tank II and Tank III filtration models, which have the highest and most significant difference in chromium reduction, it is the Tank III filtration model. This can be seen from the results of the mean difference between the Tank III filtration model treatment and the Tank II filtration model treatment, which has the highest value, namely 8.52 with a significant value of 0.010 (<0.05), indicating a significant difference. Therefore, it can be concluded that the Bak III filtration model is the

most effective in reducing chromium levels in leather tanning waste. The graph showing the average percentage decrease in chromium levels can be seen in Figure. 4.

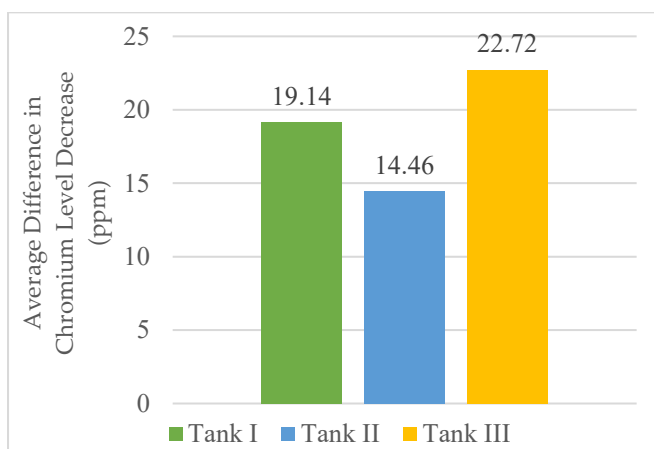


Figure 4. Average difference in chromium level decrease (ppm)

4. DISCUSSION

Chromosomal B is a chemical used in the tanning process that can shorten tanning time. The presence of chromium metal in liquid waste pollutes the environment and can even cause adverse health effects because chromium metal is one of the contents of liquid waste that is classified as a Hazardous Toxic Substance (B3).⁽²⁾ The use of avocado seeds and bamboo charcoal can serve as adsorbents for heavy metals, including chromium, due to their good adsorption capacity. Avocado seeds and bamboo can adsorb chromium by being converted into activated charcoal, thereby effectively absorbing chromium chemicals.

The Tank III filtration model (a filtration tank with a mixture of avocado seed charcoal and bamboo charcoal) is capable of reducing the highest chromium levels. This is because Tank III uses two layers of media, namely avocado seed charcoal and bamboo charcoal, so that the wastewater is adsorbed by the avocado seed charcoal and then re-adsorbed by the bamboo charcoal. In addition, avocado seed charcoal and bamboo charcoal also have good adsorption capacity. Chemically, the components of avocado seeds contain 43.3% amylose and 37.7% amylopectin, which have the ability to adsorb heavy metals, including chromium.⁽¹³⁾ Meanwhile, bamboo has a larger surface area than wood charcoal, reaching 300 m²/gram and a highly porous structure, allowing chromium chemicals to be trapped and demonstrating high adsorption potential.⁽¹⁴⁾

Adsorption is the process of binding a substance to the surface of a solid material. This absorption of substances occurs because the molecules on the surface of the solid material have an unbalanced force that tends to be attracted inward.⁽¹⁵⁾ This adsorption process uses avocado seed charcoal and bamboo charcoal as adsorbents to absorb chromium (Cr) contained in liquid waste. With the adsorption capacity of avocado seed charcoal and bamboo charcoal, the mixture of the two types of charcoal shows that the adsorption of chromium chemicals in waste can be more optimal.

This study demonstrated that the Tank III filtration model, which uses a mixture of avocado seed charcoal and bamboo charcoal, can reduce chromium levels by an average of 22.72 ppm. The reduction in chromium levels in the Tank III filtration model was greater than that in the Tank I filtration model, which uses avocado seed charcoal, and the Tank II filtration model, which uses bamboo charcoal.

The results of this study are in line with various previous studies which state that carbonized and activated biomass has high potential as a heavy metal adsorbent. Based on a study, activated carbon from avocado seeds is effective in reducing heavy metal levels such as Pb and Cd through physical and chemical adsorption mechanisms against chromium (Cr) ion absorption.⁽¹⁶⁾ The organic compound content and active functional groups in avocado seeds enable interactions between metal ions and the adsorbent surface. Another study shows that activated bamboo charcoal has a higher heavy metal adsorption capacity than non-activated bamboo charcoal.⁽¹⁷⁾

The production of activated carbon from bamboo is quite effective and easy because bamboo contains relatively high levels of lignin and cellulose. The cellulose content—the primary component in carbon formation—ranges from 42.4% to 53.5%; the lignin content ranges from 19.8% to 26.6%; the pentosan content ranges from 1.24% to 3.77%; ash content ranges from 1.24% to 3.77%, and silica content ranges from 0.10% to 1.78%.⁽¹⁸⁾

This is due to the large specific surface area of bamboo charcoal and its well-developed microporous structure. Amanina et al. (2024) also stated that bamboo charcoal has high porosity and density characteristics, making it effective as an adsorbent for various chemical compounds in wastewater.⁽¹¹⁾ Mechanistically, the process of reducing chromium levels in this study occurs through adsorption, which is the binding of chromium ions (Cr³⁺) to the surface of the adsorbent. Adsorption

occurs due to the attractive force between molecules or metal ions and solid surfaces that have unbalanced surface energy. Avocado seed charcoal provides active functional groups such as hydroxyl (–OH) and carboxyl (–COOH) that are capable of binding chromium ions through electrostatic bonds and ion exchange. Meanwhile, bamboo charcoal functions as a physical adsorbent that has a large number of micro and mesopores, so that chromium ions can be trapped in its pore structure. Samosir et al. (2025) stated that porous materials with a high surface area will increase the adsorption capacity of heavy metals because they enlarge the contact area between the adsorbent and the adsorbate.⁽¹⁴⁾

The use of a mixture of avocado seed charcoal and bamboo charcoal in Tank III produced a synergistic effect between chemical adsorption and physical adsorption. Liquid waste passing through two types of adsorbent media in layers allows for repeated chromium adsorption, thereby optimizing chromium reduction efficiency. This is evident from the research results, which show that Tank III has the highest average chromium reduction difference compared to Tank I and Tank II. In addition to the type of adsorbent media, contact time and media thickness also affect adsorption effectiveness. According to Hashem et al. (2022), the longer the contact time between the adsorbent and adsorbate, the greater the chance of achieving adsorption equilibrium.⁽¹⁹⁾ This study was conducted over a period of 60 minutes, or 1 hour. The increase in adsorption efficiency occurred rapidly due to the continued availability of many active sites on the surface of the activated carbon until adsorption equilibrium was reached at a contact time of 60 minutes.⁽²⁰⁾ The thickness of the charcoal media can increase the contact area, thereby increasing the chance of chromium ions being adsorbed by the adsorbent.

This study has several limitations. First, the filtration media thickness was limited to 9 cm, which may have restricted the adsorption capacity of the charcoal media. Second, the contact time was fixed at 60 minutes, and other contact times were not evaluated. Third, the study was conducted using a fixed flow rate of 800 mL/minute and only three filtration media configurations, so the optimal operating conditions may not have been fully determined. Therefore, further studies are recommended to evaluate different media thicknesses, contact times, flow rates, and media compositions to determine the optimal filtration

conditions for chromium removal from tannery wastewater.

5. CONCLUSION

The filtration tank model had a significant effect on the reduction of total chromium in leather tanning wastewater ($p = 0.034$). The Tank III filtration model (a combination of avocado seed charcoal and bamboo charcoal) is the most effective treatment method, with an average reduction of 22.72 ppm, and shows a significant difference compared to Tank II ($p = 0.010$). The filtration device model using local organic adsorbents has the potential to be an appropriate technology for treating liquid waste from the leather tanning industry, particularly for reducing total chromium.

Based on the results of the study conducted using a limited charcoal bed with a thickness of 9 cm, this can be developed with a thicker charcoal bed for more optimal results. In addition, future research is recommended to explore variations in media thickness, contact time, and flow rate to obtain optimal operating conditions. The potential for regeneration and reuse of adsorbent materials should also be further investigated to enhance the sustainability and economic value of this treatment method.

Ethical Approval

Not required.

Acknowledgement

The researchers would like to thank PT. ASA for agreeing to participate in this study, the field assistants who contributed to this research, and the Yogyakarta Health Polytechnic of the Ministry of Health for this opportunity.

Competing Interests

All the authors declare that there are no conflicts of interest.

Funding Information

No funds were received for this study.

Underlying Data

Derived data supporting the findings of this study are available from the corresponding author on request.

REFERENCES

- Kuncoro YM, Soedjono ES. Studi Pustaka: Teknologi Pengolahan Air Limbah pada Industri Penyamakan Kulit. Jurnal Teknik ITS. 2022;11(3):C142-C149. <http://dx.doi.org/10.12962/j23373539.v11i3.99654>
- Mahmud Z, Manik MRK, Rahman A, Karim MM, Islam LN. Impact of untreated tannery wastewater in the evolution of multidrug-resistant bacteria in Bangladesh. Scientific Reports. 2024;14(1):20379. <http://dx.doi.org/10.1038/s41598-024-71472-6>
- Vunain E, Njewa JB, Biswick TT, Ipadeola AK. Adsorption of chromium ions from tannery effluents onto activated carbon prepared from rice husk and potato peel by H3PO4 activation. Applied Water Science. 2021;11(9):150. <http://dx.doi.org/10.1007/s13201-021-01477-3>
- Nur-E-Alam Md, Mia MdAS, Ahmad F, Rahman MdM. An overview of chromium removal techniques from tannery effluent. Applied Water Science. 2020;10(9):205. <http://dx.doi.org/10.1007/s13201-020-01286-0>
- Bedada D, Angassa K, Tiruneh A, Kloos H, Fito J. Chromium removal from tannery wastewater through activated carbon produced from Parthenium hysterophorus weed. Energy, Ecology and Environment. 2020;5(3):184–195. <http://dx.doi.org/10.1007/s40974-020-00160-8>
- Adane T, Dessie A. Adaptability of Teff husk activated carbon for removal of hexavalent chromium from tannery wastewater at optimized process condition. Applied Water Science. 2020;10:199. <http://dx.doi.org/10.1007/s13201-020-01269-1>
- Younas F, Bibi I, Afzal M, Al-Misned F, Niazi NK, Hussain K, Shahid M, Shakil Q, Ali F Wang H. Unveiling Distribution, Hydrogeochemical Behavior and Environmental Risk of Chromium in Tannery Wastewater. Water. 2023;15(3):391. <http://dx.doi.org/10.3390/w15030391>
- Ho S, Nordin NA, Kannan R. A Review of the Bamboo-Based Activated Carbon: Wastewater Treatment & Supercapacitor Device Applications. International Journal of Engineering Trends and Technology. 2023;71(11):69–83. <http://dx.doi.org/10.14445/22315381/ijett-v71i11p207>
- Payel S, Hashem MdA, Hasan MdA. Recycling biochar derived from tannery liming sludge for chromium adsorption in static and dynamic conditions. Environmental Technology & Innovation. 2021;24:102010. <http://dx.doi.org/10.1016/j.eti.2021.102010>
- Hashem MA, Hasan M, Momen MA, Payel S, Nur-A-Tomal MS. Water hyacinth biochar for trivalent chromium adsorption from tannery wastewater. Environmental and Sustainability Indicators. 2020;5:100022. <http://dx.doi.org/10.1016/j.indic.2020.100022>
- Amanina SA, Putra GIS, Damayanti N, Agustin IT. Synthesis of Iron Oxide Biocomposite from Avocado Seeds as Cr(III) Adsorbent in Tannery Wastewater. In: Seminar Nasional Teknologi Pertanian Indonesia II (STPI) 2024. Malang: Universitas Brawijaya; 2024.
- Yahya MD, Obayomi KS, Abdulkadir MB, Iyaka YA, Olugbenga AG. Characterization of cobalt ferrite-supported activated carbon for removal of chromium and lead ions from tannery wastewater via adsorption equilibrium. Water Science and Engineering. 2020;13(3):202–213. <http://dx.doi.org/10.1016/j.wse.2020.09.007>
- Rahayu C. Activated carbon from avocado seed (*Persea americana* Mill.) as an adsorbent for reducing lead (Pb) and cadmium (Cd) concentrations. [Dissertation]. Jakarta: Universitas Sahid Jakarta; 2021.
- Samosir H, Hutabarat MA, Samosir DS. Adsorption of heavy metals by bamboo activated carbon Schizostachyum in groundwater of Balikpapan. Charm Sains: Jurnal Pendidikan Fisika. 2025;6(2):77–81. <https://doi.org/10.67006/charmsains.v6i2.477>
- Pinalia A, Widayatno T, Yuliawati T, Susilo AA. Adsorption of heavy metals (Pb) from wastewater using activated bamboo charcoal as adsorbent. J Teknol Bahan Alam. 2017;6(3):17-23.
- Putri DNR, Umam HI, Pambudi T. Studi Kinetika dan Isoterm Adsorpsi Ion Logam Berat Cr(VI) pada Arang Aktif. Jurnal Teknik Terapan. 2026;5(1):42–47. <https://doi.org/10.25047/jteta.v5i1.116>
- Kumar R, Basu A, Bishayee B, Chatterjee RP, Behera M, Ang WL, Pal P, Shah M, Tripathy SK, Ambika S, Janani VA, Chakraborty S, Nayak J, Jeon B-H. Management of tannery waste effluents towards the reclamation of clean water using an integrated membrane system: A state-of-the-art review. Environmental Research. 2023;229:115881. <http://dx.doi.org/10.1016/j.envres.2023.115881>
- Deepa A, Sonal S, Mishra BK. Application of co-immobilized microbial biochar beads in hybrid biofilter towards effective treatment of chrome tanning wastewater. Journal of Water Process Engineering. 2022;48:102821. <http://dx.doi.org/10.1016/j.jwpe.2022.102821>
- Hashem MdA, Payel S, Mim S, Hasan MdA, Nur-A-Tomal MdS, Rahman MdA, Sarker, MI. Chromium adsorption on surface activated biochar made from tannery liming sludge: A waste-to-wealth approach. Water Science and Engineering. 2022;15(4):328–336. <http://dx.doi.org/10.1016/j.wse.2022.09.001>
- Ameha B, Nadew TT, Tedla TS, Getye B, Mengie DA, Ayalneh S. The use of banana peel as a low-cost adsorption material for removing hexavalent chromium from tannery wastewater: optimization, kinetic and isotherm study, and regeneration aspects. RSC Advances. 2024;14(6):3675–3690. <http://dx.doi.org/10.1039/d3ra07476e>