ESTA JOURNAL
Energy Storage Technology and Applications

Article

jurnal.uns.ac.id/esta

Production of Biosorbents from Tea Residue

A. M. Putri[1*], A. S. Khansani[1], A. P. Sulistyowati[1], R. E. Saputra[1], and C. Yudha[1,2]

1. Chemical Engineering Department, Vocational School, Universitas Sebelas Maret, Jl. Kol. Sutarto 150K Jebres, Surakarta 57126, Indonesia
2. Centre of Excellence for Electrical Energy Storage Technology, Universitas Sebelas Maret, Jl. Slamet Riyadi 435, Surakarta 57146, Indonesia

[*] Corresponding author: adeliamaretha2003@gmail.com
doi: https://doi.org/10.20961/esta.v4i1.109728
Received: 09-10-2025; Revised: 30-03-2026; Accepted: 31-03-2026; Published: 01-04-2026

ABSTRACT: Tea residue (TR) is a ubiquitous lignocellulosic byproduct with significant potential as a sustainable biosorbent for wastewater remediation. This study investigates the utilization of TR for the removal of Methylene Blue (MB) from aqueous solutions. Chemical characterization revealed that TR consists of 37% cellulose and 14% lignin, providing essential hydroxyl and carboxyl functional groups that facilitate the adsorption of cationic dyes through electrostatic interactions. The biosorption performance was evaluated via batch experiments, focusing on the effect of contact time on removal efficiency. Physical properties were assessed through moisture content analysis, while MB concentration changes were monitored using visible-light spectrophotometry at λ_{max} = 670 nm. The results demonstrated a robust adsorption capacity, characterized by a consistent decline in solution absorbance as contact time increased. Specifically, significant dye removal was achieved within an 8-minute interval, indicating rapid adsorption kinetics. These findings suggest that tea residue serves as an efficient, eco-friendly, and cost-effective alternative for the treatment of textile-derived industrial effluents.

Keywords: Tea residue, biosorbent, Methylene Blue, adsorption, wastewater treatment.

1. INTRODUCTION

Biomass is a complex solid natural product derived from organic matter, primarily plants, and is fundamentally characterized by its composition of hydrocarbon compounds, including carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). In modern environmental engineering, biomass is extensively recognized for its versatility, serving as both a renewable energy precursor and a high-efficiency biosorbent. The transformation of agricultural waste into functional materials is a key strategy in mitigating environmental degradation while promoting resource recovery [1, 2].

The functional efficiency of biosorbents is primarily determined by their surface chemistry, which contains various active groups such as phenolic, hydroxyl, carboxyl, amine, and phosphate compounds. These groups provide essential active sites that facilitate the sequestration of diverse pollutants from aqueous solutions. Through mechanisms such as surface complexation, ion exchange, and electrostatic attraction, these biological matrices are capable of binding hazardous substances, making them highly effective as adsorbents for environmental remediation [1, 5].

Heavy metals represent a critical class of inorganic pollutants, generally defined as chemical elements with an atomic mass equal to or greater than 200 g/mol. Most heavy metal contamination originates from unregulated industrial discharge, which has become a persistent global issue. These metals are particularly dangerous due to their non-biodegradable nature and their tendency to persist in aquatic ecosystems, leading to the long-term degradation of water quality and the disruption of local biodiversity [3, 4].

In the context of Indonesia, rapid industrial expansion has contributed to significant economic development but has also led to severe environmental consequences, particularly water pollution. Industrial processes often discharge liquid waste containing a sophisticated mixture of hazardous and poorly soluble chemical compounds, including toxic heavy metals. The release of untreated effluents into freshwater bodies significantly threatens the sustainability of water resources and the health of surrounding communities [3, 4, 6].

The human health implications of such contamination are profound, as toxic elements can enter the food chain through contaminated water or the ingestion of aquatic organisms. Because heavy metals and many organic pollutants undergo bioaccumulation, their concentrations increase within human tissues over time. This process can lead to acute and chronic toxicological effects, ranging from neurological impairment to organ damage, highlighting the urgent need for effective wastewater treatment technologies [4, 7].

While heavy metals are a primary concern, industrial effluents also contain synthetic dyes like Methylene Blue (MB), which share similar cationic properties and pose parallel environmental risks. To treat such complex liquid waste, several conventional methods have been implemented, including chemical reduction, ion exchange, bacterial reduction, and adsorption using coal or activated carbon. However, these traditional techniques often face significant limitations, such as high energy requirements, the intensive use of chemical reagents, and prohibitive operational costs [5, 6, 8].

Consequently, there is a growing demand for sustainable and low-cost alternatives in the field of adsorption. Utilizing agricultural byproducts, specifically tea residue (tea dregs), offers an eco-friendly solution for the removal of both cationic dyes and heavy metals. Tea residue is rich in lignocellulosic components—cellulose and lignin—which provide a robust structural framework and abundant functional groups for adsorption. By converting this abundant waste into a functional biosorbent, this study aims to provide an efficient and cost-effective method for wastewater treatment while aligning with the principles of a circular economy [3, 8, 9].

2. MATERIALS AND METHODS

2.1 Material and Equipment

The laboratory equipment utilized in this study included beakers, volumetric flasks, measuring pipettes, dropper pipettes, a pipette pump, an analytical balance, porcelain crucibles, a blender, a 60 mesh sieve, a pH indicator, filter cloth, filter paper, funnels, an oven, a desiccator, reaction tubes, cuvettes, and a visible-light spectrophotometer. The materials consisted of tea residue (tea dregs) as the biomass precursor, 4 M Sodium Hydroxide (NaOH) solution (250 mL), 10 ppm Methylene Blue (MB) solution (1 L), distilled water, and tap water.

2.2 Biosorbent Preparation

Initially, 100 grams of tea residue was oven-dried overnight. Once dried, the biomass was pulverized using a blender and sieved through a 60 mesh screen to ensure particle uniformity. Subsequently, 45 grams of the sieved tea residue was immersed in the NaOH solution until completely saturated. The mixture was then allowed to undergo stagnant impregnation at room temperature for 30 minutes. Following this, the mixture was filtered and washed repeatedly with tap water until a neutral pH (approximately 7) was achieved. The filtered residue was then dried in an oven to obtain the final biosorbent.

2.3 Biosorbent Analysis

The analysis of the processed material was divided into two primary methods: the determination of water content and the evaluation of its performance as a wastewater absorbent.

2.3.1 Determination of Water Content

The moisture content was determined gravimetrically. Five grams of the prepared biosorbent were weighed and dried in an oven at 105 °C until a constant weight was reached (approximately 1 hour). The samples were then placed in a desiccator to cool while maintaining a constant weight. Finally, the moisture content (MC) was calculated and expressed as a percentage (%).

2.3.2 Determination of Performance of Biosorbent as Wastewater

The performance of the biosorbent was evaluated by measuring the absorbance of Methylene Blue (MB) solutions using a visible-light spectrophotometer at a maximum wavelength λ_{max} of 670 nm. In this process, 5 grams of dry biosorbent were mixed with 100 mL of 10 ppm MB solution and allowed to react for a specific duration. Samples of 10 mL were collected and filtered using filter paper every 2 minutes for a total period of 10 minutes to monitor the concentration change over time.

3. RESULTS AND DISCUSSION

Biosorbents are characterized by their high porosity, which facilitates the adsorption process occurring both on the pore walls and across specific surface areas of the particles. Adsorption itself is a separation process where a fluid phase (adsorbate) is transferred to the surface of a solid adsorbent (biosorbent) due to unbalanced atomic or molecular attraction forces on the solid's surface [10].

In this study, the biosorbent was synthesized from tea residue biomass. The initial preparation involved grinding 100 grams of dry biomass and sieving it to 60 mesh to ensure particle uniformity. Subsequently, 45 grams of the processed biomass was immersed in 250 mL of 4M NaOH at room temperature for 30 minutes. The application of NaOH aims to chemically activate the biomass by dissolving certain organic components and removing impurities from the surface. As illustrated in Figure 1, the impregnated biomass was filtered and rinsed with water until a neutral pH (approximately 7) was achieved.

Figure 1. Filter Mixture

The washed residue was then oven-dried to obtain the final biosorbent, as shown in Figure 2. Post-drying analysis focused on calculating the yield and conversion of the produced material. Additionally, the moisture content was determined by weighing 5 grams of the biosorbent and drying it at 105 °C for approximately one hour until a constant weight was reached. Samples were stabilized in a desiccator prior to final weighing to determine the moisture percentage accurately.

Figure 2. Testing sample with spectrophotometer

Table 1. Yield of tea residue biosorbent after chemical activation

No.	Biomass Mass (grams)	Yield Biomass (%)	Biosorbent Water Content (%)
1.	100	32.61	4
2.	100	94.42	1.75
3.	100	41.4	6
4.	100	22.22	1.4

The adsorption performance was evaluated using a 10 ppm Methylene Blue (MB) solution. The initial and final absorbance values were monitored using a visible-light spectrophotometer at a maximum wavelength of 670 nm (Figure 3). In the batch experiment, 5 grams of the dry biosorbent were mixed with 100 mL of the MB solution. This mixing phase allows the biosorbent to bind MB molecules, resulting in a clarified filtrate. Samples of 10 mL were collected and filtered every 2 minutes for a duration of 10 minutes to analyze the kinetics of the process.

Figure 3. Testing Absorbance

Based on the experimental data, a biosorbent yield of 41.4% was achieved. The relationship between contact time and absorbance was characterized by the linear regression equation: $y = -0.0726x + 0.7294$. This negative slope indicates a consistent decrease in absorbance over time, confirming the successful removal of MB from the solution.

Table 2. Test Adsorption Methylene Blue Each Group

No	Time Adsorption			
	2 min	4 min	6 min	8 min
1.	0.045	0.043	0.041	0.039
2.	0.167	0.129	0.054	0.038
3.	0.592	0.466	0.318	0.115
4.	0.155	0.139	0.092	0.065

Furthermore, several critical factors influenced the biosorbent production and its efficiency:

1. Adsorbent Material Properties

   The removal capacity varies significantly depending on the polarity of the precursor material and the specific activation method utilized.

2. Particle Size

   A smaller particle diameter increases the total surface area available for adsorption, thereby enhancing the overall removal efficiency.

3. pH Levels

The pH of the solution is a vital parameter as it determines the degree of ionization. In this study, the optimal adsorption performance was observed within a pH range of 6–8.

4. Contact Time

Increased contact time generally enhances the sequestration capacity of the active sites, allowing for a more thorough binding of the adsorbate molecules.

4. CONCLUSION

The production of a functional biosorbent from tea residue was successfully conducted through a chemical activation process using 4 M NaOH. The synthesis yielded a final product of 41.4%, characterized by a 60 mesh particle size to maximize the available surface area for pollutant sequestration. The moisture content analysis and characterization further confirmed the stability of the tea-based biomass as a viable precursor for environmental remediation materials.

In terms of adsorption performance, the study demonstrated that tea-derived biosorbents are highly effective in removing Methylene Blue from aqueous solutions. Contrary to the initial observation, the data trends indicate that a longer contact time leads to a significant and consistent decrease in the absorbance values of the solution. This trend is quantitatively represented by the linear regression equation $y = -0.0726x + 0.7294$, where the negative slope confirms the progressive removal of dye molecules as they bind to the active sites of the biosorbent. These findings suggest that tea residue is an efficient, low-cost, and sustainable alternative for the treatment of industrial wastewater containing cationic dyes.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Mr. Cornelius Satria Yudha, S.T., M.T., and Ms. Himmah Sekar Eka Ayu Gustiana, S.T., M.Eng., for their invaluable guidance and mentorship throughout the Chemical Engineering Process II Practicum. Their technical expertise and insightful suggestions were instrumental in the successful completion of this research and the preparation of this manuscript. The authors also thank all parties who contributed to the implementation and success of this study.

AUTHOR CONTRIBUTION

Conceptualization, A.M. and A.S.; methodology, A.P.; software, R.E. and A.M.; validation, A.S. and A.P.; formal analysis, R.E.; investigation, A.P.; resources, A.M.; data curation, A.S. and R.E.; writing—original draft preparation, A.S.; writing—review and editing, A.M. and A.P.; visualization, A.M.; supervision, C.S. All authors have read and agreed to the published version of the manuscript.

REFERENCES

[1] S. A. Gunawan, "Utilization of Adsorbent from Corn Cob as Activated Carbon to Reduce Motor Vehicle Exhaust Emissions," *Journal of Materials Engineering*, 2020.

[2] L. R. Harimu, "Study on the Variation of NaOH and H_2SO_4 Concentration for Purifying Silica from Rice Husk Ash as Metal Ion Adsorbents," *Journal of Chemical Research*, vol. 6, no. 2, pp. 101-109, 2019.

[3] R. G. Muhajjalin, "Comparative Effectiveness of Black Tea and Green Tea Residues as Adsorbents for Cr(VI) Metal Ions," *Fullerene Journal of Chemistry*, vol. 6, no. 1, pp. 20-28, 2021.

[4] H. Setyarini, "Characterization of Tea Residue Adsorbents: A Comparison Between Non-Activated and Activated States," 2020.

[5] T. Wirawan, "Adsorption of Methylene Blue Using Activated Charcoal Derived from Empty Fruit Bunches (EFB)," vol. 21, no. 1, pp. 8-17, 2023.

[6] G. Crini, "Non-conventional low-cost adsorbents for dye removal: A review," *Bioresource Technology*, vol. 97, no. 9, pp. 1061-1085, 2006.

[7] M. A. Salleh et al., "Cationic and anionic dye adsorption by agricultural solid wastes: A comprehensive review," *Desalination*, vol. 280, no. 1-3, pp. 1-13, 2011.

[8] X. He et al., "Investigation of tea waste as a low-cost adsorbent for the removal of dyes from wastewater," *Journal of Cleaner Production*, vol. 171, pp. 1546-1554, 2018.

[9] M. J. Ahmed and S. K. Theydan, "Physical and chemical characteristics of agricultural waste-based adsorbents," *Journal of Environmental Chemical Engineering*, vol. 1, no. 4, pp. 1100–1109, 2013.

[10] M. Z. Siswarni, et al., "Adsorption of heavy metals and dyes using biomass-based materials," *Journal of Chemical Engineering and Industrial Technology*, 2017.