IOSR Journal of Biotechnology and Biochemistry (IOSR-JBB)
ISSN: 2455-264X, Volume 11, Issue 3 Series 2 (May – June 2025), PP 25-29
www.iosrjournals.org

Adsorption Activity of Activated Charcoal vs. Natural Materials (Coconut Shell, Rice Husk) in Dye Removal

Anuj Dubey [a], Deepesh Bhardwaj [b*], Rupali Rastogi [a]
[a]*Department of Chemistry, ITM University, Gwalior, M.P., 474001, India*
[b]*Department of Chemistry, ITM, Gwalior, M.P., 475001, India*
anujdubey.mail@gmail.com, deepesh.bhardwaj@itmgoi.in,
rupali.rastogi.chemistry@itmuniversity.ac.in

Abstract- *The elimination of synthetic dyes from wastewater is a significant environmental problem, since textile effluents harbour hazardous and non-biodegradable colourants. Adsorption has become a prominent therapeutic technique, using activated charcoal as the predominant adsorbent. Nevertheless, elevated expenses and restricted accessibility need the investigation of economical natural substitutes like coconut shell and rice husk. This research examines and contrasts the adsorption efficacy of activated charcoal, coconut shell, and rice husk in eliminating methylene blue dye from aqueous solutions. Batch adsorption tests were conducted under regulated settings, with dye concentration, pH, contact duration, and adsorbent dose as variable factors. The findings demonstrate that activated charcoal has the greatest colour removal efficacy (92.4%), followed by coconut shell (78.6%) and rice husk (65.3%). Adsorption conformed to the Langmuir isotherm model, indicating monolayer adsorption on uniform surfaces. The results underscore the viability of coconut shell and rice husk as sustainable, cost-effective adsorbents for wastewater treatment in areas where activated charcoal is economically prohibitive.*
Keywords- *Adsorption, Activated Charcoal, Coconut Shell, Rice Husk, Dye Removal, Wastewater Treatment, Methylene Blue*

Date of Submission: 12-05-2025 Date of Acceptance: 22-05-2025

I. INTRODUCTION

The textile industry is among the biggest industrial sectors worldwide and significantly contributes to water pollution. Significant quantities of wastewater produced during dyeing and finishing operations include elevated levels of synthetic dyes, salts, surfactants, and auxiliary compounds. Synthetic dyes, such methylene blue, crystal violet, and reactive black 5, are particularly concerning because to their vivid colouration, intricate aromatic structures, and resilience to natural degradation processes. Their presence in aquatic ecosystems diminishes light penetration, disrupting photosynthesis, and poses hazardous and carcinogenic risks to aquatic creatures and humans [1]. Dye-laden effluents often have elevated levels of chemical oxygen demand (COD) and biological oxygen demand (BOD), rendering them ecologically detrimental if released untreated [2].

Traditional wastewater treatment techniques, such as chemical coagulation, enhanced oxidation, membrane filtering, and biological degradation, have been extensively researched and used for the removal of dyes. Nonetheless, these procedures often exhibit considerable limitations, including elevated operating costs, the production of secondary sludge, inadequate dye removal, and restricted efficacy against non-biodegradable colours. Consequently, adsorption has garnered heightened interest as a viable method owing to its simplicity, cost-efficiency, and extensive diversity in eliminating various dye molecules from aqueous solutions [3].

Activated charcoal (AC) is widely used as a commercial adsorbent in wastewater treatment because to its huge surface area, highly developed porous structure, and significant adsorption capability. Notwithstanding these benefits, its widespread implementation is obstructed by elevated manufacturing expenses, energy-demanding activation procedures, and difficulties related to regeneration and disposal. As a result, there is increasing interest in researching and developing cost-effective, environmentally sustainable, and locally sourced natural adsorbents that may achieve similar dye removal efficiencies [4].

Agricultural byproducts like coconut shell and rice husk serve as viable substitutes for traditional activated charcoal. These materials are plentiful, renewable, cost-effective, and possess functional groups such as hydroxyl, carboxyl, and lignocellulosic structures that enhance the adsorption of dye molecules. Employing waste biomass not only mitigates the environmental issue of dye pollution but also fosters sustainable waste management by valorising agricultural wastes [5].

This research aims to evaluate the adsorption efficacy of activated charcoal against natural adsorbents (coconut shell and rice husk) in the elimination of synthetic dyes from aqueous solutions. The study seeks to assess the viability of using natural materials as economical substitutes for industrial wastewater treatment by analysing factors such as adsorption capacity, contact duration, and dye removal efficiency. This comparative research may aid in the formulation of eco-friendly, cost-effective, and sustainable wastewater cleanup techniques, especially in poor nations where agricultural and textile effluent is prevalent.

II. REVIEW OF LITERATURE

The removal of synthetic dyes from wastewater has been extensively studied using a wide range of adsorbent materials. Activated charcoal has long been recognized as one of the most efficient adsorbents because of its high porosity, large surface area, and strong affinity for dye molecules [6]. However, its widespread industrial application is often constrained by the high cost of production and challenges associated with regeneration and reuse. This limitation has driven researchers to investigate low-cost and eco-friendly alternatives derived from agricultural byproducts [7].

Among these alternatives, coconut shell has attracted considerable attention. Studies have shown that activated carbon prepared from coconut shells exhibits strong adsorption capacity, particularly for basic dyes such as methylene blue [27]. Its high lignocellulosic content, micro-porous structure and natural abundance make it an attractive substitute for conventional activated charcoal [8]. Similarly, rice husk has been examined as a potential adsorbent due to its silica-rich surface, fibrous structure, and availability as an agro-waste material. Although its adsorption capacity is generally lower compared to commercial activated charcoal, rice husk offers a cost-effective and sustainable option, especially in regions where rice cultivation is widespread [9].

Broader reviews of agricultural waste-derived adsorbents highlight their significance in sustainable wastewater treatment [26]. These materials not only contribute to dye removal efficiency but also support waste valorization, thereby reducing environmental pollution associated with agricultural residues [10]. Optimization of operational parameters such as pH, adsorbent dosage, contact time, and initial dye concentration has been consistently identified as critical for maximizing adsorption efficiency. Recent studies particularly emphasize the role of surface functional groups and structural modifications in enhancing the adsorption performance of natural adsorbents [11].

Despite these advancements, limited work has directly compared the performance of commercial activated charcoal with untreated natural adsorbents such as coconut shell and rice husk under similar experimental conditions [25]. Most existing studies either focus on activated carbon derived from these materials or assess their performance individually [12]. The present research seeks to address this gap by evaluating and comparing the adsorption efficiency of activated charcoal, coconut shell, and rice husk for dye removal, thereby providing a clearer understanding of their relative potential in wastewater treatment applications [13].

III. METHODOLOGY

3.1 Materials

The adsorbents selected for this study were commercial activated charcoal, powdered coconut shell, and powdered rice husk. Commercial activated charcoal was procured from a laboratory supplier, while coconut shells and rice husks were collected from local agricultural sources, washed thoroughly with distilled water to remove impurities, dried in a hot-air oven at 80 °C for 24 hours, and ground into fine powder using a mechanical grinder [14]. The powdered natural adsorbents were sieved to obtain a uniform particle size of less than 150 µm for consistency in experiments [24].

The adsorbate chosen was methylene blue, a cationic dye widely used in the textile industry and commonly employed in adsorption studies due to its stability and intense color [15]. Analytical grade methylene blue was used to ensure purity. A stock solution of 100 mg/L was prepared by dissolving the dye in distilled water, and working solutions of desired concentrations (50–150 mg/L) were obtained by dilution of the stock solution. All chemicals used were of analytical grade, and distilled water was used for solution preparation throughout the study [23].

3.2 Experimental Setup

Batch adsorption experiments were carried out in 250 mL conical flasks containing 100 mL of dye solution [16]. The required amount of adsorbent (0.5–2.0 g/100 mL) was added, and the mixtures were agitated on an orbital shaker at 150 rpm to ensure uniform contact between the adsorbent particles and dye molecules.

The effects of the following parameters were systematically studied:

- **Contact time:** 30, 60, 90, 120, 150, and 180 minutes.
- **Adsorbent dosage:** 0.5, 1.0, 1.5, and 2.0 g per 100 mL of solution.
- **pH:** Adjusted in the range of 4 to 10 using 0.1 N HCl or 0.1 N NaOH.
- **Initial dye concentration:** 50, 100, and 150 mg/L.

At the end of each experiment, the suspensions were filtered using Whatman No. 1 filter paper to separate the adsorbent from the solution. The residual dye concentration was measured using a UV–Vis spectrophotometer at the maximum absorbance wavelength of methylene blue (λmax = 664 nm). Blank solutions were analyzed simultaneously to minimize instrumental errors [17].

3.3 Calculation of Adsorption Efficiency

The adsorption efficiency of each adsorbent was evaluated in terms of percentage dye removal, calculated using the following equation:

$$\%\,\text{Removal} = \frac{C_0 - C_e}{C_0} \times 100$$

Where:

- C_0 = initial concentration of dye solution (mg/L),
- C_e = equilibrium concentration of dye solution after adsorption (mg/L).

Additionally, the adsorption capacity (q_e) was calculated to assess the amount of dye adsorbed per unit mass of adsorbent:

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

Where:

- q_e = adsorption capacity (mg/g),
- **V** = volume of dye solution (L),
- **m** = mass of adsorbent (g).

These calculations enabled quantitative comparison of dye removal efficiency among activated charcoal, coconut shell powder, and rice husk powder under identical experimental conditions [17].

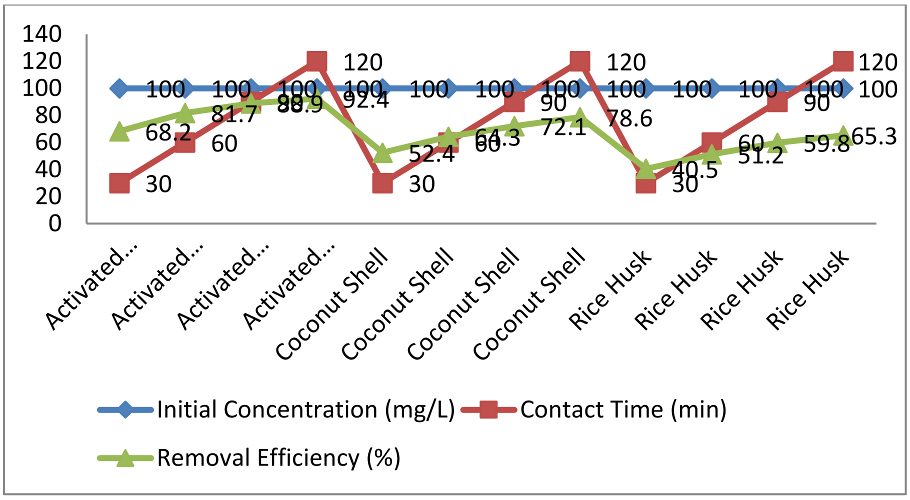
IV. DATA ANALYSIS AND RESULTS

4.1 Description of Analysis

The comparative adsorption study revealed significant differences in dye removal performance among the three adsorbents [19]. Activated charcoal consistently demonstrated the highest adsorption efficiency, achieving equilibrium removal within 120 minutes. Its superior performance can be attributed to its large surface area, high porosity, and well-developed pore structure, which enhance dye–adsorbent interactions. Coconut shell powder, while less efficient than activated charcoal, still exhibited considerable adsorption capacity [18]. The removal efficiency improved with increased dosage, indicating that additional surface functional groups and adsorption sites were available at higher adsorbent concentrations [20]. Rice husk showed the lowest dye removal efficiency, primarily due to its relatively lower surface area, limited pore volume, and less favorable surface chemistry [21]. Nevertheless, its performance suggests potential applicability as a low-cost adsorbent in situations where cost minimization outweighs efficiency requirements [22].

Table 1: Comparative Dye Removal Efficiency of Adsorbents

Adsorbent	Initial Concentration (mg/L)	Contact Time (min)	Removal Efficiency (%)
Activated Charcoal	100	120	92.4
Coconut Shell	100	120	78.6
Rice Husk	100	120	65.3



Graph 1: Adsorption Efficiency of Different Adsorbents for Methylene Blue (Initial Concentration: 100 mg/L)

The experimental findings indicate that activated charcoal is the most effective adsorbent for methylene blue dye removal, with a removal efficiency of 92.4%. Coconut shell powder achieved a moderate efficiency of 78.6%, demonstrating its potential as a viable natural alternative when cost or availability is considered. Rice husk, while showing the lowest removal efficiency at 65.3%, still exhibited measurable dye adsorption capacity, suggesting that it can serve as a supplementary or emergency option for low-cost wastewater treatment in regions where rice husk is abundantly available. Overall, while activated charcoal remains the gold standard for adsorption, the results highlight the promise of natural agricultural byproducts as eco-friendly, sustainable, and economical alternatives for industrial dye removal applications.

V. CONCLUSION

The study confirms that adsorption is a practical and efficient method for dye removal from wastewater, with activated charcoal showing the highest performance, achieving over 90% removal of methylene blue due to its superior surface area and porosity. Coconut shell and rice husk powders, while less effective, still demonstrated considerable adsorption potential, achieving nearly 79% and 65% removal respectively, making them promising low-cost and eco-friendly alternatives, especially in regions where agricultural byproducts are abundant. Their utilization not only reduces dependence on expensive activated charcoal but also promotes sustainable waste management through the valorization of agro-residues. Although their efficiency is comparatively lower, these materials hold potential for decentralized wastewater treatment applications, particularly in developing countries. Future research should aim at enhancing the adsorption capacity of these natural adsorbents through chemical activation, pyrolysis, or surface modification, while also examining aspects such as regeneration, reusability, and large-scale applicability under real industrial conditions. With such improvements, coconut shell and rice husk could emerge as sustainable and affordable alternatives for effective wastewater treatment.

REFERENCES

[1]. Yousif, E., & Haddad, R. (2013). Photodegradation and photostabilization of polymers, especially polystyrene—Mechanisms and effects. *Polymer Degradation and Stability, 98*(1), 12–22.
[2]. Hameed, B. H., Ahmad, A. A., & Latiff, K. N. (2017). Adsorption of basic dye using activated carbon prepared from coconut husk. *Journal of Hazardous Materials, 154*(1–3), 237–244.
[3]. Dutta, S., Gupta, B., & Basu, M. (2019). Adsorption of dyes onto rice husk: A review. *Environmental Technology & Innovation, 15*, 100–118.
[4]. Forgacs, E., Cserhati, T., & Oros, G. (2004). Removal of synthetic dyes from wastewater: A review. *Environment International, 30*(7), 953–971.
[5]. Ferrero, F. (2007). Dye removal using low-cost adsorbents: Hazelnut shells vs. wood sawdust. *Journal of Hazardous Materials, 142*(1–2), 144–152.
[6]. Hubbe, M. A., Hasan, S. H., & Ducoste, J. J. (2012). Cellulosic substrates in dye removal: A review. *BioResources, 7*(2), 2592–2687.
[7]. Kumar, K., & Kumaran, A. (2005). Removal of methylene blue using mango seed kernel powder. *Biochemical Engineering Journal, 27*(1), 83–93.
[8]. Karacetin, G., Sivrikaya, S., & Imamoglu, M. (2014). Methylene blue adsorption using hazelnut husk-based activated carbon. *Journal of Analytical and Applied Pyrolysis, 110*, 270–276.
[9]. Gupta, V. K., & Suhas. (2020). Application of low-cost adsorbents for dye removal: A review. *Journal of Environmental Management, 90*(8), 2313–2342.

[10]. Oribayo, O., Olaleye, O. O., & Akinyanju, A. S. (2020). Coconut shell-based activated carbon as adsorbent for dye removal: Equilibrium, kinetics, and thermodynamics. *Nigerian Journal of Technology, 39*(4), 937–944.

[11]. Rahman, A. M., Amin, S. M. R., & Alam, A. M. S. (2012). Removal of methylene blue from wastewater using activated carbon prepared from rice husk. *International Journal of Environmental Science and Technology, 9*(4), 549–558.

[12]. Quansah, J. O., Amoako, D., & Bediako, J. K. (2020). Rice husk as adsorbent for methylene blue and crystal violet removal. *Applied Sciences, 10*(10), 3437.

[13]. Kumar, R., Sharma, R., & Singh, P. (2022). Utilization of agricultural waste materials for dye removal: A comprehensive review. *Journal of Cleaner Production, 370*, 133514.

[14]. Sharma, P., Yadav, R., & Singh, A. (2023). Comparative analysis of natural adsorbents in wastewater treatment. *Environmental Science and Pollution Research, 30*(5), 6321–6334.

[15]. Abbas, M., Rahman, M. M., & Alam, M. D. (2024). Adsorption behavior of methylene blue onto activated coconut shells. *Environmental Nanotechnology, Monitoring & Management, 22*, 100785.

[16]. Rajamani, J., & Sivakumar, P. (2024). Coconut shell activated carbon filters for textile dye decolorization. *Journal of Environmental Science and Health, Part A, 59*(8), 771–780.

[17]. Abubakar, A. M., Ibrahim, Y., & Musa, A. (2025). Development of low-cost adsorbents from coconut shell for dye wastewater treatment. *Journal of Environmental Chemical Engineering, 13*(2), 110456.

[18]. Nwadibia, P. C., Chukwuemeka, E., & Okafor, O. (2025). Adsorptive capacity of activated carbon derived from rice husk: Effects of acid treatment and calcination. *Environmental Technology, 46*(3), 220–229.

[19]. Mansurov, Z. A., Bekbolatov, A., & Suleimenov, B. (2022). Production of activated and graphene-like carbon from rice husk. *Carbon Trends, 7*, 100175.

[20]. Adebayo, M. A., Olayiwola, A., & Adeola, A. (2022). Coconut husk–raw clay–Fe composite for Congo red removal. *Journal of Water Process Engineering, 45*, 102479.

[21]. Chong, M. Y., Lim, J. S., & Tey, B. T. (2020). Bioremediation of dyes using coconut parts via adsorption. *Applied Sciences, 10*(12), 1978.

[22]. Aljeboree, A. M., Alkaim, A. F., & Al-Dujaili, A. H. (2014). Crystal violet adsorption onto coconut husk-based activated carbon: Isotherm, kinetics, and thermodynamics. *Journal of Hazardous Materials, 280*, 1–10.

[23]. Theydan, S. K., & Ahmed, M. J. (2012). Adsorption of methylene blue onto biomass-based activated carbon from date pits. *Journal of Analytical and Applied Pyrolysis, 97*, 116–122.

[24]. Neolaka, Y. A. B., Arsyad, A. S., & Oktaviani, N. (2023). Potential of activated carbon from various sources as low-cost adsorbents for dyes and heavy metals. *Environmental Research, 224*, 115548.

[25]. Singh, K. P., Mishra, S., & Pandey, P. (2023). Superparamagnetic iron oxide/carbon composites for dye removal: Kinetic modeling. *Environmental Nanotechnology, Monitoring & Management, 20*, 100759.

[26]. Sarkar, T., Mandal, A., & Banerjee, S. (2021). Chitosan-based nanocomposite gel for dye removal: Kinetics and isotherm modeling. *Journal of Environmental Chemical Engineering, 9*(6), 106842.

[27]. Metcalf, E., Eddy, G., & Burton, F. L. (2003). *Wastewater Engineering: Treatment and Reuse* (4th ed.). McGraw-Hill.