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Preparation and Utilization of Rice Husk-Based Activation Carbon for Dye Removal

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Abstract: *The present study focuses on the preparation of activated carbon (AC) from rice husk waste, an abundant agricultural by-product, using chemical activation with potassium hydroxide (KOH). The developed rice husk activated carbon (RHAC-KOH) was utilized for the adsorptive removal of Bismarck Brown dye from aqueous solutions. The process involved two major steps—carbonization of rice husk at controlled temperature, followed by chemical activation using KOH to enhance surface porosity and adsorption efficiency. The prepared adsorbent was characterized by its surface texture, pore structure, and color removal efficiency, confirming successful activation. Batch adsorption experiments were conducted by varying parameters such as contact time, dye concentration, and adsorbent dosage. The adsorption data were analyzed using kinetic and isotherm models, and results indicated that the process followed the pseudo-second-order kinetic model, suggesting chemisorption as the dominant mechanism. The maximum adsorption efficiency of RHAC-KOH for Bismarck Brown dye was observed at neutral pH (≈7) and a contact time of 150 minutes, demonstrating the potential of rice husk-based activated carbon as a low-cost, eco-friendly, and effective adsorbent for dye- contaminated wastewater treatment.*

Keywords: Rice Husk , Activated Carbon , Adsorption , pH , Potassium hydroxide (KOH) , Response surface methodology , dye removal

I. INTRODUCTION

BACKGROUND ON WASTE WATER

In today's modern world, rapid industrialization, growth of chemical-based industries, and increasing dependence on synthetic materials have significantly increased the release of complex pollutants into water systems. Activated carbon has become one of the most important materials in pollution control and wastewater treatment because of its exceptional ability to remove contaminants from liquids and gases. It is no longer viewed as just a filtration medium; it has become a critical environmental material of the 21st century.

Activated carbon is a highly porous carbon-based substance made from materials like coconut shells, coal, wood, or agricultural wastes. It contains an extensive network of micro-, meso-, and macropores, giving it a very high surface area and strong adsorption capability. Modern activated carbon carries a wide range of surface functional groups that enable it to attract and capture pollutants such as dyes, heavy metals, pesticides, oils, phenolic compounds, and synthetic chemicals. Industrial effluents often contain toxic, non-biodegradable, or color- causing molecules that conventional biological treatment cannot remove completely. Activated carbon becomes essential in such cases due to its ability to adsorb even very low concentrations of contaminants.

If wastewater containing harmful chemicals and dyes is discharged without proper treatment, it can pollute groundwater and surface water, affect aquatic ecosystems, reduce light penetration, hinder photosynthesis, and cause severe health hazards to humans and animals. Activated carbon plays a crucial role in preventing such environmental damage. Because of its high adsorption efficiency, fast pollutant removal rate, and ability to work under a wide range of pH and temperature, activated carbon has become a trusted material for advanced treatment technologies.

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Introduction

Water pollution due to industrial and technological activities has become a serious environmental issue worldwide. Among various pollutants, textile dyes are one of the major contributors to water contamination. These dyes are highly stable, synthetic, and resistant to conventional wastewater treatment, causing reduced dissolved oxygen in water, toxicity to aquatic life, and potential risks to human health. Bismarck Brown dye, commonly used in textile industries, is one such pollutant that negatively impacts water quality and ecosystem balance.

Micropollutants, including pharmaceuticals, pesticides, personal care products, endocrine- disrupting compounds, and synthetic dyes, have become a major environmental concern due to their persistence and potential toxic effects even at trace concentrations. These contaminants enter aquatic systems through industrial discharge, agricultural runoff, and domestic wastewater, where conventional treatment plants often fail to remove them effectively because many micropollutants are chemically stable, biologically resistant, and present in extremely low concentrations. As a result, they remain in treated effluents and accumulate in surface water, groundwater, and sediments, posing risks to ecosystems and human health. Recent studies have highlighted the inefficiency of traditional methods such as activated sludge, sedimentation, and simple filtration for degrading micropollutants, leading to increasing interest in advanced and sustainable alternatives. Adsorption using low-cost bio-based materials, including rice husk–derived activated carbon and biochar, has gained significant attention as a promising approach due to its high surface area, tunable porosity, and cost- effectiveness (Biochar Review, 2023; Rice Husk Adsorbent Study, 2024). These materials offer an eco-friendly solution for capturing persistent micropollutants from wastewater and can complement existing treatment technologies to achieve higher removal efficiencies (Sustainable Adsorption Review, 2022; Agricultural Waste Adsorbents Study, 2023).

A wide range of wastewater treatment methods has been explored for removing synthetic dyes, including membrane filtration, ion exchange, and various advanced oxidation processes. However, many of these approaches are often costly, require sophisticated equipment, or generate toxic by-products, making them less suitable for large-scale dye-containing effluent treatment. As a result, increasing attention has shifted toward low-cost, sustainable, and biomass-derived adsorbents. Among these, rice husk and rice-husk-based activated carbon have emerged as promising materials due to their high silica content, porous structure, and strong adsorption capacity. Recent studies have demonstrated the effectiveness of rice husk, modified rice husk, and activated rice-husk biochar in removing heavy metals and synthetic dyes from wastewater (Rice Husk-Based Adsorbents Review, 2023; Activated Rice Husk Biochar, 2024; Phosphoric-Acid Modified Rice Husk, 2018). Additionally, rice-husk-derived adsorbents have shown excellent performance in removing methylene blue and reactive dyes, confirming their potential as cost-effective and environmentally friendly alternatives to conventional treatment methods (Springer Methylene Blue Study, 2025; Shrimp-Shell + Rice Husk Composite Adsorbent, 2024). Therefore, rice-husk-based materials represent a sustainable solution for wastewater treatment, supporting both pollution control and agricultural waste utilization

Rice husk, an agricultural byproduct obtained during rice milling, contains about 15–20% silica and 35–40% carbon. Due to its high carbon content, availability, and low cost, rice husk has emerged as an excellent raw material for preparing activated carbon. Converting rice husk into activated carbon not only provides a sustainable method of waste utilization but also addresses environmental concerns associated with agricultural waste disposal.

Activated carbon derived from rice husk can be used in water treatment to remove dyes, heavy metals, and organic pollutants; in air purification to adsorb harmful gases and odors; and in industrial processes such as sugar and oil decolorization and as a catalyst support. The development of rice husk-based activated carbon is therefore both economically and environmentally significant, providing a renewable, eco-friendly, and efficient adsorbent material.

II. MATERIALS AND METHODS

Materials

Rice husk waste was collected from a farm in Karnataka. Whatman No. 1 filter paper, potassium hydroxide (KOH), and Bismarck Brown dye were purchased from Omkar Traders, Mumbai, India. Aqueous Bismarck Brown dye solutions were prepared using double-distilled water. All chemicals and reagents used in the study were of analytical grade and were utilized without further purification.

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Collection of Rice Husk waste

The RH was collected from farm in Humnabad in Bidar District, Karnataka, India, and washed carefully with double distilled water to remove contaminant particles, dried at 80- 90◦C for 2-3 hours.

Preparation of Rice Husk

Activated carbon (AC) from RH was prepared by chemical activation with Potassium hydroxide (KOH) according to with slight changes. Briefly, 33 gms RH was impregnated with 133gms KOH, then incubated at room temperature for 24 h, dried an oven-air at 80- 90◦C for 2-3 h. After impregnation, the pretreated RH was placed in a crucible and then carbonized at 400 ◦C in a muffle furnace for 4 hrs under nitrogen (N2) atmosphere. After activation, the achieved RH was made to powder and then washed with double distilled water until pH 7.0 and dried in hot air-oven at 60-70 ◦C. The AC was grounded and stored in a sealed container until future use.

Characterization of RH

The characterization of rice husk is essential to understand its structural, chemical, and functional properties, especially when it is used as an adsorbent or raw material in environmental applications. Rice husk is a lignocellulosic agricultural waste composed mainly of cellulose, hemicellulose, lignin, and a significant amount of silica. To evaluate its suitability for dye removal and other adsorption studies, different analytical techniques are employed to determine its functional groups, surface morphology, elemental composition, and mineral content. In this study, rice husk was characterized using Fourier Transform Infrared Spectroscopy (FTIR) to identify chemical functional groups, along with additional observations of its physical and structural features. The results obtained from these characterization methods help in understanding the adsorption behaviour of rice husk and confirm its potential as a low-cost and environmentally friendly adsorbent.

The FTIR spectrum of the rice husk sample reveals the characteristic functional groups associated with its lignocellulosic and silica-rich composition. A prominent absorption band observed around 3174 cm^{-1} corresponds to O–H stretching vibrations, which are typically present in cellulose, hemicellulose, and residual moisture, confirming the natural plant-based structure of the husk. The peak at 1572 cm^{-1} indicates C=C stretching in aromatic rings, representing the lignin component of the biomass. Another noticeable band at 1368 cm^{-1} is attributed to C–H bending vibrations, further supporting the presence of cellulose and hemicellulose. One of the most significant features of the spectrum is the strong absorption near 1005 cm^{-1}, which corresponds to Si–O–Si stretching vibrations, clearly confirming the presence of silica (SiO_2)—a major component of rice husk known for its high ash and mineral content. Additionally, the region between 522–660 cm^{-1} shows characteristic Si–O bending peaks, providing further evidence of silica within the sample. Overall, the FTIR analysis demonstrates that the rice husk contains cellulose, hemicellulose, lignin, and a substantial amount of silica, aligning well with the known chemical composition of rice husk and confirming the authenticity of the sample used in the study.

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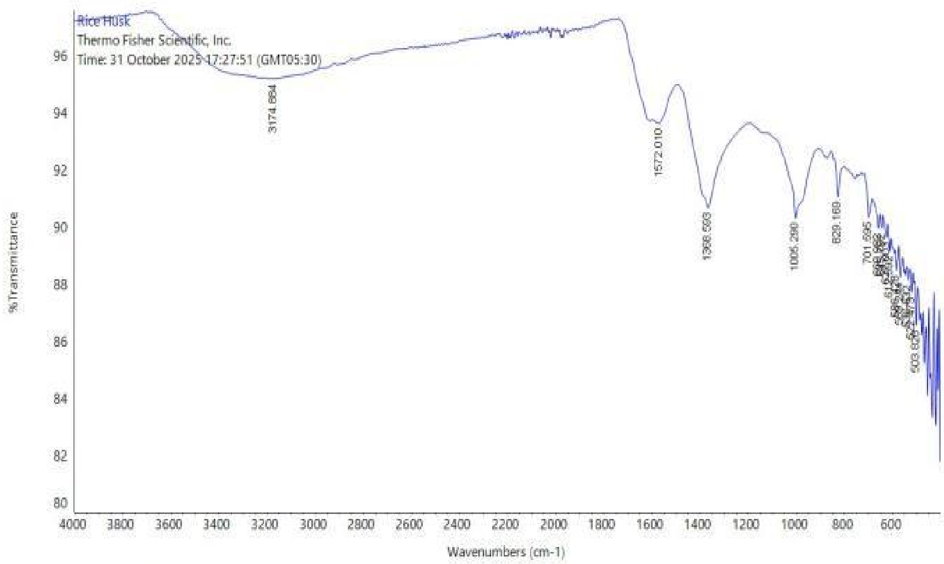
Report created: 31-10-2025 17:29 (GMT05:30)

Rice Husk



Title: Rice Husk

Measurement date: 31-10-2025 17:27:51

Number of sample scans: 16

Number of background scans: 10

Instrument Serial: BHT2510163

Smart accy: B122111

Model: Nicolet Summit X

Source: IR

Detector: DTGS KBr

Smart Accessory Title: Everest ATR

Smart Accessory ID: B122111

Crystal type: : None

Beamsplitter: KBr

Sample spacing: 1.0

Digitizer bits: 24

Optical velocity: 0.4747

Aperture: 100.0

Sample gain: 1.0

High pass filter: 20.0

Low pass filter: 11000.0

Comments: None

Regions:

Region 1: 3978.34-501.15

Threshold: 97.427

Sensitivity: 50.000

Position	Intensity
503.826	86.564
522.473	87.707
536.632	88.133
569.244	88.239
586.428	88.480
612.592	89.146
627.003	89.636
645.792	89.944
660.982	89.947
701.595	90.337
829.169	91.050
1005.290	90.312
1368.593	90.671
1572.010	93.605
3174.884	95.166

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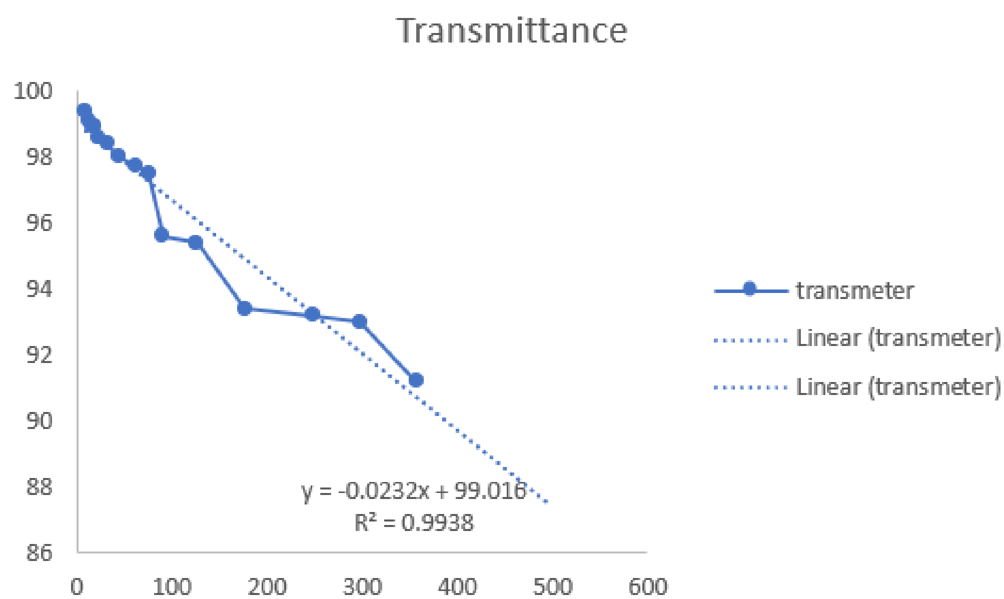
III. RESULT AND CALCULATION

Concentration	Transmittance
500	
357.142	91.2
297.619	93
248.015	93.2
177.154	93.4
126.5387	95.4
90.3847	95.6
75.32	97.5
62.76721	97.7
44.833	98
32.024	98.4
22.8743	98.6
19.061	98.9
15.8849	98.9
13.2374	99.1
9.455	99.4



Interpretation of Transmittance vs. Concentration for Activated Carbon Adsorption of Bismarck Brown Dye

Figure X shows the relationship between dye concentration and optical transmittance of Bismarck Brown solutions following treatment with activated carbon. As the dye concentration increased, a clear decrease in transmittance was observed. This inverse relationship is consistent with the Beer–Lambert law, which states that increasing chromophore concentration results in greater light absorption and consequently lower transmittance.

The linear regression applied to the dataset generated the equation:

$$Y = -0.0232X + 99.016$$

with a coefficient of determination (R2=0.9386) The high R2 value indicates strong linearity between dye concentration and the amount of light transmitted, confirming that optical measurements reliably reflect changes in dye concentration within the tested range.

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At lower concentrations (<100–150 mg/L), transmittance remained relatively high, indicating that activated carbon effectively removed a substantial portion of the dye. However, as initial concentration increased, a more pronounced decline in transmittance was observed. This suggests reduced removal efficiency at higher concentrations, likely due to progressive saturation of adsorption sites on the activated carbon surface. The overall downward trend in transmittance therefore reflects not only the intrinsic optical behavior of the dye but also the decreasing availability of active adsorption sites at elevated dye loads.

These results demonstrate that spectrophotometric transmittance measurements provide a reliable indicator of adsorption performance and confirm that activated carbon efficiently removes Bismarck Brown dye at lower concentrations, with diminishing efficiency as concentration rises. This trend is consistent with typical adsorption behavior of organic dyes onto porous carbons, where active site saturation governs removal capacity at higher solute concentrations.

RESULT

• EQUATION

$Y = -0.02332X+99.016$

$R^2 = 0.9386$

CALCULATION (EXAMPLE)

$Y = -0.02332X+99.016$

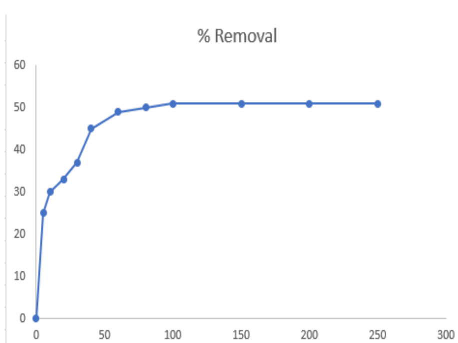
$Y= -0.02332*99.2+99.016$

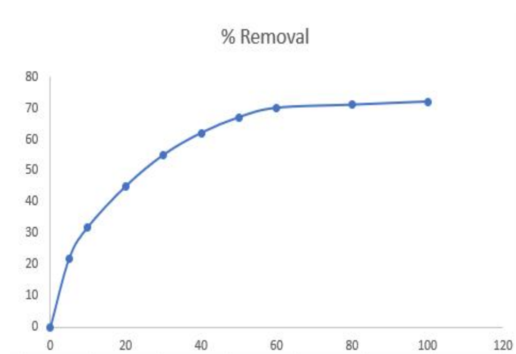
$Y= 96.702656$

RESULT

SR NO	TIME	READING	Y
1	INITIAL	99.5	96.7026
2	1	97.6	96.7399
3	2	98	96.7306
4	3	98.3	96.7236
5	4	98.6	96.7166
6	5	98.8	96.7119
7	6	99	96.7073

higher initial dye concentrations provide more available dye molecules for adsorption onto the activated carbon surfaces, resulting in increased adsorption capacities. This phenomenon is consistent with the Langmuir isotherm model, where higher initial concentrations typically lead to higher adsorption capacities until a saturation point is reached.





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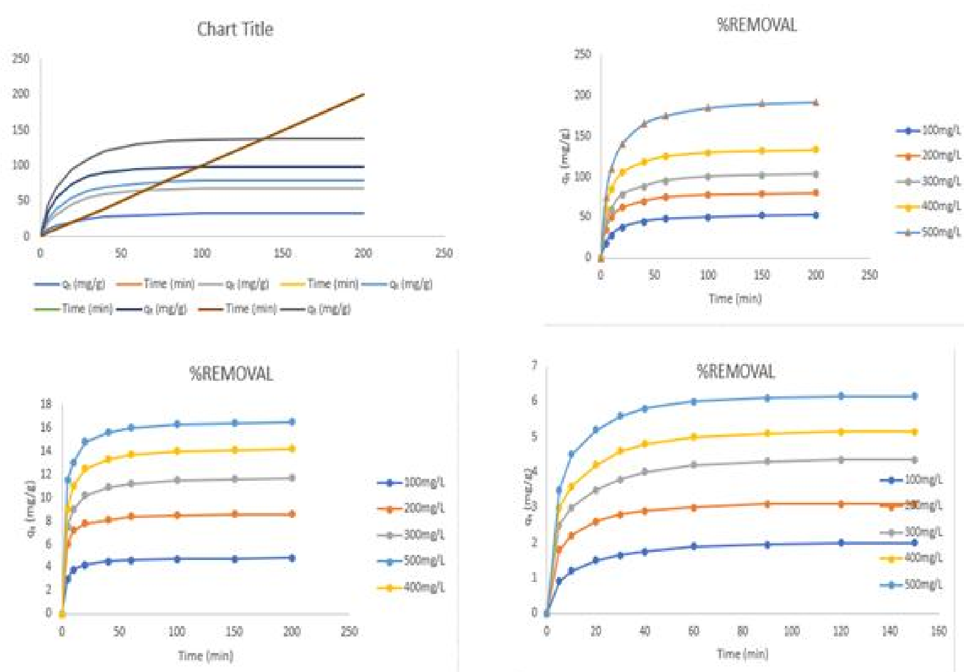

Results and Discussion

Effect of Contact Time on BBR Dye Adsorption

The adsorption of Bismarck Brown R (BBR) dye onto KOH-activated rice husk carbons (AC- 55 and AC-65) as a function of contact time is presented in Fig. 4 (a) and (b). A rapid increase in adsorption was observed during the initial period, followed by a gradual leveling off as equilibrium was approached.

• AC-55 reached equilibrium within 120–180 min.

• AC-65 achieved equilibrium faster, within 90–150 min.

The shorter equilibrium time of AC-65 can be attributed to its higher surface area and better- developed pore structure, which allow faster diffusion of dye molecules and more efficient utilization of active sites.

Effect of Initial Dye Concentration

Figure 4(c) and (d) illustrate the effect of initial BBR concentration on adsorption capacity. Increasing the dye concentration from 100 to 500 mg L^{-1} led to a significant increase in adsorption:

• AC-55: 41.93 → 126.55 mg g^{-1}

• AC-65: 47.30 → 173.07 mg g^{-1}

This demonstrates that higher initial concentrations provide a greater driving force for mass transfer and that AC-65 consistently exhibits higher capacity due to its more favorable surface properties. These results highlight the importance of considering initial dye concentration when designing adsorption systems using KOH-activated rice husk carbon.

Effect of Contact Time on Zn^{2+} Adsorption

Figures 4(e) and (f) show Zn^{2+} adsorption over time. Equilibrium times differed between the two materials:

• AC-55: equilibrium at 135 min

• AC-65: equilibrium at 75 min

Based on these observations, contact times of 165 min for AC-55 and 105 min for AC-65 were used in subsequent experiments to ensure equilibrium. The faster kinetics of AC-65 indicate enhanced surface reactivity and a more accessible pore network for Zn^{2+} adsorption.

Effect of Initial Zn^{2+} Concentration

Figures 4(g) and (h) show that increasing the Zn^{2+} concentration (10–50 mg L^{-1}) increased the adsorption capacity for both carbons:

- AC-55: equilibrium reached within 90 min at 10 mg L^{-1} and 120–165 min at higher concentrations
- AC-65: equilibrium within 60–105 min across all concentrations

The enhanced adsorption at higher concentrations is due to increased driving force and interaction between Zn^{2+} ions and oxygen-containing surface groups (–OH, $–COO^-$, $–O^-$) on the activated carbon. AC-65 exhibited faster adsorption and higher capacity, highlighting its efficiency for heavy-metal removal.

Summary

- AC-65 consistently shows faster equilibrium times and higher adsorption capacities than AC-55 for both BBR dye and Zn^{2+} ions.
- Adsorption capacity increases with higher initial pollutant concentrations.
- KOH-activated rice husk carbon is effective for removing both organic dyes and metal ions, demonstrating potential for practical wastewater treatment applications

IV. CONCLUSION

The present study successfully demonstrated the preparation and application of activated carbon derived from rice husk for the removal of Bismarck Brown dye from wastewater. Rice husk, an abundant agricultural by-product, proved to be an excellent low-cost and eco-friendly precursor for activated carbon production. Through a two-step process involving carbonization and chemical activation using KOH, the rice husk was effectively converted into a highly porous and adsorptive material. The activation process significantly enhanced the surface area, pore volume, and functional groups, improving the material's ability to adsorb dye molecules from aqueous solutions.The batch adsorption experiments, analyzed using a UV–Vis spectrophotometer, confirmed that the prepared activated carbon efficiently removed Bismarck Brown dye from water. The reduction in absorbance indicated a high adsorption efficiency and strong interaction between dye molecules and the activated carbon surface. This project highlights that agro-waste–based adsorbents like rice husk activated carbon offer a sustainable, cost-effective, and environmentally friendly alternative to conventional methods of wastewater treatment. The method not only helps in managing agricultural waste but also provides a valuable solution to industrial dye pollution, reducing environmental hazards and protecting aquatic ecosystems.

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