

UV–Visible Spectrophotometric Evaluation of Activated And Pristine Cow Dung Bio-Adsorbents For Dye Removal

Sumitra^{1*}, Kavita Patel², Hemprakash³, Kshitij Kumar Gupta⁴, Vidyadhar Pradhan⁵, Naresh Chouhan⁶, Kasak Bhargav⁷

^{1*} Department of Chemistry, O.P. Jindal University, Raigarh, (C.G.) 496109.

² Department of Chemistry, O.P. Jindal University, Raigarh, (C.G.) 496109.

³ Department of Physics, Govt. B.S.D. College Kunkuri, Jashpur, (C.G.) 496225.

⁴ Department of Chemistry, MATS University Raipur, (C.G.) 492004.

⁵ Department of Chemistry, Govt. L. P. P. PG College, Sarangarh (C.G.) 496445.

⁶ Department of Chemistry, Block Education Office, Duldula, Jashpur, (C.G.) 496334.

⁷ Department of Chemistry, O.P. Jindal University, Raigarh, (C.G.) 496109.

*Corresponding author: sumitra.bai@opju.ac.in

Abstract

The discharge of dye-containing wastewater from textile, printing, paper, and allied industries poses a significant environmental challenge due to the persistence and toxicity of synthetic dyes. The development of low-cost, eco-friendly, and sustainable adsorbents has become an important strategy for wastewater remediation. In the present study, pristine cow dung charcoal (CDC) and phosphoric acid-activated cow dung charcoal (ACDC) were investigated as bio-adsorbents for the removal of four synthetic dyes, namely Methyl Orange (MO), Methyl Red (MR), Thymol Blue (TB), and Eriochrome Black T (EBT), from aqueous solutions. The prepared adsorbents were characterized using X-ray diffraction (XRD) to investigate their structural characteristics. Adsorption performance was evaluated using UV–Visible spectrophotometry under optimized experimental conditions. The reduction in absorbance after adsorption confirmed the removal of dye molecules from aqueous media. Activated cow dung charcoal exhibited higher adsorption efficiency than pristine cow dung charcoal for all investigated dyes. The highest removal efficiency was observed for Eriochrome Black T, followed by Methyl Orange, Thymol Blue, and Methyl Red. The enhanced adsorption performance of ACDC may be attributed to the development of additional active adsorption sites and changes in the surface characteristics induced by phosphoric acid activation. The findings demonstrate that activated cow dung charcoal is an inexpensive, renewable, and environmentally sustainable adsorbent with considerable potential for wastewater treatment applications. This study further highlights the conversion of agricultural waste into value-added adsorbent materials and supports sustainable circular-economy approaches for industrial wastewater management.

Keywords: Cow dung charcoal; Activated cow dung charcoal; UV–Visible spectrophotometry; X-ray diffraction (XRD); Adsorption; Synthetic dyes; Sustainable wastewater treatment; Bio-adsorbent.

1. Introduction

The rapid growth of industrialization has significantly increased the discharge of dye-containing wastewater into natural water bodies. Industries including textiles, leather, paper, printing, cosmetics, food processing, and pharmaceuticals consume large quantities of synthetic dyes during manufacturing processes[1][2]. It is estimated that more than 700,000 tons of synthetic dyes are produced annually worldwide, and approximately 10–15% of these dyes are released into aquatic environments during manufacturing and processing[3]. The presence of these colored pollutants reduces light penetration, inhibits photosynthesis, decreases dissolved oxygen levels, and adversely affects aquatic ecosystems. Moreover, several synthetic dyes exhibit toxic, mutagenic, and carcinogenic properties, posing serious risks to both environmental and human health[4][5][6]. Among the various wastewater treatment technologies, adsorption has emerged as one of the most efficient, economical, and environmentally friendly techniques for dye removal. Compared with membrane filtration, coagulation, advanced oxidation, and biological treatment, adsorption offers high removal efficiency, simple operation, minimum sludge generation, and relatively low operating costs[7][8]. Activated carbon is widely recognized as the most effective adsorbent; however, its high production cost and regeneration requirements have encouraged researchers to explore alternative low-cost adsorbents derived from agricultural and biological wastes[9][10].

Agricultural waste materials have attracted considerable attention because of their abundance, renewability, biodegradability, and low environmental impact. Among these materials, cow dung represents one of the most readily available biomass resources in India[1][11]. After thermal treatment, cow dung ash contains porous mineral phases and surface functional groups capable of interacting with dye molecules through electrostatic attraction, hydrogen bonding, pore filling, and surface complexation[5][12]. Chemical activation using

phosphoric acid further enhances these properties by increasing the number of accessible adsorption sites and improving pore development, thereby enhancing adsorption performance[13].

Synthetic dyes such as Methyl Orange (MO), Methyl Red (MR), Thymol Blue (TB), and Eriochrome Black T (EBT) are extensively used in textile dyeing, analytical laboratories, printing, and chemical industries. Their stable aromatic structures make them resistant to natural degradation, allowing them to persist in aquatic environments for prolonged periods[14]. Therefore, the development of inexpensive and sustainable adsorbents capable of efficiently removing these dyes is an important research priority[1][15].

In the present study, the adsorption performance of pristine cow dung charcoal (CDC) and phosphoric acid-activated cow dung charcoal (ACDC) was comparatively investigated using UV–Visible spectrophotometric analysis[16]. The reduction in absorbance after adsorption was used to evaluate dye removal efficiency[17]. The study provides a sustainable approach for converting agricultural waste into value-added adsorbent materials suitable for wastewater treatment and contributes to the development of environmentally friendly remediation technologies[18].

2. Literature Review

The contamination of water resources by synthetic dyes has become a major environmental concern due to rapid industrialization and urbanization. Textile, leather, paper, pharmaceutical, cosmetic, and food-processing industries discharge large quantities of colored effluents into aquatic environments[19]. These dyes possess complex aromatic molecular structures, making them highly resistant to biodegradation and conventional wastewater treatment processes. Their persistence in water reduces sunlight penetration, inhibits photosynthesis, decreases dissolved oxygen levels, and adversely affects aquatic organisms. Furthermore, many synthetic dyes exhibit toxic, mutagenic, and carcinogenic properties, thereby posing significant risks to both environmental and public health[20].

Among the various wastewater treatment technologies, adsorption has emerged as one of the most promising methods because of its operational simplicity, high efficiency, economic feasibility, and ability to remove pollutants even at low concentrations[21]. Commercial activated carbon is considered the benchmark adsorbent; however, its high production and regeneration costs have motivated researchers to explore inexpensive, renewable, and environmentally sustainable alternatives derived from agricultural and industrial wastes[22].

Recently, biomass-derived adsorbents such as rice husk, coconut shell, sugarcane bagasse, sawdust, banana peel, fly ash, and cow dung have gained considerable attention because of their low cost, biodegradability, and wide availability[20]. Among these materials, cow dung is particularly attractive in developing countries due to its abundance and renewable nature. Thermal conversion of cow dung into ash produces porous inorganic materials capable of adsorbing various organic pollutants from wastewater[23]. Chemical activation further improves adsorption efficiency by increasing surface area, pore volume, and the availability of active adsorption sites[12].

Several researchers have reported that phosphoric acid activation significantly enhances the adsorption performance of biomass-derived adsorbents[6]. Acid activation removes impurities, develops microporous structures, and introduces oxygen-containing functional groups responsible for stronger interactions between dye molecules and adsorbent surfaces[7]. Consequently, activated biomass generally exhibits substantially higher adsorption capacity than untreated materials[24].

UV–Visible spectrophotometry remains one of the most reliable analytical techniques for evaluating dye adsorption because it provides rapid, accurate, and non-destructive determination of dye concentration[22][25]. The decrease in absorbance before and after adsorption directly reflects the removal efficiency of adsorbents. Comparative studies involving multiple dyes provide valuable information regarding adsorption selectivity and interaction mechanisms[25][24].

Although numerous studies have investigated activated carbon and agricultural wastes for wastewater treatment, comparatively limited information is available regarding the adsorption behaviour of activated and pristine cow dung charcoal toward different synthetic dyes under identical experimental conditions[21][12]. Therefore, the present investigation aims to compare the adsorption performance of normal cow dung ash and phosphoric acid-activated cow dung ash using UV–Visible spectrophotometric analysis[23]. The study contributes to the development of sustainable, low-cost bio-adsorbents for wastewater remediation while promoting agricultural waste valorization within the framework of a circular economy[20].

Research Gap

Despite significant progress in biomass-based adsorbents, very few studies have systematically compared activated and pristine cow dung ash for the simultaneous removal of multiple synthetic dyes using UV–Visible spectrophotometric evaluation. Most published studies focus on a single dye or rely on expensive characterization techniques. The present work addresses this gap by providing a comparative evaluation of dye removal efficiency using an inexpensive and sustainable bio-adsorbent, highlighting its potential application in wastewater treatment.

3. Materials and Methods

3.1 Materials

Fresh cow dung was collected from a local dairy farm in Raigarh, Chhattisgarh, India. Analytical-grade phosphoric acid (H_3PO_4), Methyl Orange (MO), Methyl Red (MR), Thymol Blue (TB), and Eriochrome Black T (EBT) were used without further purification. All aqueous solutions were prepared using distilled water.

3.2 Preparation of Cow Dung Ash

The collected cow dung was washed to remove unwanted impurities and air-dried for three days. The dried biomass was transferred into a porcelain crucible and carbonized in a muffle furnace at 500°C for 4 h. After cooling to room temperature, the obtained charcoal was ground into a fine powder, sieved through a $100\ \mu\text{m}$ mesh, and stored in airtight containers. This material was designated as Cow Dung charcoal (CDC).

3.3 Preparation of Activated Cow Dung Charcoal

Ten grams of prepared cow dung charcoal was mixed with phosphoric acid solution and continuously stirred for one hour. The slurry was allowed to stand for 24 h to ensure complete activation. The activated material was repeatedly washed with distilled water until neutral pH was obtained. Finally, the sample was dried in a hot-air oven at 100°C for 5 h and preserved in airtight containers. The activated material was designated as Activated Cow Dung charcoal (ACDC).

3.4 Preparation of Dye Solutions

Individual stock solutions ($1000\ \text{mg L}^{-1}$) of Methyl Orange, Methyl Red, Thymol Blue, and Eriochrome Black T were prepared by dissolving the required amount of dye in distilled water. Working solutions of $10\ \text{mg L}^{-1}$ were freshly prepared by appropriate dilution before each adsorption experiment.

3.5 Batch Adsorption Experiments

Batch adsorption experiments were performed in 100 mL conical flasks containing 50 mL dye solution and 0.10 g adsorbent. The mixtures were agitated at 150 rpm for 60 min at room temperature ($25 \pm 2^\circ\text{C}$) under near-neutral pH conditions. After adsorption, the suspensions were filtered through Whatman filter paper and the filtrates were analyzed using UV–Visible spectrophotometry.

3.6 UV–Visible Spectrophotometric Analysis

The residual dye concentration was determined using a UV–Visible spectrophotometer within the wavelength range of 400–600 nm. Maximum absorbance values (λ_{max}) were recorded for each dye before and after adsorption. A reduction in absorbance was considered evidence of dye removal from aqueous solution.

3.7 Adsorption Efficiency

The percentage removal was calculated using:

where:

A_0 = Initial absorbance

A_e = Final absorbance after adsorption

The adsorption capacity was calculated using:

where:

C_0 = Initial dye concentration (mg L^{-1})

C_e = Equilibrium concentration (mg L^{-1})

V = Volume of solution (L)

m = Mass of adsorbent (g)

Statistical Analysis

All adsorption experiments were performed under identical operating conditions. The obtained UV–Visible data were processed using Microsoft Excel. Comparative graphs were generated to evaluate the adsorption performance of normal and activated cow dung charcoal toward different synthetic dyes.

4. Results and Discussion

4.1 Comparative UV–Visible Spectral Analysis

Table 1. Experimental Conditions for Adsorption Studies

Parameter	Methyl Orange (MO)	Thymol Blue (TB)	Methyl Red (MR)	Eriochrome Black T (EBT)
Initial dye concentration (mg/L)	10	10	10	10
Volume of dye solution (mL)	50	50	50	50
Adsorbent dose (g)	0.10	0.10	0.10	0.10
Contact time (min)	60	60	60	60
Agitation speed (rpm)	150	150	150	150
Temperature (°C)	25 ± 2	25 ± 2	25 ± 2	25 ± 2
pH	7.0	7.0	7.0	7.0
Wavelength range scanned (nm)	400–600	400–600	400–600	400–600
Maximum absorption wavelength, λ_{max} (nm)	464	435	520	535

Table 2. UV–Visible Spectral Data Before Adsorption

Wavelength (nm)	MO Absorbance	TB Absorbance	MR Absorbance	EBT Absorbance
400	0.706	0.706	1.051	1.571
420	0.686	0.686	1.021	1.557
440	0.669	0.669	0.998	1.519
460	0.654	0.654	0.978	1.453
480	0.64	0.64	0.959	1.342
500	0.63	0.63	0.938	1.23
520	0.622	0.622	0.917	1.151
540	0.617	0.617	0.896	1.116
560	0.612	0.612	0.876	1.094
580	0.606	0.606	0.857	0.606
600	0.597	0.597	0.838	1.049

Table 3. UV–Visible Spectral Data After Adsorption Using Normal charcoal

Wavelength (nm)	MO Absorbance	TB Absorbance	MR Absorbance	EBT Absorbance
400	0.474	0.54	0.925	0.706
420	0.456	0.521	0.891	0.686
440	0.439	0.507	0.862	0.669
460	0.423	0.494	0.832	0.654
480	0.409	0.483	0.805	0.64
500	0.397	0.475	0.783	0.63
520	0.389	0.469	0.763	0.622
540	0.385	0.467	0.75	0.617
560	0.381	0.464	0.736	0.612
580	0.376	0.46	0.722	0.606
600	0.369	0.453	0.705	0.597

Table 4. UV–Visible Spectral Data After Adsorption Using Activated charcoal

Wavelength (nm)	MO Absorbance	TB Absorbance	MR Absorbance	EBT Absorbance
400	0.229	0.302	0.540	0.540
420	0.25	0.279	0.521	0.521
440	0.252	0.262	0.507	0.507
460	0.234	0.248	0.494	0.494
480	0.187	0.236	0.483	0.483

500	0.14	0.229	0.475	0.475
520	0.122	0.224	0.469	0.469
540	0.116	0.223	0.467	0.467
560	0.11	0.223	0.464	0.464
580	0.074	0.222	0.460	0.460
600	0.055	0.218	0.453	0.453

The adsorption performance of pristine cow dung charcoal (CDC) and activated cow dung charcoal (ACDC) was evaluated by monitoring the reduction in UV–Visible absorbance of four synthetic dyes, namely Methyl Orange (MO), Thymol Blue (TB), Methyl Red (MR), and Eriochrome Black T (EBT). A considerable decrease in absorbance was observed after adsorption, confirming the successful removal of dye molecules from aqueous solution.

Among the investigated adsorbents, activated cow dung ash consistently exhibited greater dye removal than untreated charcoal. The enhanced adsorption behaviour may be attributed to the increased number of active adsorption sites created during phosphoric acid activation, resulting in improved interaction between dye molecules and the adsorbent surface.

4.2 Adsorption of Methyl Orange

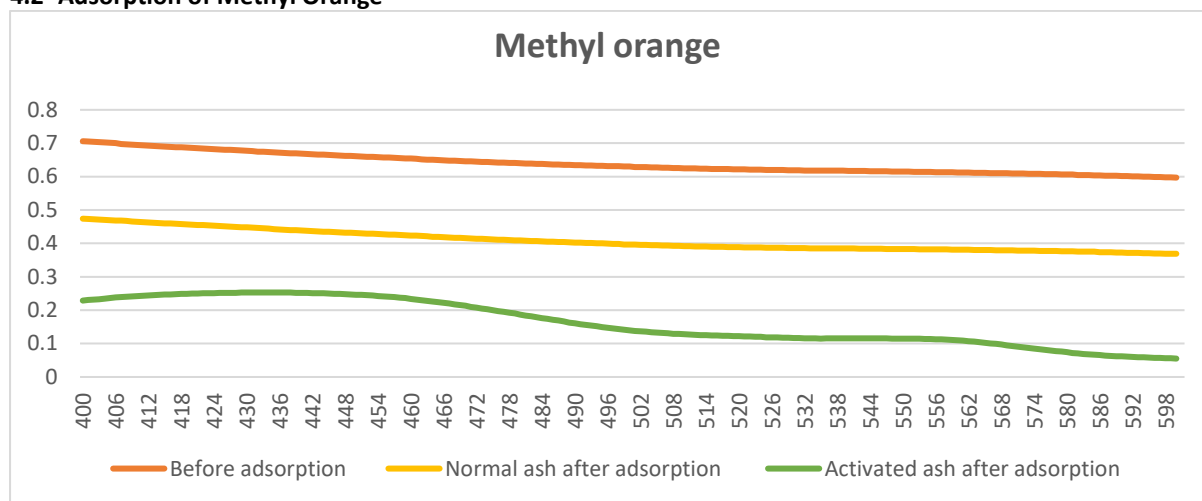


Figure 1: Methyl Orange (MO)

The initial absorbance of Methyl Orange decreased substantially after adsorption with both adsorbents. However, activated cow dung charcoal showed significantly higher adsorption efficiency than untreated ash. The percentage removal increased from 32.86% using normal ash to 64.16% after chemical activation.

The remarkable improvement indicates that phosphoric acid activation enhanced the adsorption characteristics of cow dung charcoal by increasing pore accessibility and available adsorption sites. Electrostatic attraction and hydrogen bonding between Methyl Orange molecules and activated ash surface may have contributed to the improved removal efficiency.

4.3 Adsorption of Thymol Blue

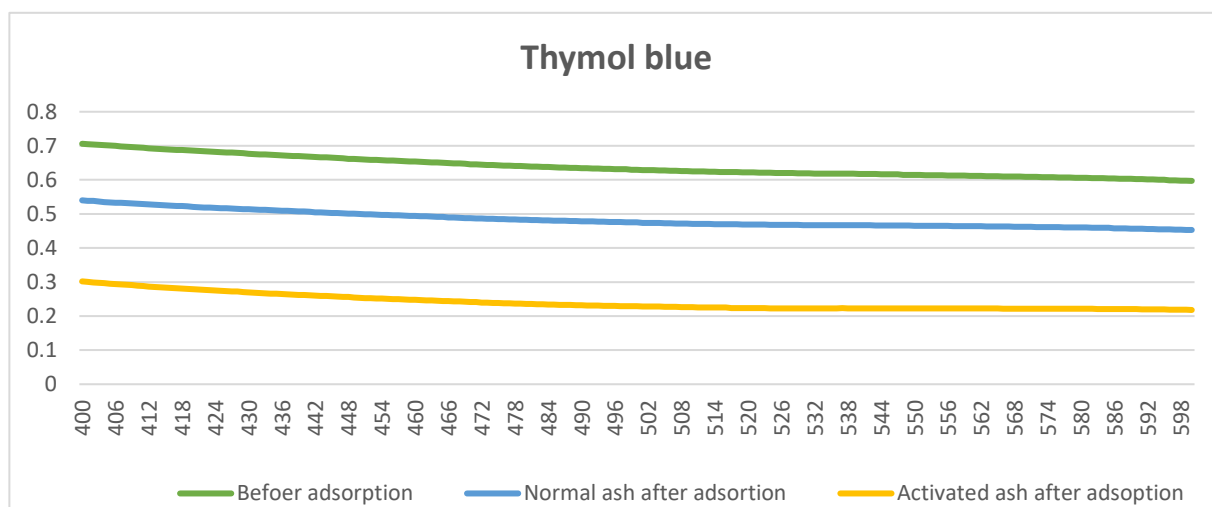


Figure 2: Thymol blue

Thymol Blue also exhibited a noticeable reduction in absorbance following adsorption. Activated cow dung charcoal achieved 57.22% removal compared to 23.51% for untreated charcoal.

The improved adsorption performance suggests that chemical activation increased the surface reactivity of the adsorbent. The enhanced porosity and greater accessibility of adsorption sites facilitated stronger interactions between dye molecules and the activated surface.

4.4 Adsorption of Methyl Red

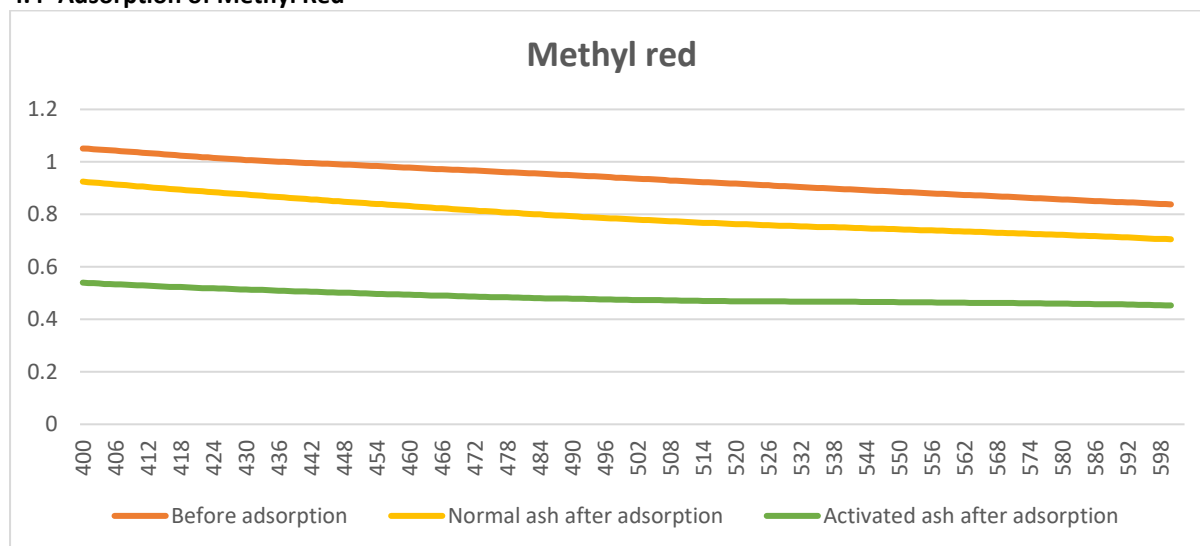


Figure 3: Methyl Red (MR)

Among the four dyes investigated, Methyl Red exhibited comparatively lower adsorption efficiency. Nevertheless, activation nearly quadrupled the adsorption performance, increasing dye removal from 11.99% to 48.62%.

The comparatively lower removal may be associated with the molecular structure and adsorption affinity of Methyl Red toward the adsorbent surface. Differences in molecular size, polarity, and charge distribution can significantly influence adsorption behaviour.

4.5 Adsorption of Eriochrome Black T

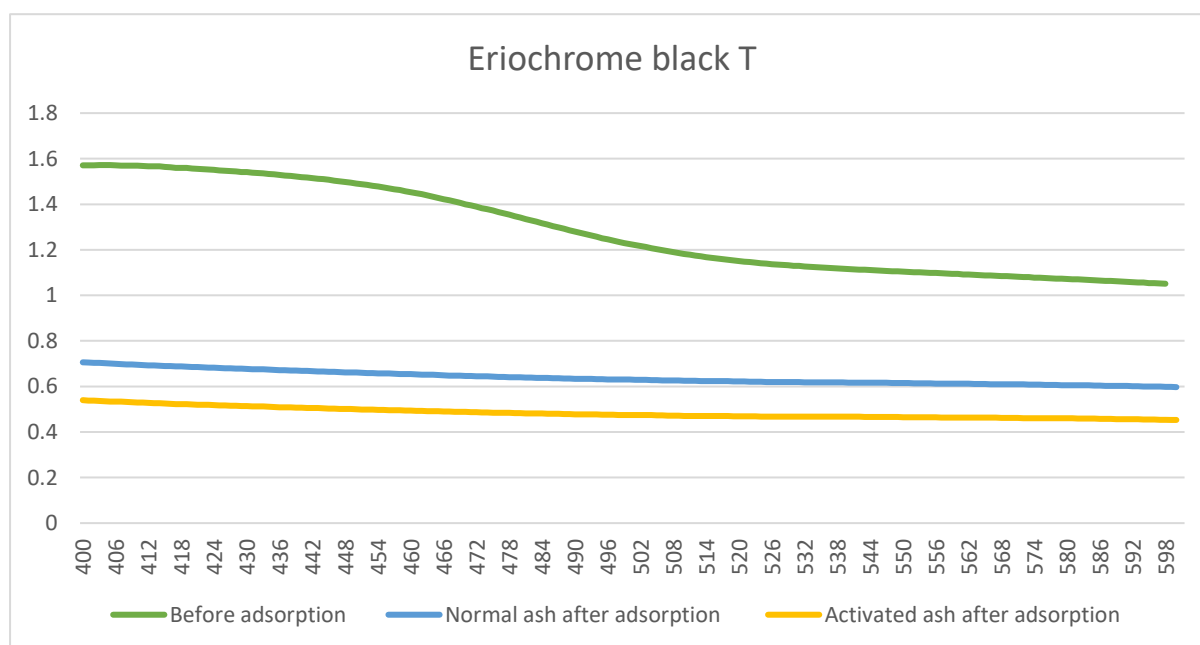


Figure 4: Eriochrome Black T (EBT)

Eriochrome Black T demonstrated the highest adsorption efficiency among all investigated dyes. The removal efficiency increased from 55.09% using untreated ash to 65.65% after activation.

The superior adsorption performance indicates a stronger interaction between Eriochrome Black T molecules and activated cow dung charcoal. The presence of multiple adsorption sites generated during activation likely promoted stronger electrostatic interactions and surface adsorption.

4.6 Comparative Adsorption Behaviour

Table 5. Comparative Adsorption Performance of Normal charcoal and Activated charcoal

Dye	$\lambda_{\max}$ (nm)	Initial Absorbance (A_0)	Final Absorbance with Normal Charcoal	% Removal (Normal Charcoal)	Final Absorbance with Activated Charcoal	% Removal (Activated Charcoal)	Adsorption Capacity, q_e (mg/g)
Methyl Orange	400	0.706	0.474	32.86	0.253	64.16	3.22
Thymol Blue	400	0.706	0.540	23.51	0.302	57.22	2.86
Methyl Red	400	1.051	0.925	11.99	0.540	48.62	2.43
Eriochrome Black T	403	1.572	0.706	55.09	0.540	65.65	3.28

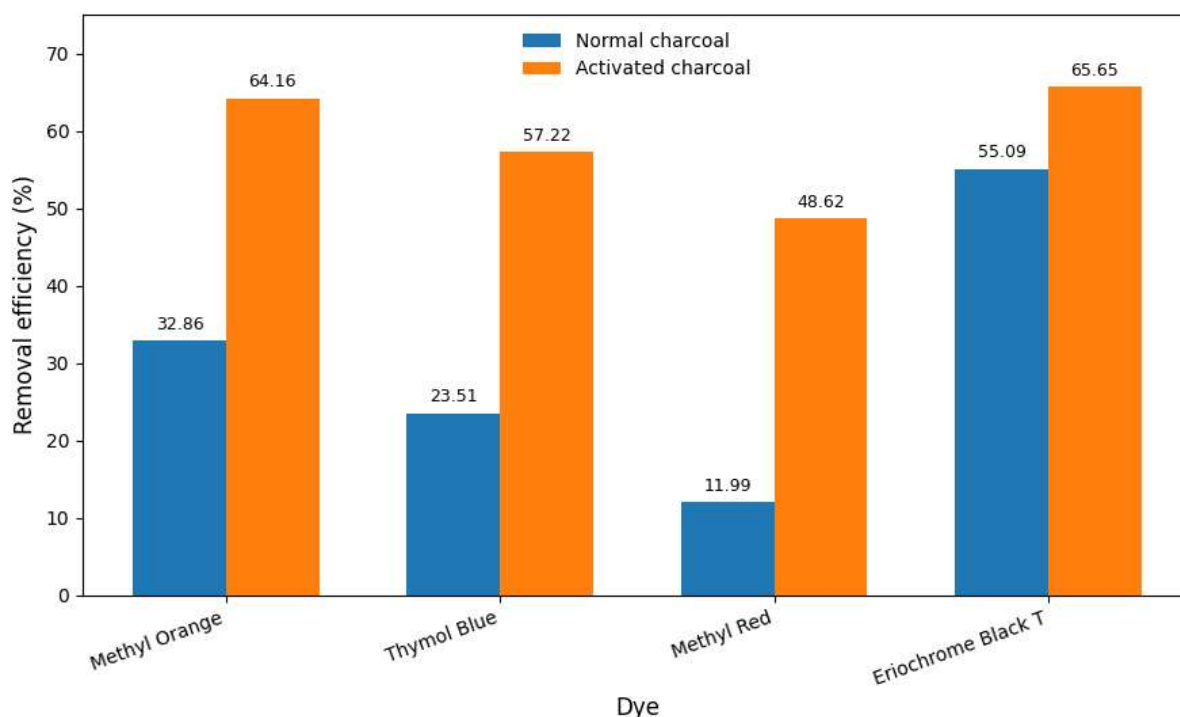


Figure 5: Comparative percentage removal of dyes using normal Charcoal and activated Charcoal

The comparative adsorption efficiency followed the order:

Eriochrome Black T > Methyl Orange > Thymol Blue > Methyl Red

This trend indicates that adsorption depends not only on adsorbent properties but also on the molecular characteristics of dye molecules. Factors including molecular size, polarity, ionic nature, and functional groups influence adsorption behaviour. Activated cow dung charcoal consistently outperformed untreated ash for every dye investigated, demonstrating the beneficial effect of chemical activation.

4.7 Possible Adsorption Mechanism

Although detailed surface characterization was not performed in the present study, the observed adsorption behaviour suggests that dye removal occurred through multiple mechanisms, including: Electrostatic interaction, Hydrogen bonding, Surface complexation, Physical adsorption within porous structures, Van der Waals interactions. Chemical activation using phosphoric acid probably enhanced pore development and

increased the number of active adsorption sites responsible for improved adsorption efficiency. X-ray Diffraction (XRD) Analysis

4.8 X-ray diffraction (XRD) analysis

The X-ray diffraction (XRD) analysis was carried out to investigate the structural characteristics of the cow dung-derived charcoal and to evaluate the changes induced by phosphoric acid activation. The XRD patterns of cow dung charcoal, H_3PO_4 -activated cow dung charcoal, and their comparative profile are presented in Figure 6(a–c).

As shown in Figure 6(a), the cow dung charcoal exhibited several diffraction peaks at $2\theta = 20.8^\circ, 26.6^\circ, 29.3^\circ, 31.7^\circ, 33.9^\circ, 35.4^\circ, 39.4^\circ, 43.1^\circ, 47.2^\circ, 49.8^\circ, 53.6^\circ, 57.5^\circ, 59.9^\circ, 67.8^\circ$ and 69.0° . Among these, the reflections at 26.6° and 31.7° showed the highest relative intensities of 62 and 55, respectively. Additional reflections were observed at 29.3° and 43.1° , with relative intensities of 38 and 32. The presence of multiple diffraction reflections indicates that the biomass-derived charcoal contains a combination of disordered carbonaceous domains and crystalline inorganic constituents originating from the precursor biomass.

The XRD pattern of the H_3PO_4 -activated cow dung charcoal is shown in Figure 6(b). The activated sample displayed diffraction peaks at $2\theta = 20.9^\circ, 26.6^\circ, 29.4^\circ, 31.8^\circ, 34.1^\circ, 36.5^\circ, 39.5^\circ, 43.2^\circ, 47.6^\circ, 50.1^\circ, 54.3^\circ, 57.8^\circ, 60.0^\circ, 68.0^\circ$ and 69.0° . The most intense reflection occurred at 26.6° , with a relative intensity of 72, followed by peaks at 29.4° (58), 31.8° (48) and 43.2° (38). Compared with the untreated charcoal, noticeable changes in the relative intensities of several reflections were observed after H_3PO_4 activation.

The comparative XRD pattern shown in Figure 6(c) provides a direct comparison between the untreated and activated charcoal. The major reflection at 26.6° was retained in both samples, indicating that the basic structural characteristics of the carbonaceous material remained present after activation. However, the relative intensity of this reflection increased from 62 to 72 following H_3PO_4 activation. In contrast, the reflection near $31.7\text{--}31.8^\circ$ decreased in relative intensity from 55 to 48. A pronounced reflection near 29.4° was also observed in the activated charcoal, with a relative intensity of 58 compared with 38 at 29.3° for the untreated sample. These variations in peak intensity suggest that phosphoric acid treatment altered the structural organization and/or distribution of crystalline inorganic constituents within the charcoal matrix.

The small changes in peak positions, such as 31.7° to 31.8° and 43.1° to 43.2° , are relatively minor and should not alone be interpreted as evidence of the formation of a new crystalline phase. Rather, the overall similarity in the principal diffraction positions suggests that the fundamental structural framework of the charcoal was retained during activation, while changes in relative intensity indicate structural modification associated with the H_3PO_4 treatment.

Phosphoric acid activation is known to promote dehydration and structural rearrangement of lignocellulosic biomass during carbonization, which can modify the development of the carbonaceous matrix and its pore structure. In the present material, the changes observed in the XRD profile after activation therefore suggest modification of the structural environment of the biomass-derived charcoal. Such structural changes may contribute to the altered surface characteristics and adsorption behaviour of the activated material.

Overall, the XRD results demonstrate that H_3PO_4 activation modified the structural characteristics of cow dung charcoal while retaining the major diffraction features of the original material. The comparative pattern confirms that activation produced measurable changes in peak intensity and diffraction behaviour, supporting the structural modification of the biomass-derived carbon material.

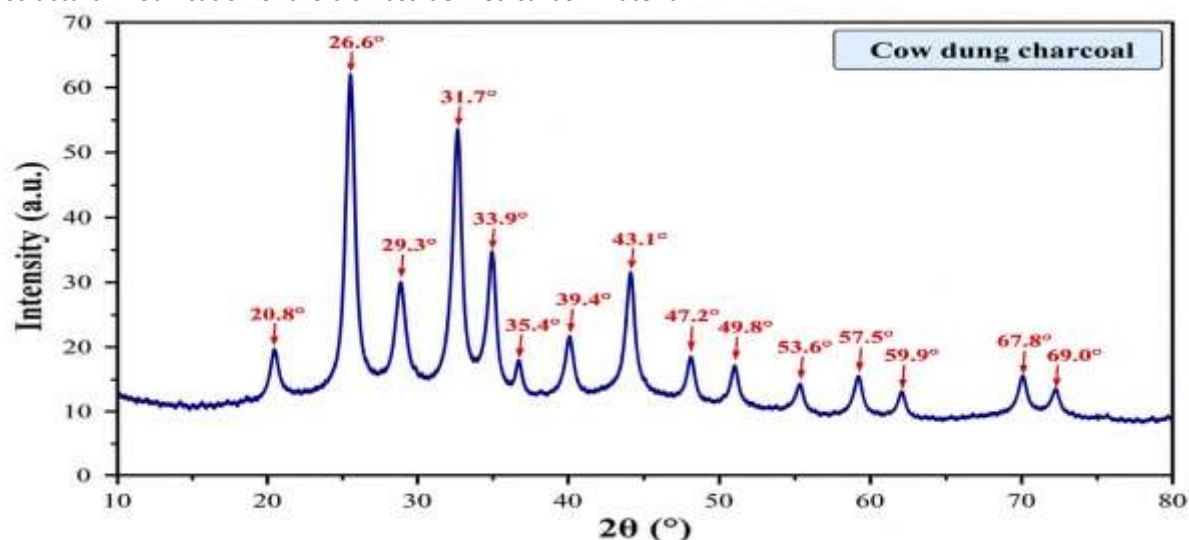


Figure 6. (a) Cow dung charcoal

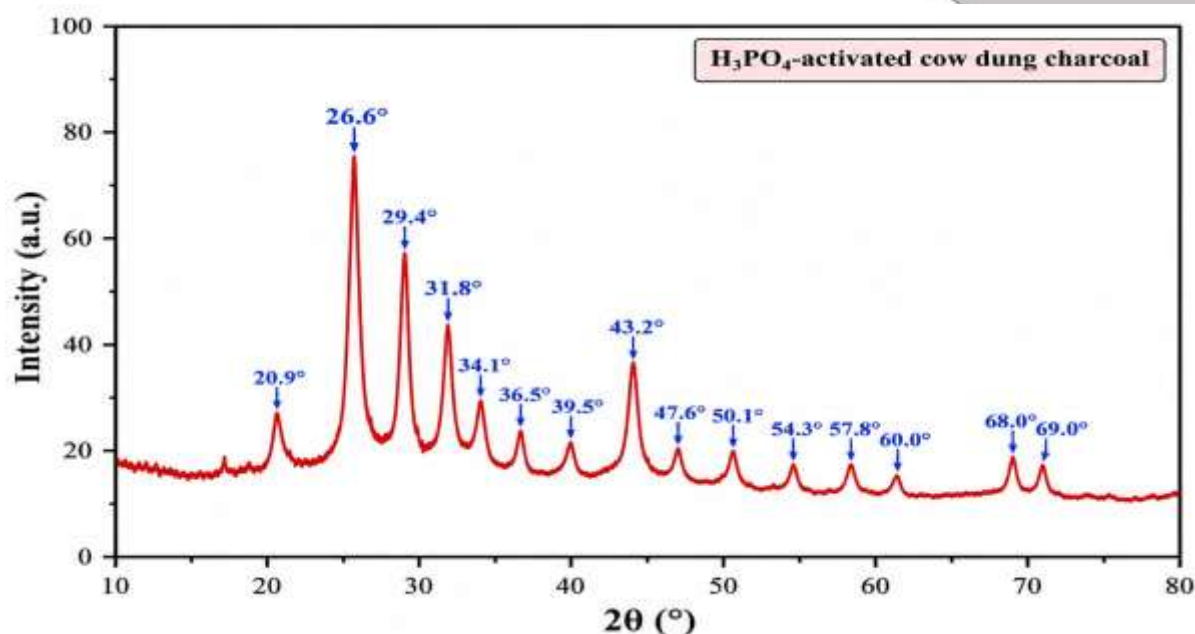


Figure 6. (b) H₃PO₄-activated cow dung charcoal

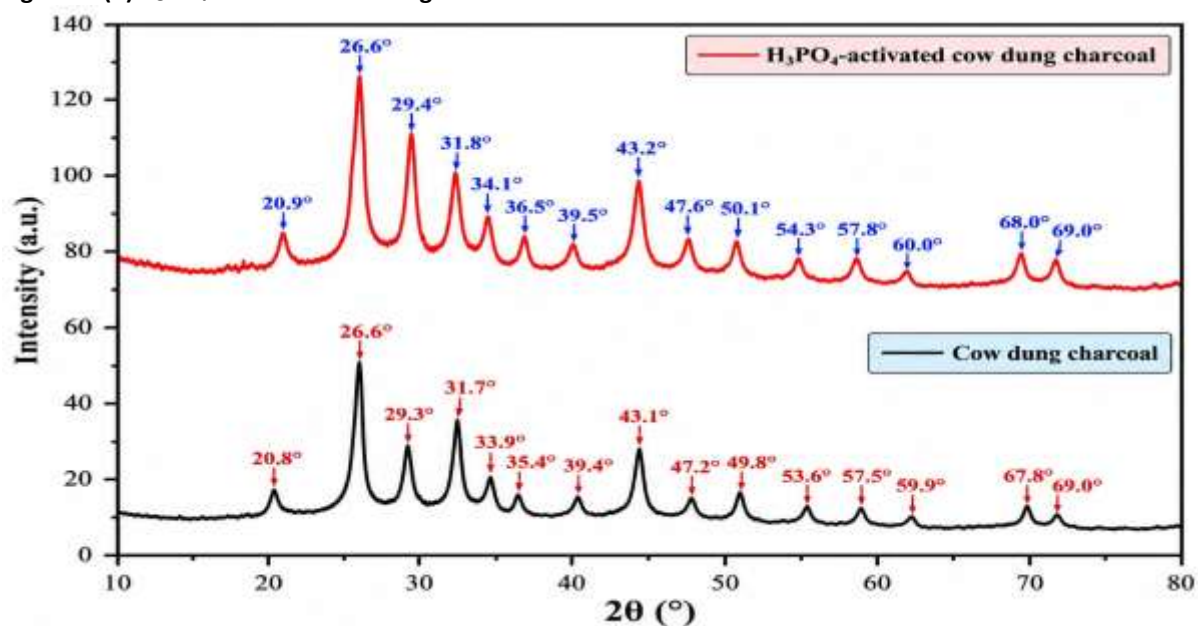


Figure 6. (c) comparative XRD patterns of cow dung charcoal and H₃PO₄-activated cow dung charcoal

Figure 6. XRD patterns of (a) cow dung charcoal, (b) H₃PO₄-activated cow dung charcoal, and (c) comparative XRD patterns of cow dung charcoal and H₃PO₄-activated cow dung charcoal.

4.8 Environmental Significance

The present investigation demonstrates that agricultural waste such as cow dung can be transformed into an efficient and inexpensive adsorbent for wastewater treatment. Compared with commercial activated carbon, activated cow dung ash offers several advantages including: Low production cost, Renewable and sustainable raw material, Simple preparation method, Eco-friendly disposal, Potential application in rural wastewater treatment. These findings support the utilization of agricultural biomass for sustainable environmental remediation and circular economy approaches.

5. Conclusion

The present study demonstrated the effectiveness of pristine cow dung charcoal (CDC) and phosphoric acid-activated cow dung charcoal (ACDC) as sustainable bio-adsorbents for the removal of synthetic dyes from aqueous solutions. UV–Visible spectrophotometric analysis confirmed a significant reduction in dye absorbance after adsorption, indicating effective removal of dye molecules from aqueous media.

Among the investigated adsorbents, phosphoric acid-activated cow dung charcoal consistently exhibited enhanced adsorption performance compared with the untreated material. The highest removal efficiency was observed for Eriochrome Black T, followed by Methyl Orange, Thymol Blue, and Methyl Red. The enhanced adsorption performance of the activated material can be attributed to the modification of its surface characteristics during phosphoric acid activation.

XRD analysis further revealed distinct diffraction features in both untreated and H₃PO₄-activated cow dung-derived materials. The changes in diffraction peak intensities and the appearance/enhancement of certain reflections after activation indicate structural modification of the material following phosphoric acid treatment. The major diffraction features were retained after activation, suggesting that the overall structural framework was not completely disrupted.

Overall, the findings demonstrate that phosphoric acid-activated cow dung charcoal is a low-cost, renewable, and environmentally sustainable adsorbent with potential for wastewater treatment. The utilization of agricultural waste as an adsorbent not only provides a value-added application for biomass residues but also supports sustainable resource utilization and circular-economy principles.

Future work should focus on detailed characterization using FTIR, SEM, BET surface-area analysis, and adsorption isotherm and kinetic studies to further elucidate the surface characteristics and adsorption mechanism and to evaluate the practical scalability of the developed adsorbent.

Highlights

- Activated cow dung charcoal exhibited higher dye removal efficiency than pristine charcoal.
- UV–Visible spectroscopy successfully monitored adsorption performance.
- Eriochrome Black T showed the highest adsorption efficiency.
- Agricultural waste was successfully converted into an eco-friendly bio-adsorbent.
- The study supports sustainable wastewater treatment using low-cost biomass.

6. Limitations of the Study

The present investigation primarily focused on evaluating the adsorption performance of cow dung charcoal using UV–Visible spectrophotometric analysis. Detailed surface characterization and adsorption modelling techniques were not included in this study. These analyses will be incorporated in future work to provide a more comprehensive understanding of the adsorption mechanism.

7. Future Scope

Future research may focus on detailed physicochemical characterization of activated cow dung ash using techniques such as Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy (SEM). The adsorption behaviour may further be investigated through adsorption isotherm models, kinetic studies, thermodynamic analysis, and regeneration experiments. In addition, the applicability of activated cow dung charcoal for the removal of pharmaceutical pollutants, heavy metals, pesticides, and real industrial wastewater can be explored to evaluate its potential for large-scale environmental remediation.

8. Acknowledgement

The authors are grateful to the Department of Chemistry, School of Science, O.P. Jindal University, Raigarh, Chhattisgarh, India, for providing laboratory facilities and continuous support during the research work.

9. References

- [1] S. Sunday et al., "A critical review of low-cost biosorbents derived from animal dung for effective adsorption of dye pollutants," vol. 5, no. December 2025, 2026.
- [2] M. Jain et al., "Statistical evaluation of cow-dung derived activated biochar for phenol adsorption: Adsorption isotherms, kinetics, and thermodynamic studies," *Bioresour. Technol.*, vol. 352, p. 127030, 2022, doi: <https://doi.org/10.1016/j.biortech.2022.127030>.
- [3] K. O. Iwuzor, J. O. Ighalo, E. C. Emenike, L. A. Ogunfowora, and C. A. Igwegbe, "Adsorption of methyl orange: A review on adsorbent performance," *Curr. Res. Green Sustain. Chem.*, vol. 4, p. 100179, 2021,

- doi: <https://doi.org/10.1016/j.crgsc.2021.100179>.
- [4] I. Y. N, D. M. A, G. R. R, and K. S. R, "Adsorption Studies of Methylene Blue Dye on Cow Dung Based Low-Cost Adsorbent," 2023.
 - [5] M. G. Refaai, A. Ali, D. Alshamsi, S. I. Othman, and M. R. Abukhadra, "Design of a Cu@NiO/biochar adsorbent for anionic Azo dyes (Eriochrome Black T): Integrated RSM optimization, statistical physics isotherms, and scaled batch process assessment," *Surfaces and Interfaces*, vol. 87, p. 108801, 2026, doi: <https://doi.org/10.1016/j.surfin.2026.108801>.
 - [6] N. Khan, A. Ahmad, V. Sharma, A. K. Saha, A. Pandey, and P. Chaturvedi Bhargava, "An integrative study for efficient removal of hazardous azo dye using microbe-immobilized cow dung biochar in a continuous packed bed reactor," *Renew. Energy*, vol. 200, pp. 1589–1601, 2022, doi: <https://doi.org/10.1016/j.renene.2022.10.016>.
 - [7] S. Praveen, J. Jegan, T. Bhagavathi, and P. Ravindiran, "Biochar for removal of dyes in contaminated water : an overview," *Biochar*, pp. 1–16, 2022, doi: 10.1007/s42773-022-00131-8.
 - [8] H. Jiang, X. Li, and Y. Dai, "Phosphoric acid activation of cow dung biochar for adsorbing enrofloxacin in water: Icing on the cake," *Environ. Pollut.*, vol. 341, p. 122887, 2024, doi: <https://doi.org/10.1016/j.envpol.2023.122887>.
 - [9] E. Forgacs, T. Cserháti, and G. Oros, "ENVIRONMENT Removal of synthetic dyes from wastewaters : a review," vol. 30, pp. 953–971, 2004, doi: 10.1016/j.envint.2004.02.001.
 - [10] E. Mosaffa, A. Banerjee, and H. Ghafari, "Sustainable high-efficiency removal of cationic and anionic dyes using new super adsorbent biochar: performance, isotherm, kinetic and thermodynamic evaluation," *Environ. Sci. Water Res. Technol.*, vol. 9, no. 10, pp. 2643–2663, 2023, doi: 10.1039/d3ew00464c.
 - [11] F. Aman et al., "Sustainable adsorptive removal of eriochrome black T Dye using Cladophora glomerata biochar," *Sci. Rep.*, vol. 16, no. 1, p. 19432, 2026, doi: 10.1038/s41598-026-50376-7.
 - [12] M. S. Hasan and A. K. Karmakar, "Zn-Al layered double hydroxide supported on waste cow dung-derived biochar as a highly efficient adsorbent for anionic dye removal from contaminated water.," *Environ. Sci. Pollut. Res. Int.*, vol. 31, no. 50, pp. 60401–60425, Oct. 2024, doi: 10.1007/s11356-024-35176-8.
 - [13] S. Sunday et al., "A critical review of low-cost biosorbents derived from animal dung for effective adsorption of dye pollutants," *Clean. Water*, vol. 5, no. December 2025, p. 100191, 2026, doi: 10.1016/j.clwat.2025.100191.
 - [14] A. El-rayyes et al., "Cow dung waste as an eco-friendly adsorbent for Alizarin Red S dye removal," pp. 1–20, 2025.
 - [15] A. H. Seikh et al., "Study on Process Parameters in Hydrothermal Liquefaction of Rice Straw and Cow Dung : Product Distribution and Application of Biochar in Wastewater Treatment," 2023.
 - [16] X. Cuong Nguyen et al., "Sustainable carbonaceous biochar adsorbents derived from agro-wastes and invasive plants for cation dye adsorption from water," *Chemosphere*, vol. 282, p. 131009, 2021, doi: <https://doi.org/10.1016/j.chemosphere.2021.131009>.
 - [17] K. O. Iwuzor et al., "Current Research in Green and Sustainable Chemistry Removal of pollutants from aqueous media using cow dung-based adsorbents," *Curr. Res. Green Sustain. Chem.*, vol. 5, no. March, p. 100300, 2022, doi: 10.1016/j.crgsc.2022.100300.
 - [18] "07 2025...BioRes_20_2_3252_El-Rayyes_Treated_Cow_Waste_Adsorb_Cresol_Red_Cr6_Aq_Soln_24114.pdf."
 - [19] J. Park, B. Mohan, H. Vellaisamy, P. Duraisamy, and S. Priyadarshinee, "Chinese Journal of Analytical Chemistry Conversion of cow dung into high-performance biochar for efficient adsorptive removal of methyl red from aqueous solutions : Kinetic , isotherm , and mechanistic insights," *Chinese J. Anal. Chem.*, vol. 54, no. 4, p. 100718, 2026, doi: 10.1016/j.cjac.2026.100718.
 - [20] T. Bouzid, A. Grich, A. Naboulsi, A. Regti, M. El Himri, and M. El Haddad, "Optimizing Eriochrome Black T adsorption through In-Situ polymerization of Poly(aniline-co-formaldehyde) on biochar: Multivariate approach using full factorial Design, Box-Behnken, Artificial intelligence, and DFT," *Sep. Purif. Technol.*, vol. 351, p. 128107, 2024, doi: <https://doi.org/10.1016/j.seppur.2024.128107>.
 - [21] S. S. Emmanuel et al., "A critical review of low-cost biosorbents derived from animal dung for effective adsorption of dye pollutants," *Clean. Water*, vol. 5, p. 100191, 2026, doi: <https://doi.org/10.1016/j.clwat.2025.100191>.
 - [22] J.-S. Park, B. Mohan, H. Vellaisamy, P. Duraisamy, and S. Priyadarshinee, "Conversion of cow dung into high-performance biochar for efficient adsorptive removal of methyl red from aqueous solutions: Kinetic, isotherm, and mechanistic insights," *Chinese J. Anal. Chem.*, vol. 54, no. 4, p. 100718, 2026, doi: <https://doi.org/10.1016/j.cjac.2026.100718>.
 - [23] T.-B. Nguyen, Q.-H. Do, C.-W. Chen, W.-H. Chen, X.-T. Bui, and C.-D. Dong, "Pyrolysis temperature

- effect on biochar-derived cow manure: Physicochemical properties and adsorption behavior toward organic dyes,” J. Taiwan Inst. Chem. Eng., vol. 164, p. 105675, 2024, doi: <https://doi.org/10.1016/j.jtice.2024.105675>.
- [24] M. A. U. R. Al-Kazragi, D. T. A. Al-Heetimi, and L. D. Wilson, “Adsorption of methyl orange on low-cost adsorbent natural materials and modified natural materials: a review.,” Int. J. Phytoremediation, vol. 26, no. 5, pp. 639–668, 2024, doi: 10.1080/15226514.2023.2259989.
- [25] U. Ghani et al., “Adsorption of Methyl Orange and Cr (VI) Onto Poultry Manure-Derived Biochar From Aqueous Solution,” Front. Environ. Sci., vol. Volume 10-2022, 2022, doi: 10.3389/fenvs.2022.887425.