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ECO-FRIENDLY DYE REMEDIATION USING COCONUT SHELL ACTIVATED CHARCOAL : A COMPARATIVE ANALYSIS OF FREE AND IMMOBILIZED SYSTEMS

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ABSTRACT

The discharge of synthetic dyes into water bodies poses serious environmental concerns due to their persistence and toxicity. In this study, activated charcoal derived from coconut shell was used for the removal of Methylene Blue and Congo Red from aqueous solutions. The charcoal was applied in two forms: as free powder and as immobilized beads prepared using Sodium alginate. Dye reduction experiments were conducted at different charcoal concentrations and incubated for 72 hours under dark conditions. Optical density was measured using a colorimeter at 680 nm and 490 nm for methylene blue and Congo red, respectively. The results indicated that powdered charcoal exhibited higher dye removal efficiency (up to ~81% for methylene blue), whereas immobilized beads showed moderate removal efficiency but offered advantages in ease of separation and handling. The study highlights that while free charcoal is more efficient, immobilized systems provide a practical and eco-friendly alternative for wastewater treatment.

KEYWORDS: Activated charcoal, Immobilization methylene blue, Congo red, dye removal,

1. INTRODUCTION

Water pollution caused by synthetic dyes is a major environmental issue associated with industrial activities such as textile processing. These dyes are resistant to degradation and can adversely affect aquatic life and human health. Among commonly used dyes, Methylene Blue and Congo Red are frequently used as model pollutants in adsorption studies.

Activated charcoal derived from biomass is widely used for pollutant removal due to its high surface area and adsorption capacity (Ahmad et al., 2014; Mohan et al., 2014; Foo &

Hameed, 2012). Biochar and activated carbon materials have been reported to effectively remove both organic pollutants and heavy metals from aqueous systems through adsorption mechanisms such as ion exchange and surface complexation. These materials are considered cost-effective and environmentally sustainable alternatives for wastewater treatment (Babel & Kurniawan, 2003). However, the powdered form of charcoal presents difficulties in separation after treatment.

To overcome this limitation, immobilization techniques using natural polymers such as Sodium alginate have been developed. These systems improve handling and allow easy recovery of the adsorbent while maintaining reasonable adsorption efficiency (Mohan et al., 2014; Ahmad et al., 2014). The present study aims to compare the efficiency of free activated charcoal and immobilized charcoal beads for dye removal and evaluate their practical applicability.

2. MATERIALS AND METHODS

Preparation of Activated Charcoal

Mature coconut shells were collected, washed with distilled water, and sun-dried. The dried shells were carbonized under limited oxygen conditions using an open-fire method. The resulting char was cooled, crushed, and chemically activated using citric acid obtained from lemon extract by soaking overnight. The material was washed until neutral pH, dried, and ground into fine powder (Ioannidou and Zabaniotou, 2007).

Preparation of Immobilized Beads

A solution of Sodium alginate (1 g in 50 mL distilled water) was prepared. Calcium chloride (1.66 g in 50 mL) was used as a crosslinking agent. Activated charcoal was added to alginate in concentrations ranging from 0.25 g to 1.25 g. The mixtures were added dropwise into calcium chloride solution to form beads, which were washed with distilled water (Lee and Mooney, 2012).

Preparation of Dye Solutions

Stock solutions (100 ppm) of methylene blue and Congo red were prepared by dissolving 10 mg of dye in 100 mL distilled water. Working solutions (1 ppm) were prepared by diluting 1 mL of stock solution to 100 ml (Crini, 2006).

Dye Reduction Using Immobilized Beads

Twenty beads were added to conical flasks containing 50 mL of dye solution. A control without beads was maintained. The flasks were kept under dark conditions for 7 hours. After incubation, optical density (OD) was measured using a colorimeter OD (Gupta and Suhas, 2009).

Dye Reduction Using Free Activated Charcoal

Activated charcoal powder was added directly to dye solutions at concentrations of 0.5 g, 1.0 g, 1.5 g, 2.0 g, and 2.5 g in separate conical flasks. A control without charcoal was maintained. After incubation for 72 hours under dark conditions, the charcoal was removed by filtration using Whatman No. 1 filter paper. The filtrate was analyzed by measuring.

Measurement of Optical Density

After incubation, the optical density (OD) of the dye solutions was measured using a colorimeter. The wavelength was set at 680 nm for Methylene Blue and 490 nm for Congo Red (Robinson et al., 2001).

3. RESULTS

Preparation of Activated Charcoal

The coconut shells were successfully carbonized under limited oxygen conditions, resulting in the formation of char. The obtained material was further processed into fine powdered activated charcoal after chemical activation.

Activated charcoal was successfully incorporated into the alginate matrix, and uniform beads were formed upon addition into calcium chloride solution. The beads were stable and retained their structure after washing.

Figure 1: Activated charcoal prepared from coconut shells.

Preparation of Dye Solutions

Clear and homogeneous dye solutions were prepared at the required concentrations. The concentrations of the dye prepared 1mg/ml.

Dye Treatment Process

The addition of immobilized beads and free charcoal to the dye solutions resulted in visible interaction between adsorbent and dye. The systems were incubated under dark conditions to facilitate adsorption and to prevent photolytic dye degradation.

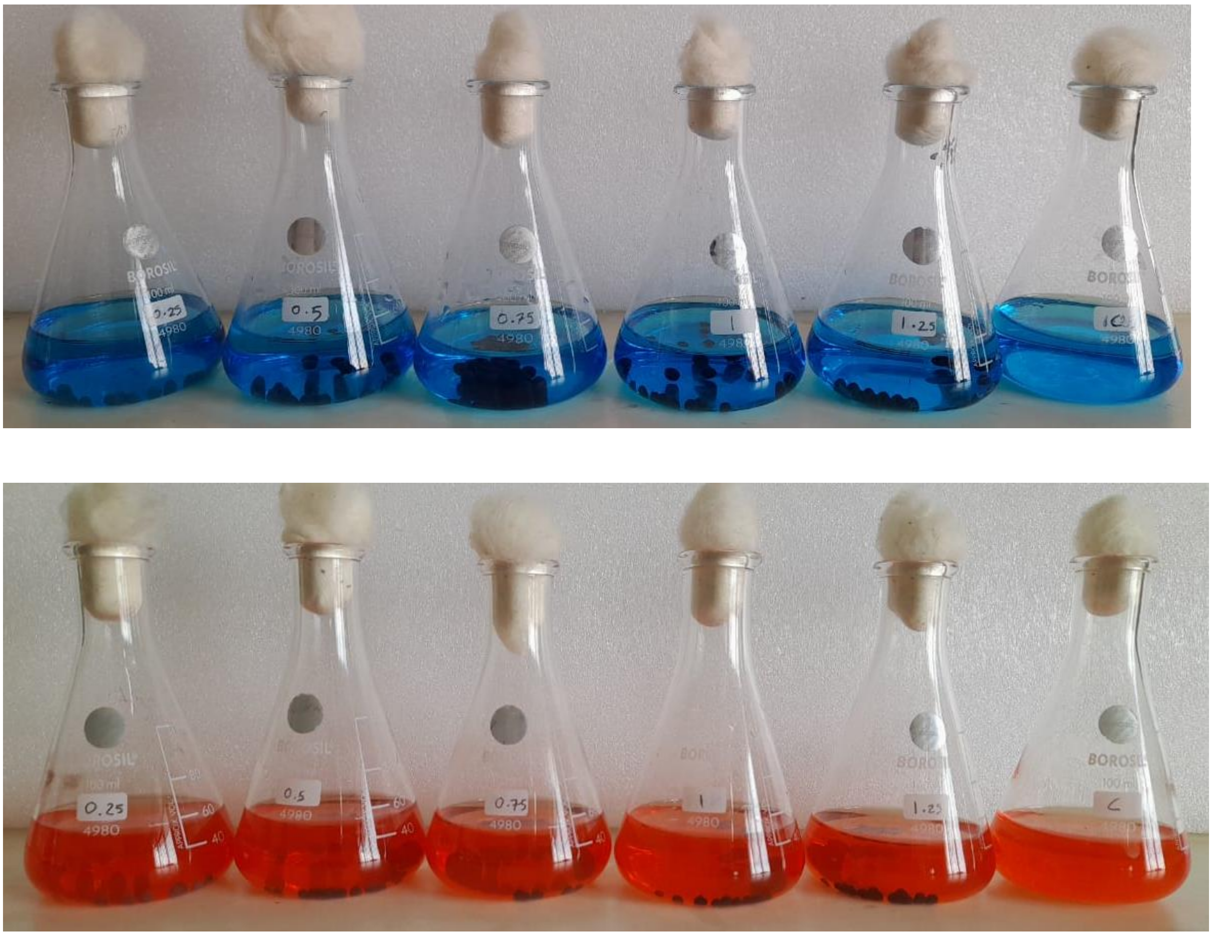

Figure 2: Dye reduction with immobilized beads

Figure 3: Dye reduction with free activated charcoal powder

Dye Removal Efficiency

A noticeable reduction in the intensity of the colour was observed after 72 hours of incubation, indicating effective dye removal. The extent of removal varied with charcoal concentration and form. Free activated charcoal showed significantly higher efficiency, with a maximum removal of 81.08% for methylene blue whereas immobilized beads exhibited a maximum removal of 35.14%.

In the case of Congo red, the highest removal of 63.16% was observed with powdered charcoal, while bead-based systems showed comparatively lower and variable removal efficiencies. These results clearly indicate that powdered charcoal is more effective than immobilized beads for dye adsorption.

Table 1: Comparative Dye Removal Efficiency of immobilized and free charcoal.

System	Charcoal (g)	MB OD Initial	MB OD Final	MB % Removal	CR OD Initial	CR OD Final	CR % Removal
control		0.37	0.37	0.00%	0.19	0.19	0.00%
Beads	0.25	0.37	0.32	13.51%	0.19	0.08	57.89%
Beads	0.50	0.37	0.26	29.73%	0.19	0.16	15.79%
Beads	0.75	0.37	0.27	27.03%	0.19	0.18	5.26%
Beads	1.00	0.37	0.27	27.03%	0.19	0.18	5.26%
Beads	1.25	0.37	0.24	35.14%	0.19	0.17	10.53%
control		0.37	0.37	0.00%	0.19	0.19	0.00%
Powder	0.50	0.37	0.10	72.97%	0.19	0.12	36.84%
Powder	1.00	0.37	0.07	81.08%	0.19	0.07	63.16%
Powder	1.50	0.37	0.08	78.38%	0.19	0.16	15.79%
Powder	2.00	0.37	0.11	70.27%	0.19	0.15	21.05%

Powder	2.50	0.37	0.17	54.05%	0.19	0.13	31.58%

4. DISCUSSION

The higher efficiency observed in powdered charcoal can be attributed to its greater surface area and availability of adsorption sites. Immobilization slightly reduces surface exposure, resulting in lower efficiency (Mohan et al., 2014; Ahmad et al., 2014). However, powdered charcoal requires filtration for separation, making the process less convenient. Immobilized beads allow easy recovery and reuse without additional processing. Thus, although free charcoal provides higher efficiency, immobilized beads offer better practical applicability. The results are consistent with previous studies on biochar and activated carbon materials, which demonstrate effective pollutant removal through adsorption mechanisms such as surface adsorption, ion exchange, and complexation (Tan et al., 2015; Liu et al., 2022; Babel & Kurniawan, 2003). These findings are also supported by earlier studies on low-cost adsorbents for dye removal (Crini, 2006).

5. CONCLUSION

Activated charcoal prepared from coconut shell demonstrated effective removal of Methylene Blue and Congo red from aqueous solutions. The results showed that free activated charcoal exhibited higher adsorption efficiency, achieving up to approximately 81% removal for methylene blue, whereas immobilized charcoal beads showed comparatively lower removal efficiency. However, the immobilized system offered significant advantages in terms of ease of separation, handling, and potential reusability.

Although powdered charcoal provides better adsorption performance, the practical limitations associated with its recovery highlight the importance of immobilization techniques. Therefore, immobilized activated charcoal beads can be considered a promising and eco-friendly alternative for wastewater treatment applications. Further studies on optimization and reusability of the beads may enhance their efficiency and large-scale applicability.

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