IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 1 Ver. I (Jan- Feb. 2015), PP 94-96
www.iosrjournals.org

Blue Dye Removal from Textile Wastewater Using Low-Cost Adsorbents

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Abstract: *Activated carbon is widely used for dye removal from industrial wastewater; however, its high cost and difficulties associated with regeneration and disposal limit its large-scale application. In this study, an economical alternative approach has been explored for the removal of blue dye from textile wastewater using low-cost adsorbents. Activated carbon prepared from agricultural wastes such as wheat straw and rice husk was evaluated and compared with commercially available activated carbon. The agricultural residues were converted into activated carbon through laboratory-scale dehydration, carbonization, and activation processes. Batch adsorption experiments were conducted to study the effects of adsorbent dosage and contact time on color removal efficiency. The results indicate significant dye removal under different experimental conditions, with removal efficiencies ranging from 86.11% to 98.23%. Among the tested adsorbents, activated carbon derived from wheat straw exhibited superior performance compared to rice husk and commercial activated carbon. The findings demonstrate that agricultural waste-based activated carbon can serve as an effective, economical, and sustainable alternative for textile wastewater treatment.*
Keywords: *Textile wastewater, dye removal, blue dye, activated carbon, low-cost adsorbent*

I. Introduction

Color is one of the most visible and objectionable pollutants present in textile wastewater, and environmental regulations worldwide require effective decolorization before discharge into natural water bodies. Many textile dyes possess complex molecular structures and xenobiotic characteristics, making them resistant to biodegradation. Consequently, conventional municipal wastewater treatment systems are often ineffective in removing color from dye-laden effluents.

The presence of dyes in aquatic environments reduces light penetration, adversely affecting photosynthesis and aquatic life. Furthermore, anaerobic degradation of dyes in sediments may result in the formation of toxic aromatic amines, posing serious ecological risks. Due to these concerns, numerous treatment methods have been investigated to either remove dyes from wastewater or chemically degrade them.

Among physical treatment methods, adsorption using activated carbon is considered one of the most effective techniques for dye removal. Its high adsorption capacity is attributed to its porous structure, large surface area, and modifiable surface chemistry. Despite these advantages, commercially available activated carbon suffers from several limitations, including high cost, complex regeneration procedures, loss of adsorption capacity during reuse, and challenges related to safe disposal after saturation. These drawbacks have motivated researchers to explore alternative low-cost adsorbents derived from waste materials.

Agricultural and forest residues such as sawdust, bark, rice husk, and wheat straw are abundantly available and possess favorable physicochemical properties for adsorption. These materials contain organic compounds like cellulose, lignin, and hemicellulose with functional groups capable of binding dye molecules through mechanisms such as ion exchange, complexation, and hydrogen bonding. Previous studies have demonstrated the potential of such materials for dye removal; however, their application for economical color removal from actual textile wastewater remains limited.

Therefore, the present study aims to investigate the effectiveness of activated carbon prepared from wheat straw and rice husk for the removal of blue dye from textile industry wastewater and to compare their performance with commercially available activated carbon.

II. Materials And Methods

2.1 Collection of Textile Wastewater

Wastewater samples were collected from Oriental Craft Dyeing Industries located in Gurgaon, Haryana, India. The selected effluent contained blue dye with a typical mixture of organic and inorganic constituents. Grab sampling was employed, and samples were collected in clean PVC containers. Appropriate preservation techniques were used prior to analysis.

2.2 Preparation of Activated Carbon

Activated carbon was prepared in the laboratory using agricultural waste materials—wheat straw and rice husk—collected from farmland near Manawa village, Meerut district, Uttar Pradesh. The preparation involved three main steps:

Step 1: Dehydration

The raw materials were oven-dried at 165–175 °C for 60 minutes to remove all moisture content.

Step 2: Carbonization

The dehydrated materials were subjected to carbonization in a muffle furnace at 550–600 °C in the absence of oxygen for 15–30 minutes. During this process, volatile impurities such as tar and methanol were removed, resulting in the formation of porous char.

Step 3: Activation

The carbonized material was immediately exposed to air and lightly sprinkled with water upon removal from the furnace. It was then dried in an oven at 105 °C for 30 minutes to complete the activation process.

The activated carbons prepared from wheat straw and rice husk were subsequently used for adsorption studies.

2.3 Experimental Procedure for Color Removal

Batch adsorption experiments were conducted using 100 ml wastewater samples placed in conical flasks. Activated carbon doses ranging from 0.2 g to 1.2 g were added, and the flasks were agitated on a mechanical shaker for a fixed contact time of 1 hour. After agitation, the supernatant was separated and analyzed for transmittance. The residual color concentration and percentage removal were calculated using a standard calibration curve.

Additional experiments were performed to study the effect of contact time by varying it from 30 to 180 minutes at a fixed adsorbent dose of 1.0 g per 100 ml.

III. Results And Discussion

This section discusses the adsorption performance of different activated carbons in removing blue dye from textile wastewater.

3.1 Effect of Activated Carbon Dosage (Wheat Straw)

The results indicate that color removal efficiency increased with increasing dosage of wheat-straw-based activated carbon. Maximum color removal of 98.23% was achieved at a dose of 1.2 g/100 ml, while the minimum removal of 95.16% was observed at 0.2 g/100 ml for a contact time of 1 hour. The improvement in removal efficiency is attributed to the increased availability of adsorption sites at higher dosages.

3.2 Effect of Activated Carbon Dosage (Rice Husk)

Activated carbon prepared from rice husk showed a maximum color removal efficiency of 92.96% at a dosage of 1.0 g/100 ml. Beyond this dosage, a decline in removal efficiency was observed, likely due to charge reversal or particle aggregation effects. The minimum color removal of 90.56% was recorded at 0.2 g/100 ml.

3.3 Effect of Commercial Activated Carbon Dosage

Commercial activated carbon achieved a maximum color removal efficiency of 90.05% at a dosage of 1.0 g/100 ml. The lowest efficiency of 86.86% was observed at 0.2 g/100 ml. Although effective, its performance was inferior compared to wheat-straw-based activated carbon.

3.4 Effect of Contact Time (Wheat Straw)

At a constant dose of 1.0 g/100 ml, color removal increased with contact time, reaching a maximum of 97.72% at 150–180 minutes. This trend indicates improved adsorption equilibrium with longer contact periods.

3.5 Effect of Contact Time (Rice Husk)

Rice-husk-based activated carbon exhibited fluctuating removal efficiencies with varying contact times. Maximum removal of 90.56% occurred at 120 minutes, while the lowest value of 86.47% was observed at 180 minutes. The variation may be due to non-uniform particle size and surface charge effects.

3.6 Effect of Contact Time (Commercial Activated Carbon)

Commercial activated carbon showed gradual improvement in color removal with increasing contact time, achieving a maximum removal of 95.16% at 180 minutes.

IV. Conclusions

The study demonstrates that agricultural waste-derived activated carbon is an effective and economical adsorbent for the removal of blue dye from textile wastewater. Among the tested materials, wheat-straw-based activated carbon exhibited the highest color removal efficiency, outperforming both rice husk and commercially available activated carbon. The results indicate that color removal efficiency increases with adsorbent dosage and contact time up to an optimum level, beyond which slight reductions may occur due to charge reversal or particle interactions.

The use of low-cost agricultural waste not only reduces treatment costs but also promotes sustainable waste utilization. Therefore, activated carbon derived from wheat straw and rice husk can be considered a viable alternative to commercial activated carbon for textile wastewater treatment applications.

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