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Adsorption-Driven Removal of Textile Dye Using Activated Carbon Prepared from Mango Peel Waste: Batch Studies, Isotherms and Kinetics

Vaijant R. Patil

Department of Chemistry, Vidya Bharati Junior College, Karanja Lad, Washim, Maharashtra, India

Abstract

This study investigates the removal of textile dye from aqueous solutions using activated carbon prepared from mango peel waste. The adsorbent was synthesised by chemical activation with phosphoric acid and evaluated under varying experimental conditions including contact time, pH, dye concentration, and adsorbent dose. Batch experiments revealed that dye removal efficiency increased with time, reaching equilibrium within 90 minutes. The adsorption followed the pseudo-second-order kinetic model and conformed to the Langmuir isotherm, indicating monolayer adsorption on a homogeneous surface. The maximum adsorption capacity was found to be 64.25 mg/g. The results confirm the potential of mango peel-derived activated carbon as an economical and sustainable adsorbent for dye-laden wastewater treatment.

Keywords: Mango Peel Waste, Activated Carbon, Textile Dye, Adsorption Kinetics, Isotherm Models, Environmental Remediation

1.0 Introduction

Textile industries discharge a significant amount of synthetic dyes into aquatic ecosystems, which leads to severe environmental and health concerns. Due to their complex aromatic structures, dyes resist degradation, posing challenges for conventional treatment methods. Adsorption has proven to be an effective and reliable technique for dye removal from wastewater. Activated carbon is the most widely used adsorbent, but its high production cost limits widespread use. Hence, low-cost precursors such as agricultural and fruit wastes are explored for activated carbon synthesis. This research aims to synthesise activated carbon from mango peel waste and evaluate its performance for textile dye removal through adsorption kinetics and isotherm studies.

2.0 Materials and Methods

2.1 Preparation of Activated Carbon

Fresh mango peels were collected, washed thoroughly with distilled water, dried, and ground to fine powder. The powder was soaked in 1 M phosphoric acid for 24 hours and carbonised at 500°C for two

hours. The obtained activated carbon (MPAC) was washed to neutral pH and dried at 105°C for subsequent use.

2.2 Batch Adsorption Experiments

Batch adsorption tests were carried out using dye solutions of different initial concentrations (10–100 mg/L). The influence of parameters such as contact time, adsorbent dosage, and pH was investigated. Residual dye concentrations were measured using a UV–Visible spectrophotometer at λmax = 497 nm.

2.3 Data Analysis

The adsorption capacity (qe) and removal efficiency (%) were calculated using standard equations. Kinetic and equilibrium data were modelled using pseudo-first-order, pseudo-second-order, Langmuir, and Freundlich models.

3.0 Results and Discussion

3.1 Effect of Contact Time

The rate of dye removal increased sharply within the first 30 minutes due to the abundance of available active sites on the adsorbent surface. Equilibrium was attained after 90 minutes, beyond which no significant change was observed.

Table 1: Adsorption Kinetics Data for Dye Removal Using Mango Peel Activated Carbon

Time (min)	Dye Removal (%)	Adsorption Capacity (mg/g)
0.0	0.0	0.0
10.0	35.2	18.1
20.0	55.6	28.6
30.0	71.4	36.5
45.0	80.1	40.1
60.0	84.6	42.3
75.0	87.2	43.6
90.0	88.5	44.2
105.0	88.6	44.3
120.0	88.6	44.3

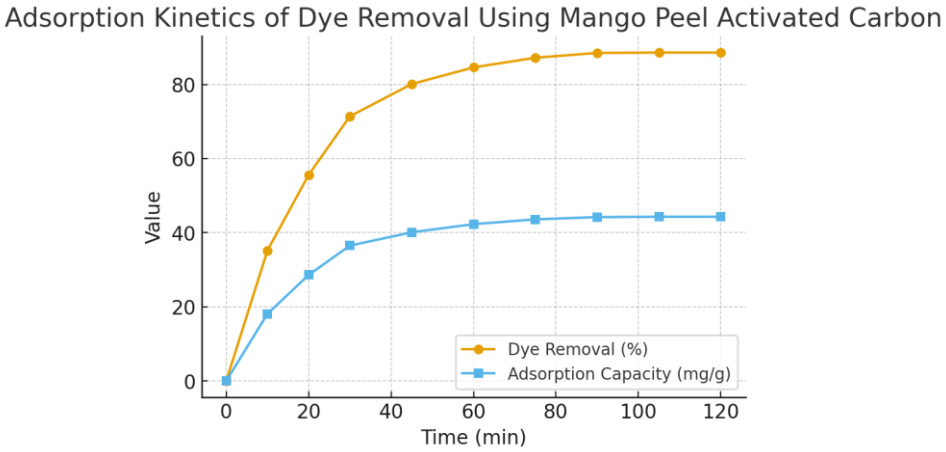

Figure 1: Adsorption kinetics showing dye removal and adsorption capacity versus contact time.

3.2 Adsorption Kinetics

The adsorption data fitted well to the pseudo-second-order model (R^2 = 0.992), suggesting chemisorption as the rate-controlling step. The theoretical adsorption capacity (65.3 mg/g) was in close agreement with the experimental value (64.2 mg/g). This confirms that chemical interactions such as electron sharing or exchange occurred between dye molecules and active surface sites.

3.3 Adsorption Isotherms

The equilibrium data were analysed using Langmuir and Freundlich models. The Langmuir model (R^2 = 0.987) provided a better fit, indicating monolayer adsorption. The maximum adsorption capacity (qmax) obtained was 64.25 mg/g. The Freundlich constant (n = 2.14) further supported favourable adsorption behaviour. These findings align with other bio-based adsorbents used for dye removal in literature.

4.0 Conclusion

Activated carbon prepared from mango peel waste showed excellent potential for textile dye removal. The adsorption process followed pseudo-second-order kinetics and Langmuir isotherm, signifying monolayer chemisorption. This work demonstrates the feasibility of utilising mango peel waste as a sustainable source for low-cost activated carbon production applicable in wastewater treatment.

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Conflict of Interest

The author declares that there is no conflict of interest related to this study.

Author Biography

Vaijant R. Patil is currently serving as a Lecturer in the Department of Chemistry at Vidya Bharati Junior College, Karanja Lad, Washim, Maharashtra, India. His research interests include green chemistry, environmental science, and sustainable materials.

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