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Eco-friendly synthesis of magnetic activated carbon from used water filter cartridges for efficient methylene blue adsorption

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ABSTRACT

Using activated carbon (AC) derived from used water filter cartridges (UWFC), we developed a waste-to-resource method to remove dyes from water. Mild reactivation at 400°*C* for 1 h produced AC-UWFC, which was subsequently transformed into magnetic activated carbon (MAC-UWFC) for efficient adsorption of methylene blue (MB). Characterization confirmed a mesoporous structure (BET: 404.78 $m^2\ g^{-1}$) with high stability. Optimal adsorption occurred at a pH of 8, using 0.2 g of MAC-UWFC over 1 h. Adsorption followed the Langmuir isotherm (227.27 $mg\ g^{-1}$) and pseudo-second-order kinetics. MAC-UWFC maintained an efficiency of 92.32 % after eight cycles, demonstrating its effectiveness in wastewater treatment.

1. Introduction

Water contamination by artificial dyes poses a severe threat to global environmental health and aquatic ecosystems. These synthetic dyes, widely used across various industries, are often discharged into water bodies without adequate treatment, leading to widespread pollution. Water contamination caused by artificial dyes, particularly methylene blue (MB), presents a significant environmental challenge (Bagherzadeh et al., 2024). MB is a synthetic dye widely used in industries such as textile manufacturing, pharmaceuticals, and biological staining. Despite its utility, MB poses serious risks to both aquatic ecosystems (Oladoye et al., 2022) and human well-being (Jothi et al., 2021) due to its chemical stability, persistence in water bodies, and toxic properties (Khan et al., 2022). The discharge of MB and other synthetic dyes into aquatic environments has become a global concern, prompting the need for effective treatment technologies to mitigate their harmful effects (Hmamouchi et al., 2024).

The occurrence of MB in aquatic environments can result in various adverse consequences. MB can disrupt aquatic ecosystems by reducing light penetration (Poulin, 2023), hindering photosynthesis in marine plants, and affecting the overall balance of aquatic life (Al-Fawwaz et al., 2023; Krishna Moorthy et al., 2021). Moreover, the presence of MB in water bodies can interfere with photosynthetic processes (Rafique et al., 2018) in aquatic plants and algae, thereby disrupting primary productivity and altering nutrient cycles (Alsohaimi et al., 2023). Exposure to MB can induce both short and long-term toxic effects in aquatic organisms, including fish (Li et al., 2023), invertebrates, and other aquatic species (Soltanian et al., 2021), potentially leading to population decline and biodiversity loss. MB contamination in drinking water sources can pose health risks to humans, including respiratory issues, skin irritation, and the potential carcinogenic effects of long-term exposure (Babuji et al., 2023; Singh et al., 2025).

Even at low concentrations, MB imparts a distinct blue coloration to water, compromising its aesthetic quality and limiting its recreational use. Due to its environmental persistence, MB also presents risks of bioaccumulation and biomagnification through aquatic food chains, potentially affecting higher trophic levels and disrupting overall ecosystem functioning (Kim and Oh, 2018). These far-reaching ecological impacts underscore the urgency of developing comprehensive strategies for MB removal and preventing its release into the environment. In response to these concerns, numerous treatment techniques have been explored to mitigate dye contamination in wastewater. These

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