



Research Article

Biomass-derived sustainable mesoporous activated carbon as an efficient and recyclable adsorbent for the adsorption of hazardous dyes

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ABSTRACT

The use of activated carbon obtained from biomass in wastewater treatment has grown in popularity due to its sustainability and low manufacturing cost. Mesoporous activated carbon (MAC), with a large surface area (480 m²/g) and remarkable adsorption capacity, was produced at 550 °C using affordable *Ficus religiosa* leaf as a biomass precursor. The developed MAC was used to adsorb the hazardous contaminants of acid blue 9 (AB9) and malachite green (MG) from wastewater. To characterize MAC, various analytical techniques were used, including XRD, Raman, HR-SEM, HR-TEM, EDAX, FTIR, BET surface area analysis, XPS, TGA, and the associated DTA. The observed data confirms the production of the graphitic framework in the synthesized MAC but also demonstrates the dispersion of mesopores with a diameter of 4 nm. Also, BET, HR-SEM, and HR-TEM images confirmed the presence of high pore density and dye adsorption surface area. MAC dye adsorption capacity with optimum adsorbent dosage of 0.2g and 0.3g was estimated as 1.552×10^{-4} (mol/g) (123.04 mg/g) and 1.495×10^{-4} (mol/g) (138.58 mg/g) for AB9 and MG respectively at equilibrium of 120 min. The regression coefficients derived from the Freundlich, Langmuir, and D-R adsorption isotherms peak are compared, and the R² value of 0.99 reported by Langmuir suggests that the adsorption of AB9 and MG adheres to the Langmuir adsorption isotherm by best fitting the equilibrium, recommending monolayer coverage. The chemisorption mechanism is defined by the combination of adsorption kinetics and a pseudo-second-order model. Besides, the sustainability was shown for five adsorptions-desorption cycles judge the utility and economic viability of the adsorption process. The plausible adsorption mechanism of MAC over AB9 and MG is mediated by synergetic interactions such as π - π interactions, hydrogen bonding, and electrostatic interactions. Therefore, exceptional stability, sustainability, and reliability for up to five adsorption run cycles of MAC justify its superiority over other adsorbents in the adsorption of AB9 and MG from wastewater.

1. Introduction

Dyes are the substances used to impart color to several materials. Today, especially for the successful trading of textile products, the dyeing process is given extreme importance in the textile industries. Besides textile industries, due to their considerable coloring capacity and ability to adhere to the surfaces the utilization of dyes also has been increased in cosmetics, paper, rubber, plastic, leather, food, and drug-

related sectors [1]. It is estimated that annually $\sim 7 \times 10^5$ tons of synthetic organic-based dyes are generated globally and $\sim 10,000$ discrete dyes and pigments are consumed industrially [2]. The presence of varied functional groups such as azo, carbonyl, anthraquinone, nitro, methine, etc., as chromophores, in the chemical structure, is responsible for dye coloration [3,4]. Seepage of ~ 10 – 15 % of colorant during the dyeing process into the environment becomes one of the prime sources in addition to other contributing sources causing severe aquatic pollution

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