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Graphene oxide impregnated activated carbon derived from coconut shell through hydrothermal carbonization for cationic dye removal: Adsorptive performance, kinetics, and chemistry of interaction

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ABSTRACT

The concept of the "circular economy" aims to minimize waste generation, energy consumption, and CO_2 emissions while maximizing the use of agricultural byproducts through economically viable approaches. In this research, coconut shell (CS), an agricultural waste was used to produce carbon composite materials via the hydrothermal carbonization (HTC) technique at a low temperature. A novel CS-based activated carbon (CSAC) for the adsorption of cationic dye was prepared by incorporating graphene oxide (GO), iron oxide, and undergoing alkaline activation. Characterization revealed a well-developed porosity ($MCSAC_{SBET}$: 477.74 m^2/g, and $MGOCSAC_{SBET}$: 278.19 m^2/g) through HTC method, KOH activation, and GO-iron oxide impregnation. FTIR analysis indicated that the CS derived activated carbon produced from coconut shells contains oxygen-containing functional groups, such as hydroxyl (-OH) and carbonyl (C═O). These functional groups has the potential to change the polarity, surface energy, adsorption energy, and energy bands of carbon materials. Various operating parameters affecting the dye adsorption performance, such as initial pH, adsorbent dosage, contact time, and initial dye concentration, have been evaluated. The batch adsorption study revealed that GO and iron oxide functionalized CSAC (MGOCSAC) exhibited higher adsorption performance compared to iron oxide only functionalized CSAC (MCSAC) in COD removal, color removal, and adsorption capacity under the optimum conditions. Reusability studies further confirmed that MGOCSAC retained its high adsorption capacity, with only a 2.9% efficiency drop after five adsorption-desorption cycles. Conversely, MCSAC exhibited an 8.3% decrease, while commercial AC demonstrated a 19.2% reduction. Adsorption using both MCSAC and MGOCSAC was observed to follow the nonlinear Langmuir and Elovich models, which suggested a monolayer chemisorption. Quantum calculations highlighted potential binding interactions between the electron-withdrawing groups in adsorbents and the electron-donating groups in dye molecules, or vice versa. Furthermore, the total production cost of CS-based adsorbents was found to be 10.0%–17.0% less than commercial AC. Overall, the findings suggest that the hydrothermally carbonized and GO-iron oxide functionalized activated carbon derived from coconut shell provides an efficient, and cost-effective solution for dye removal given its simple preparation process, excellent adsorption capacity, ease of separation and high reusability ability.

1. Introduction

The agricultural sector plays a significant role in addressing extreme poverty, promoting inclusive economic growth, and ensuring food security. However, improper disposal and management of agricultural waste can have significant environmental impacts, including greenhouse gas emissions, contamination and deterioration of soil, water, and air resources (Narala et al., 2022). The conversion of agricultural waste into value-added products offers a sustainable and economically viable approach that can effectively address environmental issues and optimize resource utilization. Agricultural wastes such as crop residue, livestock waste, agro-industrial waste and aqua-cultural waste could be considered suitable raw materials to produce environmentally friendly and cost-effective carbon materials (Oribayo et al., 2021). In alignment with

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